



Exploration of Frameworks, SysML, LLMs and Data Analytics to optimize Reliability and Maintainability (R&M) Planning, Execution, and Evaluation for Safe and Successful Missions

Optimizing Reliability, Maintainability, and Data Analytics for Safe & Successful Outcomes

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NASA HQ – Office of Safety & Mission Assurance (OSMA)
RAMS Advisory Board
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Today's Topics



Key Concepts and Terminology

Background

- What do I mean by Optimization?
- Inherent relationships between Safety, Mission Success, and RMA

Evolving Safety, Safety & Mission Success (S&MS), Safety Management System (SMS)

Frameworks to improve alignment and interoperability with R&M and other discipline areas

- Exploring frameworks for digital transformation and optimal impact to Safety and Mission Success
- NASA OSMA's Policy Enabled Safety & Mission Success (SMS) framework
- NASA's Artemis Safety Management System (SMS) for Human Space Flight (HSF)
- Other Frameworks

Leveraging SysML and LLMs to optimize Planning, Execution, and Evaluation for S&MS

- "Parsing" Frameworks using Systems Modeling Language (SysML) to create Digital Threads
- "Parsing" Frameworks using Large Language Models (LLMs) to create Digital Threads

Future Digital and Data Analytics Opportunities

Key Concepts and Terminology

- **Assurance Case** – a structured argument that uses evidence to show that a system meets its requirements ([Ref 1](#))
- **Availability** – probability that a system will be available to perform its function when called upon ([Ref 2](#))
- **Data Analytics** – process of collecting, cleaning, analyzing, and interpreting large datasets to identify patterns, trends, and correlations to extract insights for improved decision-making ([Ref 3](#))
- **Digital Threads** – Is the flow of data that connects all aspects of a product/Product's life; including design, manufacturing, maintenance, and service ([Ref 4](#))
- **Evidence** – factual information that supports a claim or belief ([Ref 5](#))
- **Frameworks** – a system of rules, ideas, or beliefs that provides a structure for building or deciding something. ([Ref 6](#))
- **Graph Database** - a specialized type of database that stores data as a network of interconnected nodes and edges. ([Ref 7](#))
- **Hazard** – a situation or condition that has the potential to cause harm. ([Ref 8](#))
- **Large Language Models (LLMs)** – machine learning models that can perform Natural Language Processing (NLP) tasks ([Ref 9](#))
- **Maintainability** – probability that a failed item will be restored or repaired to a specified condition within a period ([Ref 10](#))
- **Mission Assurance** – functions, processes, and/or activities that provides grounds for justified confidence that Mission's claim toward safe and successful outcomes are true ([Ref 11](#), [Ref 12](#))
- **Mission Certification** - a structured evaluation system used to verify that a system, application, or individual within an organization meets the required standards and capabilities to perform critical functions deemed essential to the organization's core mission ([Ref 13](#))
- **Objectives** – An objective is a specific, measurable, and achievable goal that an organization sets to accomplish within a specific timeframe ([Ref 14](#)).
- **Objectives Hierarchy / Hierarchical Structure** – organizes goals into a framework with clear lines of authority and responsibility ([Ref 15](#))
- **Risk** - The potential for shortfalls with respect to achieving explicitly stated objectives characterized in terms of likelihood, impact, and scenario ([Ref 16](#)).
- **Safety** - In a risk-informed context, an overall condition that provides sufficient assurance that mishaps will not result from the mission execution ([Ref 17](#)).
- **Safety Management System** - a structured approach used by organizations to proactively identify, assess, and mitigate safety risks. ([Ref 18](#))
- **Safety Case** - is a structured argument, supported by evidence, intended to justify that a system is acceptably safe for a specific application ([Ref 19](#))
- **SysML** - general-purpose graphical Systems Modeling Language for specifying, analyzing, designing, and verifying complex systems ([Ref 20](#))

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Future Digital and Data Analytics Opportunities

What do I mean Optimization?

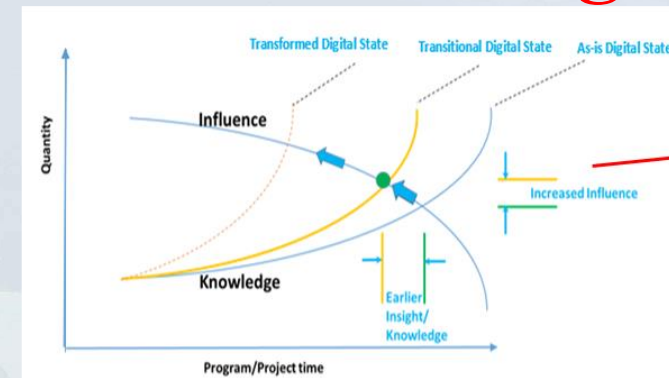
Optimize processes and flow of **R&M, and other information**, through the combination of Policy, Contract Mechanisms, and Digital Technologies (e.g., Data Analytics) for Safe and Successful NASA missions around the following:

- ▶ **Contextualization** (Relevancy of Information to inform Needed Decisions; Alignment with NASA Objectives and Requirements)
- ▶ **Fidelity** (Error Free Information and Data)
- ▶ **Timeliness** (Information to Support Decisions_
- ▶ **Data Flow** (Effort, Ease in pulling together relevant information) Data flow)
- ▶ **Learning Curve** (Easy On-Ramp)

“Decrease GAPs in the delivery of SMA related information in support of Decision – Making

Utilization of Model-Based and Assurance Case Frameworks

SMA's Challenge

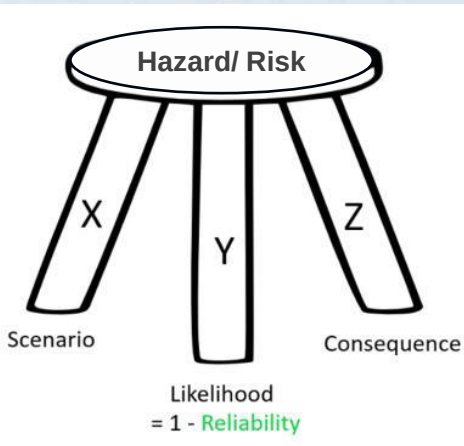


Support Critical
Decision
Making

1. Increased Decision Velocity,
2. Risk Integration and Robust Contextualization
3. Maximize Efficiency

Inherent relationships of R&M concepts with Safety and Success

Definitions: **R** (↑) and its Counterparts **M** (↓) and **A** (↑ ↓)



Reliability (R)

- The probability an item¹ will perform its intended function with **no failure** for a given time interval and under given conditions (e.g., environment and loads).
- The probability an item will be in and remain in an uptime state.

Maintainability (M)

- The probability a **failed item**¹ will be restored or repaired to a specified condition within a given time interval.
- The probability a failed item (an item in a downtime state) will be returned to an uptime state within a given time interval.

Availability (A)²

- The probability a **repairable item**¹ will perform its intended function at a given point or interval of time when operated and maintained in a prescribed manner.
- The probability a repairable item will be in an uptime state and will recover from downtime states.
- A mathematical function of R and M, **A = f(R, M)**.

Reliability, Maintainability and/or Availability (or 1 minus RMA) have inherent relationships with respect to achieving **SAFE** (i.e., Hazard) and/or **SUCCESSFUL** (i.e., Risk) outcomes.

¹ An item is a function, hardware (Hw), software (Sw), orgware (Ow), interfaces, or combination

² System Availability = $A_{HW} * A_{SW} * A_{OW} * A_{interfaces}$. System availability, dependability (i.e., operating condition, trustworthiness), and capability (i.e., meets missions demands) describe **System Effectiveness** (ref DoD).

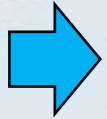
Adapted from Tim Adams' "NASA – What is Reliability" presentation as part of NASA/NSC's R&M Webinar.

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Evolving Safety, Safety & Mission Success (S&MS), Safety Management System (SMS) Frameworks to improve alignment and interoperability with R&M and other discipline areas

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Future Digital and Data Analytics Opportunities

Exploring frameworks for digital transformation and optimal impact to Safety and Mission Success

Over the past several years, **NASA OSMA** has been **exploring** use of **Safety Management System (SMS)** and **Safety & Mission Success (S&MS)** frameworks to enable ***Objectives-Driven Planning, Execution, and Evaluation of Mission Development*** activities and their corresponding products / data (i.e., Evidence) to assure that NASA and Mission Objectives and requirements are satisfactorily being met over a program/project's life cycle.

These ***frameworks*** are ***of particular interest*** as they lend themselves well to **digital thread** and ***digitally enabled information (i.e., data) flow*** in support of mission objectives for safe and successful outcomes.

Frameworks being presented today.....

1. NASA's Artemis Safety Management System (SMS) for Human Space Flight (HSF)
2. NASA OSMA's Policy Enabled Safety & Mission Success (S&MS) framework

Other Frameworks not being presented today include: [IOIF](#), [DeepLynx](#), [UAF](#), and [Moon-2-Mars \(M2M\)](#).



NASA's Artemis Safety Management System (SMS) for Human Space Flight (HSF)

ICAO Annex 19: Around 2013, Civil Aviation Authorities around the world begun structuring their SMS requirements around **4 elements or pillars** as delineated in **ICAO Document 9859 Safety Management Manual (SMM)**:

- Safety Policy and Objectives
- Safety Risk Management
- Safety Assurance
- Safety Promotion

FAA Advisory Circular: AC.450.103-1.

Released in 2021, states that Safety Organizations must:

- Implement Hazard Management processes
- Performs configuration management and controls
- Employ process for evaluating post-flight data

Clarify how different parts of the organization interface with each other, all of which is centered around 4 pillars of Aviation Safety.

As a result, NASA has begun adapting the 4 pillars of Aviation SMS captured in ICAO Document 9859 Safety Management Manual (SMM) for use on Spaceflight Missions IAW FAA recommendations.

NASA's Artemis Safety Management System (SMS) for Human Space Flight (HSF) (continued)

Specifically, **NASA**, working with industry partners, has begun adapting the **4 pillars of Aviation SMS** for Spaceflight including potential **adoption of** the Safety Management International Collaboration Group (**SM ICG**) developed **SMS Evaluation Tool for Safety Risk Management**.

Appendix 1 – Example of an evaluation summary

	Initiating	Present and Suitable	Operating	Effective	Excellence
The SMS as a Whole	The SMS is at the implementation stage.	All main elements of the SMS are in place.	The systems and processes of the SMS are operating.	The SMS is working in an effective way and is striving for continuous improvement.	The organisation is an industry leader and embraces and shares its best practices.
Safety Risk Management	The safety risk management processes are not fully developed.	A safety reporting system is in place and there is a process for how risks are assessed and managed.	The hazard and risk registers are being built up and risks are starting to be managed in proactive manner.	The organisation is continuously identifying hazards and understands its biggest risks and is actively managing them; this can be seen in their safety performance. Safety Risk Management is proactive.	Key personnel throughout the organisation are aware and understand the risks relative to their responsibilities and are continuously searching out new hazards and risks and re-evaluating existing risks.
Safety Assurance	Safety assurance activities, including safety performance indicators (SPIs) are not fully developed.	Initial SPIs linked to the safety objectives have been identified and there is a change management process in place.	The organisation has established SPIs that it is monitoring and is auditing and assessing its SMS and its outputs.	The organisation assures itself that it has an effective SMS and is managing its risk through audit, assessment, and monitoring of its safety performance.	The organisation is continuously assessing its approach to safety management and is continuously improving its safety performance and seeking out and embracing best practices.
Safety Policy and Objectives	Policies, processes, and procedures are not fully developed.	There are policies, processes, and procedures in place that detail how the SMS will operate.	There is a safety policy in place and senior management are committed to making the SMS work and is providing appropriate resources to safety management.	Senior management are clearly involved in the SMS and the safety policy sets out the organisation's intent to manage safety. This is clearly evident in day to day operations.	The organisation is an industry leader and embraces best practices.
Safety Promotion	Safety promotion activities are not fully developed.	There is a training programme and the means to communicate safety information is in place.	The organisation has trained its people and has several mediums for safety promotion that it uses for passing on safety information.	The organisation puts considerable resources and effort into training its people and publicising its safety culture and other safety information and monitors the effectiveness of its safety promotion.	In addition, the organisation provides training and safety promotion to its contracted service providers and assesses the effectiveness of its safety promotion.
Human Factors Management	Human Factors are considered but not formally captured by the organisation.	Human Factors policies and processes have been defined and documented where required by regulation.	Human Factors are being managed across the organisation and are starting to be integrated into the organisation's SMS.	Human Factors are integrated into the SMS and the operations of the organisation. All staff including management are aware of Human Factors and apply it in the way they work.	Human Factors are embedded into the day to day activities of the organisation and fully integrated into the SMS. This is evident throughout the organisation from senior management to front line staff.

Note 1: In addition to *Present, Suitable, Operating, and Effective*, this example uses two additional maturity levels: *Initiating* and *Excellence*.

Note 2: A specific line for Human Factors has also been added in this example to highlight the importance of considering Human Factors as part of the SMS.

Red Circles represent the 4 SMS Safety Pillars

Blue Circles representative Objective Evaluation Criteria

Rows/Columns represent evidence-based Evaluations traceable to both **Safety Pillars** and **Objective Evaluation Criteria**

Overall framework lends itself to creating **Digital Threads** between

- Objectives Criteria
- Evaluations (based on objective evidence)

around the **Safety Pillars** to enable clear traceability, easier Information access, and Case Assured implementation.

NASA OSMA's Policy enabled Safety & Mission Success (S&MS) framework

Legend

Red Circles = Objectives
Green Circles = Evaluation Criteria
Blue Circles = Evidence

NPD – NASA Policy Directive Level

NPD 8700.1 – NASA Safety & Mission Success Policy

Objective 1 - Assure acceptable levels of **Flight Crew Safety** and **Mission Success** Risks

Objective 2 – Protect Public, NASA Workforce, high-value property, and environment

Objective 3 – Cultivate Safety Culture

NPR – NASA Procedural Requirement Level

NPR 8705.4 – Risk Classification for NASA Payloads

(Addresses SMA Planning for Uncrewed, robotic, spaceflight missions)

NPR 8705.2 – Human Rating Criteria

Addresses SMA Planning for Crewed, Human Rated, spaceflight missions

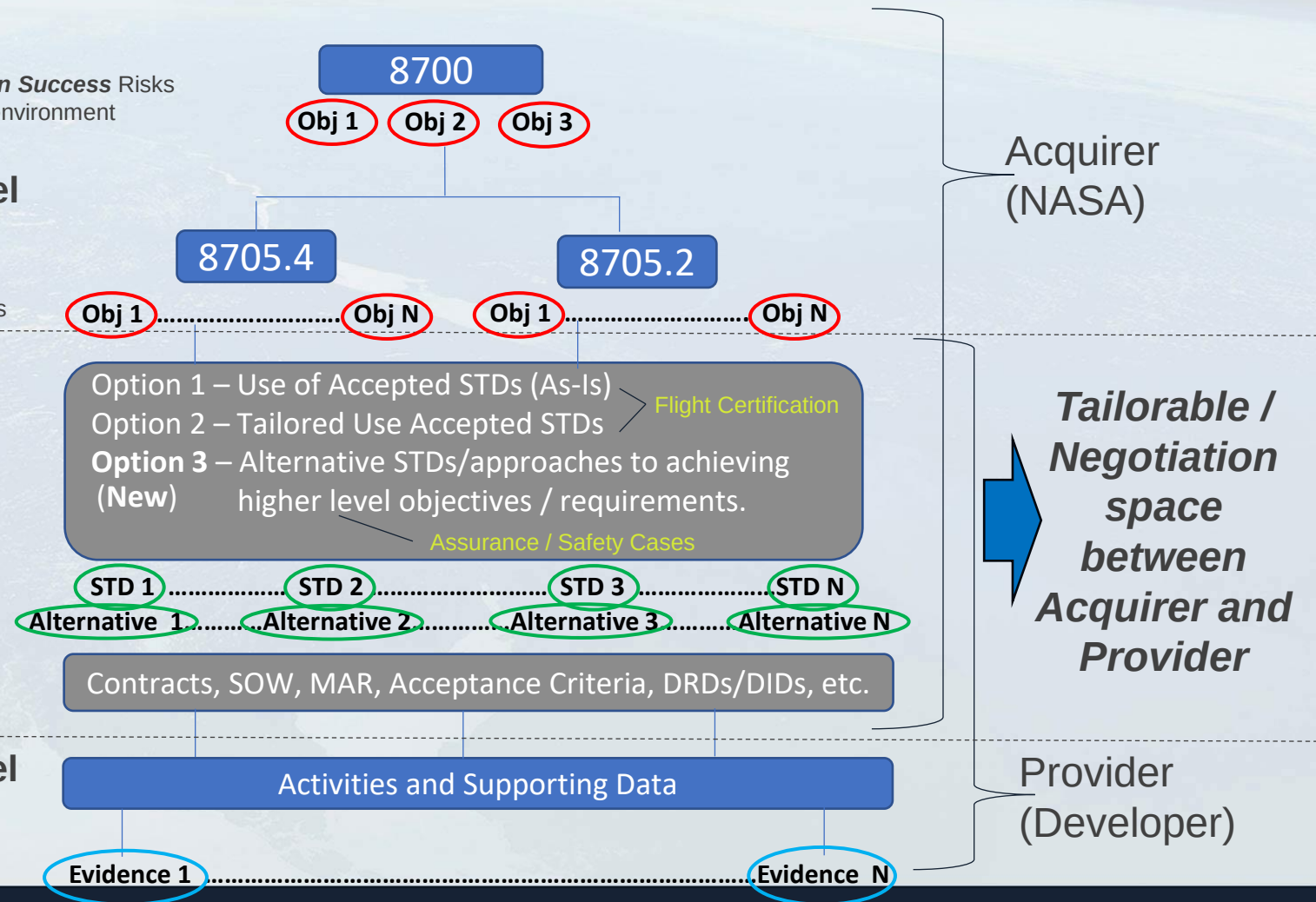
Contracting and Agreement Level

Industry - Statements of Work (SOWs), Contract Data Requirement Line (CDRL) Items, Mission Assurance Requirement (MAR) documents,

In-House - Assurance Implementation Matrices, Plans

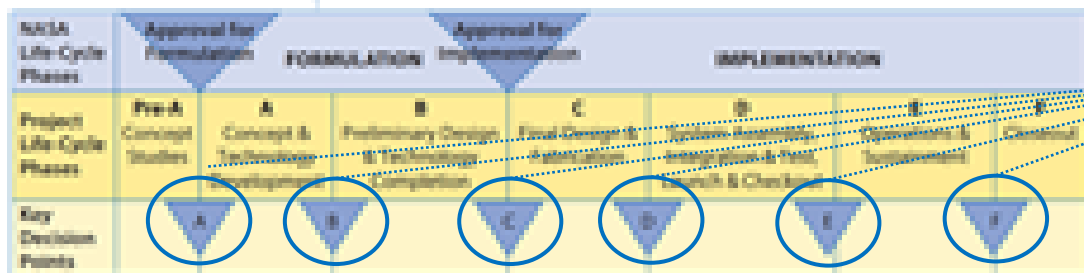
Partnerships – Memorandum of Agreements (MOAs), Memorandums of Understanding (MOAs)

Implementation / Lifecycle Evaluation Level



NASA OSMA's Policy enabled Safety & Mission Success (S&MS) framework

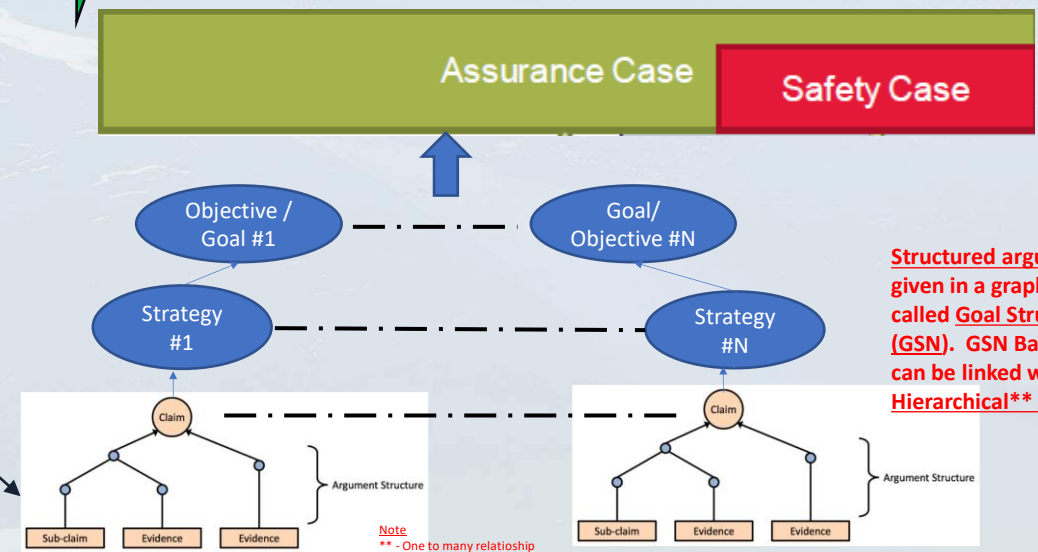
Certification – Based Life Cycle Gate Reviews



More Prescriptive
Specific activities need to be executed;
Specific Evidence generated.
Less flexibility

Less Prescriptive
Activities generate Evidence in support of Assurance/Safety Case Arguments.
More flexibility

Assurance Case Evolution



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Future Digital and Data Analytics Opportunities

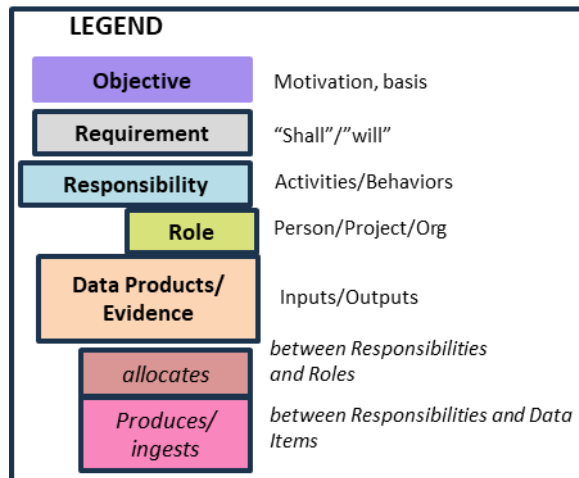
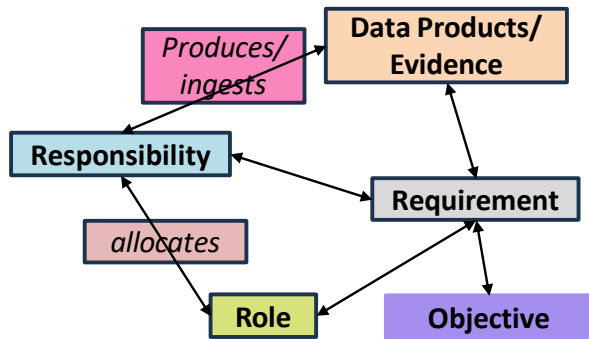
"Parsing" Frameworks using SysML to create Digital Threads

From NPR 8715.26

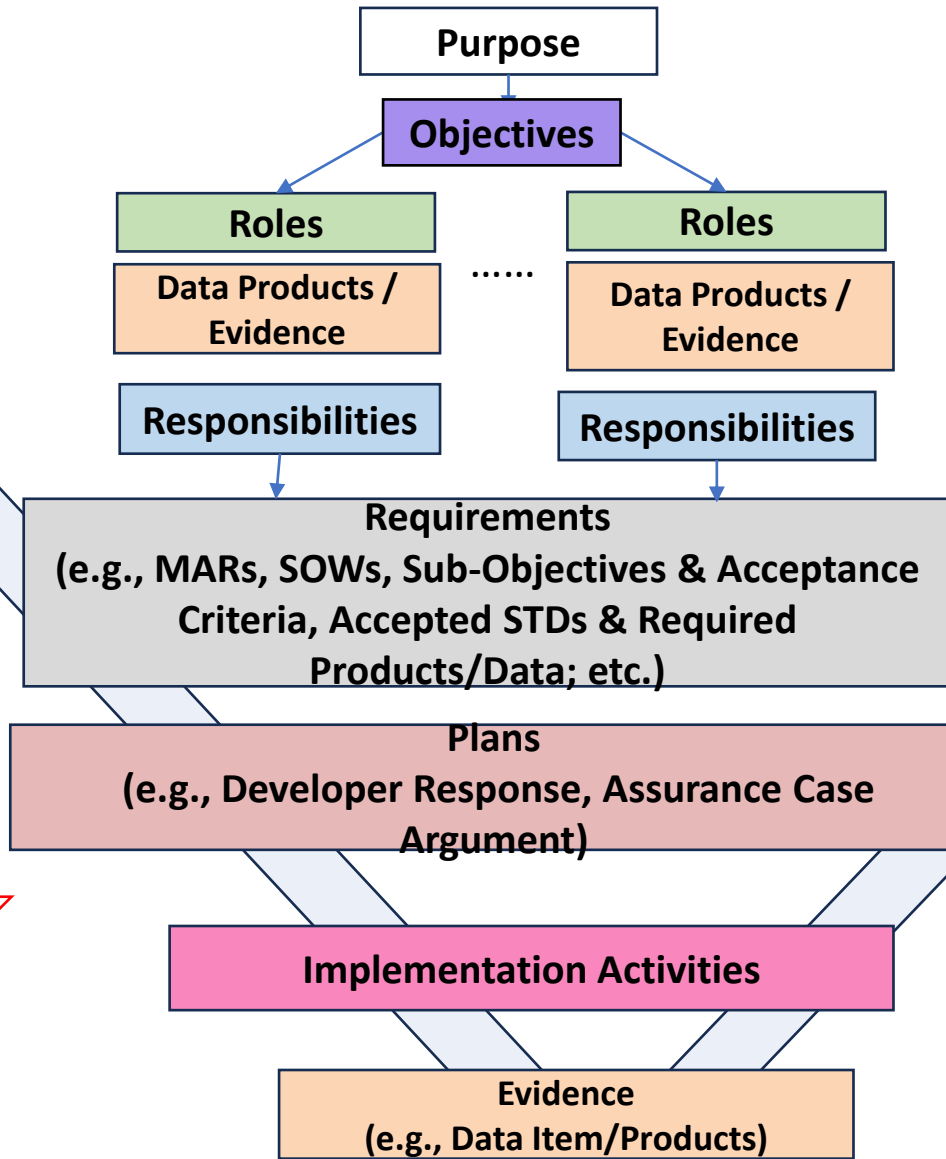
2.8.1 The Chief, SMA, is responsible for advising the Administrator and other senior officials on matters related to risk, safety, and mission success and serves as the lead SMA TA. To provide independent oversight of programs and projects in support of safety and mission success, the Chief, SMA, is responsible for:
a. Appointing a technically-qualified NASA representative to the INSRB. Whenever possible, the NFSO should not serve as the INSRB member performing the review or

We 'parse' the text and statements according to the Legend/ Ontology/ Simplified SysML MetaModel.

SIMPLIFIED SYSML METAMODEL



Objectives / Requirements Flow Down by Life Cycle Phase



Acquirer
(NASA)

Certification or Assurance / Safety Case arguments

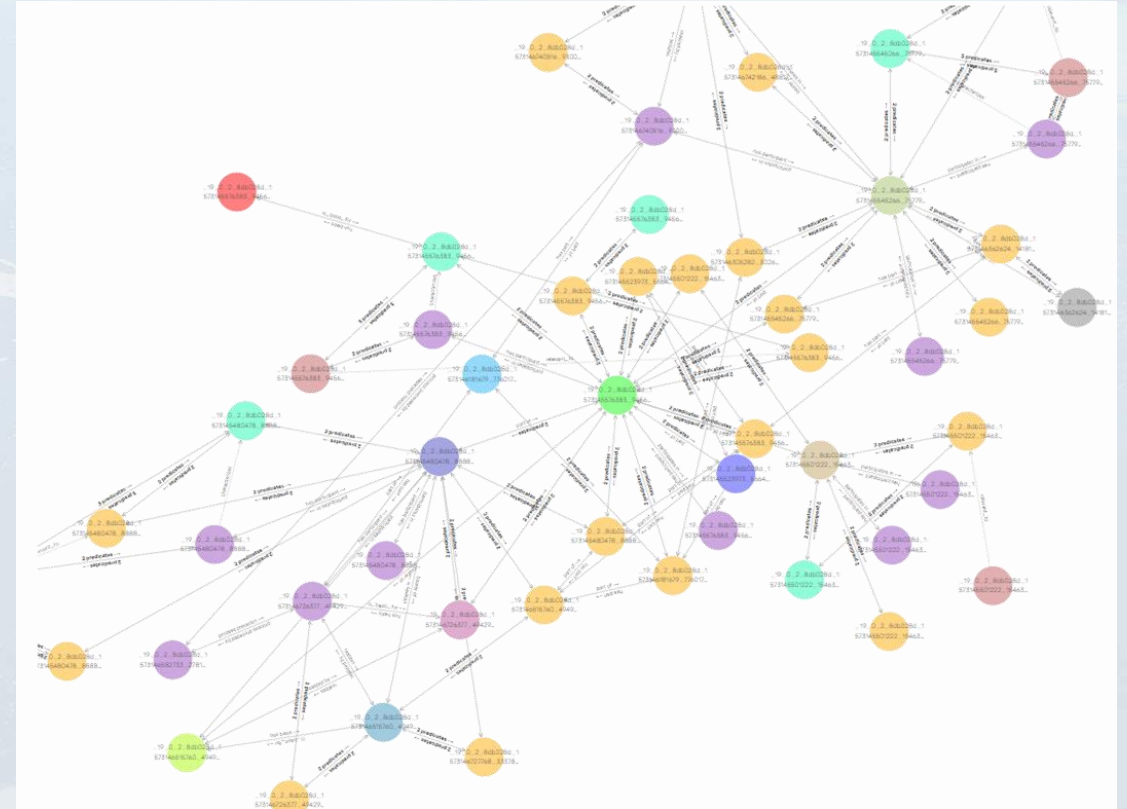
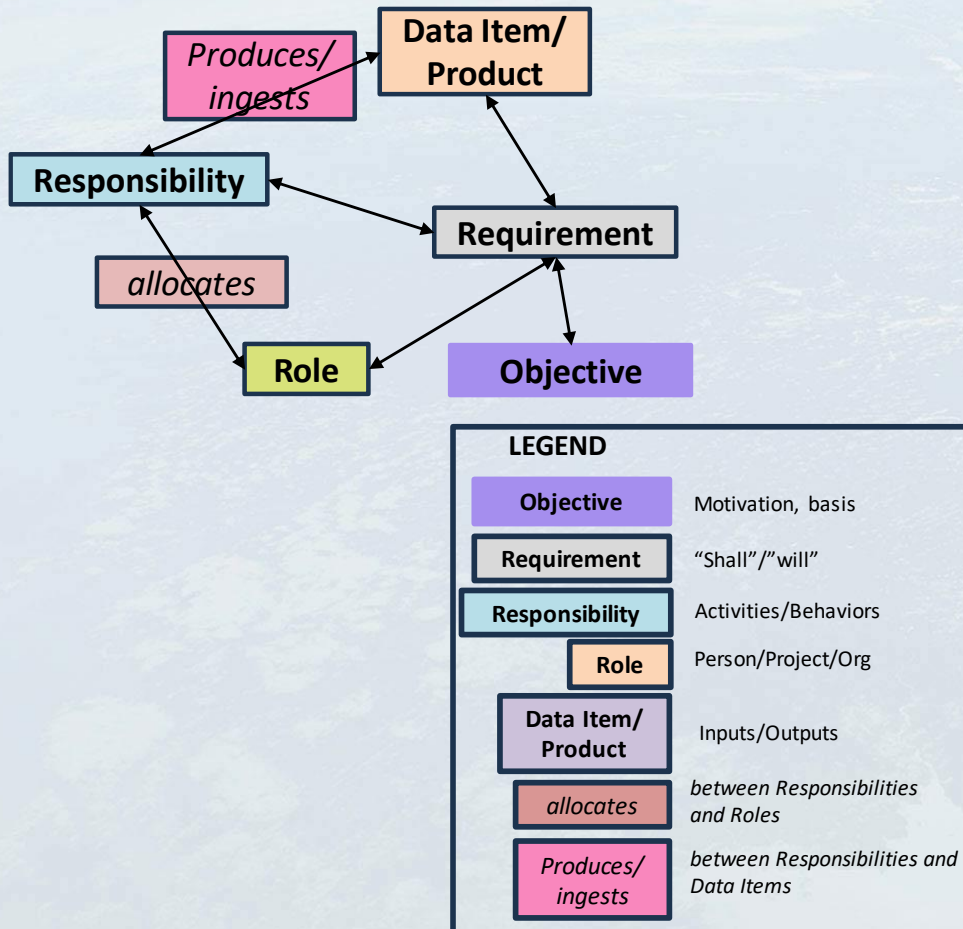
Provider
(Developer)

NASA Universal Decomposition

W-ENGINE

“Parsing” Frameworks using SysML to create Digital Threads

SIMPLIFIED SYSML METAMODEL



Notional Graph Database concept illustration

“Parsing” Frameworks using LLMs to create Digital Threads

Preprocessing

Document ingestion
(e.g. html)

Clean, structure, and
tokenize documents

Chunking optimization

Text embedding/
vectorization

Processing

LLM model selection
(possibly different for
different use cases)

Knowledge Store
(i.e. database)

Relationship definition
(e.g. RDF, NER, metadata
tagging)

Prompt Engineering

Requirement
extraction

Compute resources
(e.g. cloud services)

Ontology development
or LLM ontology
inference

Ontology cleansing
user interface

RAG workflow

Logical reasoner

Analysis

Semantic Search
(e.g SPARQL queries)

Function Calling

Graph visualization

*Adapted from NASA Funded JPL Exploration of
LLMs and Ontologies to support SMS and
S&MS Evaluations.*

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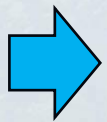
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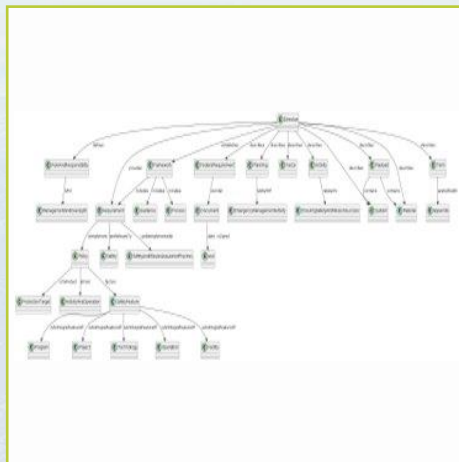
Future - Digital and Data Analytics Opportunities



Input Class	Output Format
ASCII text strings	<i>string</i>
numbers	(num <i>string</i>)
special characters	(<i>string</i>)
SGML tag	<i>symbol</i>
SGML entity	<i>symbol</i>
no-white-space	nws

1

Large Language Models: extract key relationships and vocabulary



2

Semantic Web: ensure semantic consistency

$$\begin{aligned} p &= p \\ p &= \sim\sim p \\ p \vee \sim p & \\ \sim(p \cdot \sim p) & \\ (p \cdot q) &= \sim(\sim p \vee \sim q) \\ (p \vee q) &= \sim(\sim p \cdot \sim q) \\ (p \vee q) &= (q \vee p) \\ (p \cdot q) &= (q \cdot p) \\ [(p \vee q) \vee r] &= [p \vee (q \vee r)] \\ [(p \cdot q) \cdot r] &= [p \cdot (q \cdot r)] \\ (p \supset q) &= (\sim q \supset \sim p) \\ [p \cdot (q \vee r)] &= [(p \cdot q) \vee (p \cdot r)] \\ [p \vee (q \cdot r)] &= [(p \vee q) \cdot (p \vee r)] \\ [p \supset (q \supset r)] &= [q \supset (p \supset r)] \\ (p \supset q) \supset [(q \supset r) \supset (p \supset r)] \\ [p \supset (q \supset r)] &\supset [(p \cdot q) \supset r] \\ [(p \cdot q) \supset r] &\supset [p \supset (q \supset r)] \end{aligned}$$

3

Formal logic: provide mathematical guardrails



4

Result exploration: visualization and interactive user engagement ensures accurate results

Adapted from NASA Funded JPL Exploration of LLMs and Ontologies to support SMS and S&MS Evaluations.

QUESTIONS / DISCUSSIONS

