National Aeronautics and Space Administration

NASA

EXPLORESCIENCE

Introduction to the Science Traceability Matrix

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Overview

- The Science Traceability Matrix (STM)
  - What is it?
  - How is it used?
- Relation to other mission concept aspects
  - Goals, Objectives
  - Requirements
- Structure of the STM
- Common STM concerns, solutions

The STM: What is it?

- A proposal element that…
  - is required by SMD AOs
  - summarizes key aspects of the mission's technical implementation
  - summarizes key aspects of the mission necessary for successful completion of the investigation
  - re-arranges a missions requirements from a focus on design to a focus on research
  - ***provides a single, digestible reference that every aspect of the proposal can branch off of and tie into***

- The STM is the backbone of the proposal.
  - A primary way to inspire confidence in the reviewer
  - A primary way to demonstrate a well-thought-out mission concept
  - *A primary way to lose trust of the reviewer*
  - *A primary way to display issues or disconnects with the design or the team*

The STM: How is it used?

- The STM is a guide to every aspect of the mission concept in a single, unified vision.

- For the proposer…
  - An opportunity to ensure common understanding between leadership, instrument providers, science team, and engineering team
  - An opportunity to identify issues in the design
  - A constant touchstone in the generation of a clear and consistent proposal narrative

- For the reviewer…
  - An opportunity to quickly gain a sense of the entire mission concept
  - An opportunity to identify internal disconnects or inconsistencies
    - Not just in the design, but in the team

Goals and Objectives

- Missions are formulated starting with Goals and Objectives
  - *Goal:* A broad scientific effort that is part of a larger strategy to address a program's objectives. A mission investigation will make progress towards the mission's Goals, but is not expected to completely achieve them.
    - *What part of the field will my mission help advance?*
  - *Objective:* A focused scientific effort that is part of a larger strategy to address a mission goal. A mission Objective must be achieved by a mission.
    - *What specific, quantified scientific contribution will my mission make?*

- The level of detail or scientific specificity for a Goal and an Objective depends on the science and the investigation. A Goal and an Objective must be scoped together.
  - Can be difficult to argue a narrowly focused Objective will make clear progress on an overly broad Goal
  - Can be difficult to argue that a broad Objective will be entirely completed
    - Reviewers come to a proposer with their own ideas. They may not understand a statement to be as limited as the proposer does.

Goals and Objectives

- Objectives state what the mission will complete, regardless of the type of science investigation.

- Can think of putting an Objective into one of three rough categories (*my terms*):
  - Characterization: You know enough to design a mission to study a system at a high-level.
  - Hypothesis-testing: You have specific hypotheses that a mission can be designed to resolve.
  - Analytic: You have specific knowledge gaps about an understood (to some level) system that a mission can be designed to fill.

- These are rough categories, and a clever person can force most Objectives into any category. But *remember the purpose of Objectives*.
  - Define what a mission must complete (metrics), keep design in the resource envelope
  - Clarity and consistency in proposal's narrative controls expectations and keeps the reviewer on the same page

Goals and Objectives

- No mention of “science questions” in this presentation, and that is deliberate

- Science questions aren’t defined in the SMD AO, no common community understanding of what a science question *is*
  - Some see it as falling between a Goal and an Objective
  - Some see it as falling between an Objective and a Level 1 Requirement

- Asking questions invites the reviewer to tell you what the answer could be, to interpret the question. Stating determinative Objectives tells the reviewer what you will do.
  - Can’t prove that you’ve fully answered a question, can prove you’ve fully made a determination

- A proposer’s job is to remain in control of the narrative, be clear and consistent, and inspire confidence and trust. A disconnect in understanding between the proposer and reviewers, or between different reviewers, is disadvantageous for a proposal.

Mission Design Requirements

Requirements Level	Mission Level
Level 1	Program
Level 2	Project
Level 3	Instrument, Mission System
Level 4	Subsystems

Mission requirement levels are the mission *design* requirements to complete the objectives.

The requirements levels may remind you of the levels in a mission's Work Breakdown Structure (WBS). They are based on a similar type of flowdown, but there is not a one-to-one mapping.

Mission Design Requirements

Requirements Level	Mission Level
Level 1	**Program**
Level 2	Project
Level 3	Instrument, Mission System
Level 4	Subsystems

Level 1 Requirements are the scientific determinations and/or results that are necessary for completion of each Science Objective.

- They are agnostic to mission implementation details, but mission implementation details flow up to them.

Example: The mission shall determine the average time for [auroral emission] to maximize after the impact of [solar wind structure] with an accuracy of X minutes ([confidence level]).

Mission Design Requirements

Requirements Level	Mission Level
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Level 2 Requirements are the project performance requirements that flow down from the Level 1 Requirements.

- They are the first level of mission implementation details. They are linked to the Level 1 Requirements via the mission's research plan.

Example: The mission shall determine the intensity of [auroral emission] with an accuracy of X, a precision of Y, and a cadence of Z seconds.

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Example: The mission shall determine the intensity of [gu
of X, a precision of Y, and a cadence of Z seconds.

Key point!
Developing a mission requires knowing what research you are designing it to *complete*!

Elements of the Science Traceability Matrix

Goal	Objective	Scientific Measurement Requirements		Instrument Performance Requirements	Projected Instrument Performance	Mission Requirements (Top Level)
		Physical Parameters	Observables			
Goal 1	Obj. 1	Phys. Para. 1a	Obs. 1a-1	…	…	Observing strategies Phenomena observation requirements Launch window
	Obj. 2	Phys. Para. 2a	Obs. 2a-1	…	…	
		Phys. Para. 2b	Obs. 2b-1	…	…	
Goal 2	Obj. 3	Phys. Para. 3	Obs. 3a-1	…	…	
			Obs. 3a-2	…	…	

Goal: A broad scientific effort that is part of a larger strategy to address a program's objectives. A mission investigation will make progress towards the mission's Goals, but is not expected to completely achieve them.

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			Obs. 3a-2	…	…	

Physical Parameters: The highest-order data product(s) characterizing the physical system that enables the science investigation's completion of the Objective.

- Has verification parameters (e.g. accuracy, resolution) that flow down to the Observable and to mission requirements (e.g. spatial coverage, mission lifetime)

Observable: The physical measurement that is made by the mission and that enables the determination of the Physical Parameter.

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Examples (not unique mapping)

Physical Parameter	Observable(s)
Electron density (local)	Upper hybrid frequency, magnetic field magnitude
Relative densities of elements X and Y	Emission line X, emission line Y
Map of surface elevation	Two-way travel time of emitted signal
Gravity field	Doppler shift of radio signal

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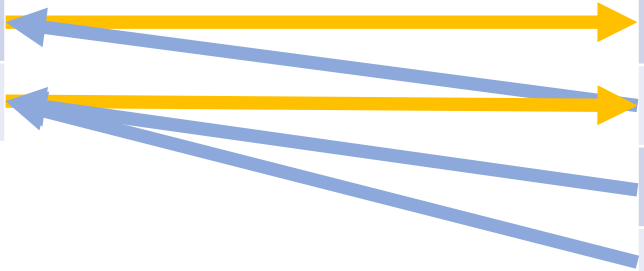
Mission Requirements: The driving mission requirements that immediately flow down from the Scientific Measurement and Instrument Performance Requirements.

- Key mission requirements that enable necessary measurement
- Varied and particular to each mission implementation

STM Elements and Req. Levels

Req. Level	Mission Level
Level 1	Program
Level 2	Project



STM Column
Objective
Physical Parameter
Observables
Mission Requirements

The mission requirement levels are formal systems engineering requirement levels for designing the mission.

- Technical engineering requirements that combine with other requirements at the same level in order to realize products for their parent requirements
- Based on objective, measurable technical performance requirements

The STM columns are a re-envisioning of the mission requirement levels based around mission operations and the mission's research plan.

- Restructured form is easier to digest, puts important information on one page

STM Elements and Req. Levels

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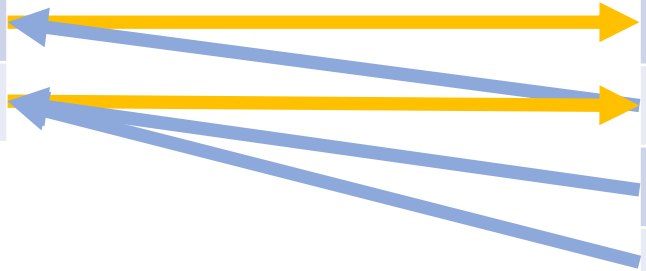

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Key point!
Developing a mission requires knowing what research you are designing it to *complete*!

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Common Concerns, STM

- No clear flowdown of the requirements across the entire STM
  - Overly broad or vague Objectives?
  - Lack of a well-focused research plan?

- Missing, inadequate, or confused measurement verification parameters, margin, error budget
  - Spatial/temporal coverage
  - Accuracy vs. precision
  - Change in units within a proposal

Common Concerns, STM

- Disconnect between Measurements and Instrument Requirements
  - Inadequate communication between science team and instrument provider?
  - Instrument Requirements far exceed the requirements to complete the science?
  - Instrument Requirements developed to justify the instrument, not to enable the science?

- Disconnect between Instrument Requirements and Instrument Performance
  - Inadequate communication between science team and instrument provider?
  - Instrument was selected before the requirements were determined?
  - Instrument was selected for reasons other than it was the most appropriate for the science?

Common Issues, Solutions

- Start early! Having an STM (even if it is later refined) will make the narrative smoother
- Start with the specific Objectives to be completed and the scientific determinations that are necessary for them to be achieved
  - Properly scope your investigation; know exactly
  - Metrics of success are science results you can publish, not volumes of data acquired
- Integrate the mission team early, ensure that everyone is on the same page
  - The PI is in charge of the mission, which means being in charge of the narrative
  - Produce a concise, self-consistent STM and do not abdicate that responsibility
- Set your requirements and check them with every update to the STM
  - Science: Spatial/temporal coverage, accuracy, etc.
  - Implementation: Resource margin, error budget, etc.

Questions?