Science Traceability

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Introduction

- Any comprehensive science mission **proposal must** be able to straightforwardly **explain the importance of mission goals** and how those goals can be **implemented**
- The science traceability matrix (STM) provides such an overview, and **relates it to** high level objectives suggested by **NASA roadmaps, decadal surveys**, etc
- The STM provides the breadth and scope needed to perform **high level trades** effecting **science outcome** and **overall design**
- The STM is the forum where **scientists, engineers and program management (ideally) come together** in sweet harmony about the potential and future direction of a mission
- The STM is a **required component of all NASA science mission proposals**

NASA Evaluation of Mission Science

- ‘**Scientific merit**’ of the proposed investigation [**25%**]

- ‘**Scientific implementation merit**’ of the proposed investigation [**25%**]
  - Both are rated as Excellent, Very Good, Good, Fair or Poor (the rating reported to the PI)

- **Technical, management, and cost** (TMC) feasibility, including cost risk, of the proposed investigation [**50%**]
  - Rated as High, Medium, Low risk

Current as of March 2008

Scientific Merit

- Intrinsic **Scientific Merit of the Baseline Mission**
  - Clear **scientific goals and objectives**?
  - **How important** are the goals?
    - **Impact on NASA's** heliophysics and astrophysics scientific objectives **and U.S. space science program**
    - **Fills gaps**, provides fundamental **progress**, **synergistic** with other missions, etc.
  - Appropriate methodology and sufficient data to complete investigation?
    - **Proposed data is appropriate and sufficient**

- **Baseline Mission**
  - Does **not include** proposed science **enhancements**
  - Does **not include** proposed **de-scopes** to reach the Minimum Mission

Scientific Implementation Merit

- **Relationship between science objectives, data returned, and scientific implementation**
  - Mission design supports scientific goals and objectives
  - "Science objectives-to-measurements-to-mission requirements" traceability
- **Instrument set** can be built with **proposed technologies**
  - Identification of, and likelihood of success for, critical technology development
- **Instrument** set will provide **necessary data**
  - Instrument set expected to deliver proposed data
- Data **analysis and archiving**: quality and timeliness
- **Probability of Success**:
  - science team, organization, mission design, technical risk (science implementation risk), resiliency (approach to de-scoping)
- Assessment of each **Co-Investigator contributions**

STM - Overview

The STM

- clearly establishes the **motivation** for the mission, and how it will be **implemented**

- provides, as a basic systems engineering tool, a logical flow from high level program objectives through mission objectives, measurement objectives, instrument requirements, spacecraft and system requirements to data products and publications

- provides a tool for evaluating the scientific consequences of changes/ reductions in objectives

- has **applicability through the life cycle of the project**, from formulation through data archiving

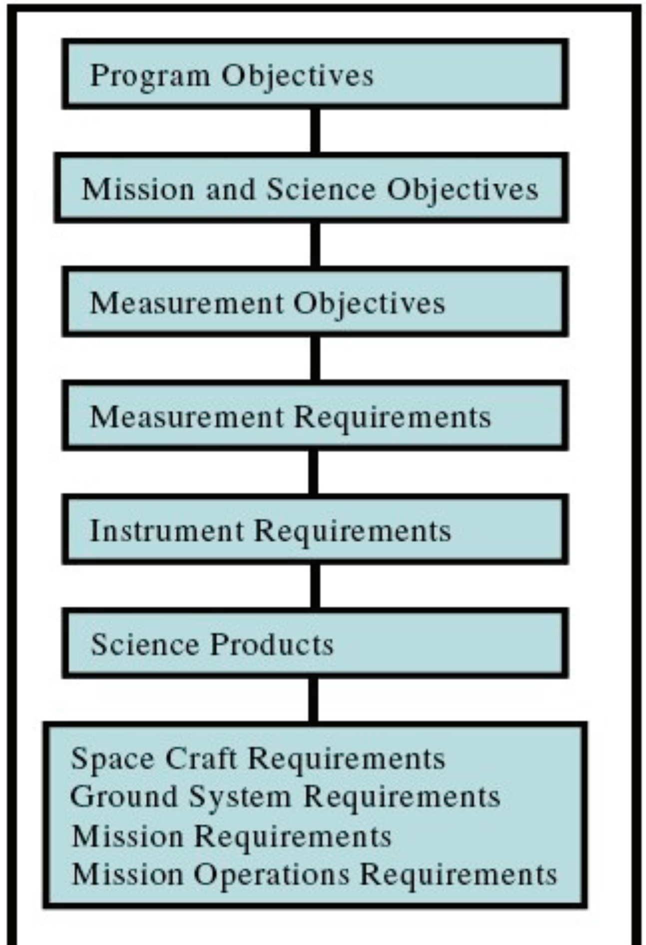

Figure 1. The contents of the science matrix include all science elements that affect resource trades for mission implementation –which is not part of the STM is summarized in the bottom box of this figure.

Key Parameters

STM requirements and objectives are based on assessment of certain key parameters underlying those requirements. These include:

- Relative importance of an observation to achieve the desired science
- End-to-end system ability to make a given measurement
- Minimum number of measurements required to achieve a given science goal
- Overall complexity of each required measurement
- Measurement fidelity to acquire the required science
- Probability for making the successful measurement
- Overall data quantity and quality
- Technology and implementation constraints
- Key science questions to be addressed

These need to be balanced with other typical parameters for instrument accommodation such as

- data rate and volume requirements,
- pointing and stability requirements,
- mounting and structure requirements and
- thermal, power, mass and volume constraints

Cross-dependencies may well exist (e.g., performance of a laser altimeter correlating with the precision of orbit determination, etc).

STM Generic Example (Fragment)

NASA Solar System Exploration Roadmap	***Objective #1:*** Learn How the Sun's Family of planets and minor bodies originated ***Objective #2:*** Determine how the solar system evolved to its current diverse state
Mission Objectives	To determine the state, atmosphere and structure of "Planet" and the structures of it's satellites

Science Objectives	Measurement Objectives	Measurement Requirements	Instruments	Instrument Requirements	Data Products
Planet					
2. Internal structure	measure gravity field	Gravity moment to order 12	Radio	3 bands to recover propogation	gravity moment of order n (n~ 12)
	measure magnetic field	Magnetic moment to order 14	Vector Magnetometer	Resolution 0.1 nT, mounting orientation to 10 arcsec	magnetic moment of order n (n~14)
3. Magnetosphere structure, plasma dynamics and radiation belts	measure magnetic field, charged particle and plasma waves over a large range of lattitudes, longitudes, and altitudes, and local time (need to rotate the line of apsides 180o)	Field direction to 1 degree, field resolution 0.1 nT, continuity 95%	magnetometer, plasma, low energy protons (LEP)		magnetosphere map, plasma spectrum, proton spectrum
Satellites					
1. Characterization interior, surface structure, activity and atmosphere.	multispectral IR imaging of surface	Map full surface at 3 meters/pixel	Mapping IR spectrometer	SNR 30, ifov 0.5 mrad, FOV 8.5 degrees	high resolution global coverage multispectral image data
	measure gravity field	circular orbit, global coverage for > 3 rotations, order 6	radio science		gravity field map
	measure magnetic field	circular orbit, global coverage for > 3 rotations	magnetometer	0.5 nT resolution	magnetic field map
	measure surface topography	100m track spacing	laser altimeter	30 meter spot size, 10 hz pulse, 1 nanosec gates	topography map

Figure 2: Generic example of a fragment of a science traceability matrix for a planetary orbiter. In this extract the science objectives are geodesy and geophysics. Note the flow from the NASA roadmap to the mission objectives (stated in an AO) to science objectives through to data products. This example illustrates several of the issues that arise during matrix formulation. The gravity field measurements have different measurement requirements for the planet and the satellite. These different requirements should be tracked separately, but this can cause the matrix to grow too large for clarity. A single science objective may have multiple supporting measurements and/or a single measurement may support several science objectives. This potential many-many relation can make it difficult to enumerate all flow-down succinctly. Though there is a host of clever ways to multiplex the parent-child relationships, the matrix is easiest to comprehend quickly when the relationships are flattened through replication. To keep the figure small, this particular example does not include the important requirements on spacecraft implementation such as bus and telemetry data rates, fields of view, power, and operational requirements.

STM through the Project Lifecycle 1

1. Formulation

- To assess approaches to implementing NASA programs near-term goals

- To assess alignment of proposed missions with previously defined NASA program goals (eg SMEX, Discovery, New Frontiers)

- To assess the alignment of a science investigation with previously defined mission goals (typical of large flagship missions)

- To assess the science utility of a proposed technology development demonstration and validation (typically New Millennium class mission)

STM through the Project Lifecycle 2

2. Requirements Development (early Phase B)

- Reality hits home as resources, design and STM requirements are matched in detail - some requirements unachievable!

- Requirements and capabilities are negotiated and entered into a tracking tool (e.g., DOORS) which (in theory) provides the ability to assess effects of changes on all subsystems

- The STM provides a useful notation for assessing and tracking the effects of these negotiations on mission/science/ measurement goals

- The STM also provides a convenient way to assess alternative approaches toward achieving a given goal

STM through the Project Lifecycle 3

3. **Mission Implementation**

- Oops - not enough resources to implement all planned capabilities
- STM should assist in prioritizing the science measurements and descoping where appropriate
- STM helps in evaluating the effect of modifying these measurements on mission/NASA goals, which may help to focus the debate over changes to the mission

4. **Mission Operations**

- Changes can arise from unforeseen resource changes (budget reductions), failure of subsystems or other unforeseen events
- STM can be used as a basis for negotiating sequencing and data return priorities in such cases

STM through the Project Lifecycle 4

5. **Outreach**

- The STM provides a compact overview of the purpose and implementation of a given mission
- Can therefore provide an excellent basis for an overview of the project in outreach products
- May even have utility in helping explaining the mission and mission changes to program and higher level managers

6. **Data Archiving**

- The STM can be used as a basis for planning types and quantity of data will be included in archives such as the Planetary Data System (PDS) and tracking completion of delivery
- STM content can be used as a mission documentation tool, and contains in compact form information required to populate databases needed to assess planning and proposal for future missions

Conclusions

- The STM is a critical and required component of all mission proposals
- It is a valuable tool for assessing both mission and systems engineering requirements
- It provides a clear means for proposal evaluation and system resource trades, providing a means for a top down or bottom up analysis providing flexibility and end-to-end visibility
- If fully implemented in the formulation phase the STM has high potential for
  - expediting the negotiation of Level 3 requirements;
  - resource trades during implementation and operation; and
  - facilitating public outreach and
  - mission archiving

An excellent reference (JPL authors)

Weiss, J.R., Smythe, W.D and Lu, W. 2005, *Science Traceability*, in Aerospace, 2005 IEEE Conference, p292-299