Data-Driven Strategy Analysis within IND

Doug Abraham
Interplanetary Network Directorate (IND)
Architecture, Strategic Planning, & System Engineering Office (903)
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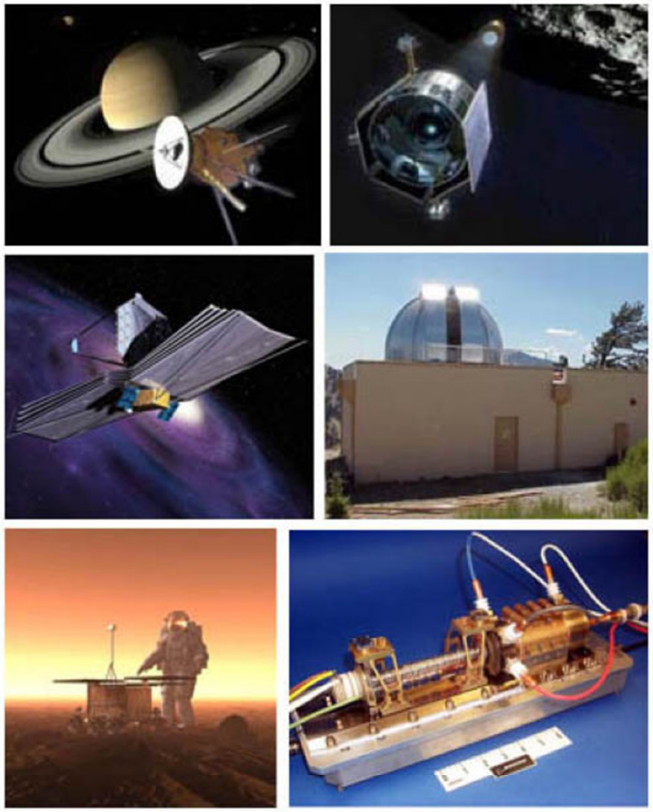

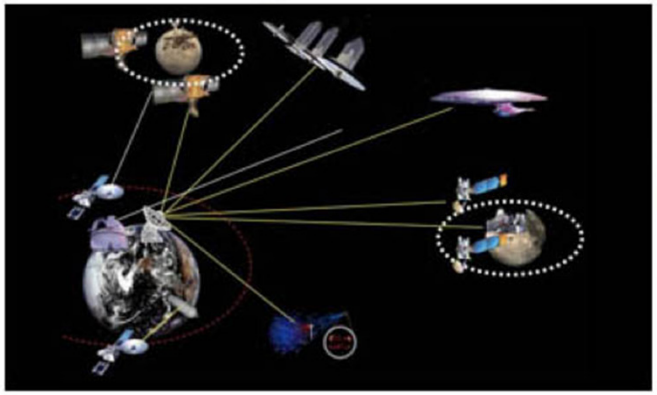

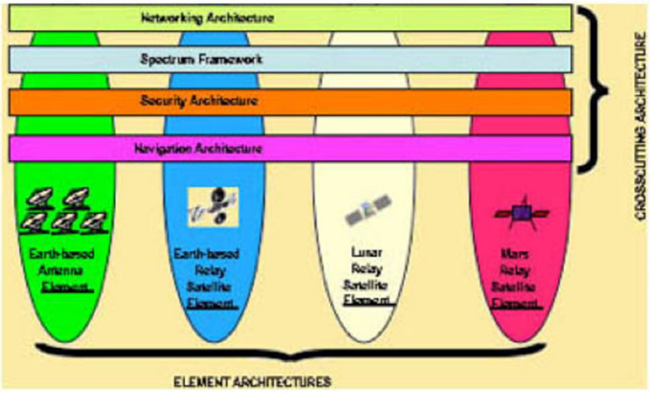

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Topics

- Foundational Considerations
- Available Methodologies
- IND's Methodology
  - Mission Analysis Steps
  - Earth-Based Analogies
- Disseminating the Results
- Arriving at Actionable Strategies
- Summary of Key Points

Foundational Considerations (1/2)

1. What are the questions that need answering?
   - Strategic vs. Tactical
   - Technology vs. Market Share vs. Economic vs. Political
   - Determines methodology
2. How will the answers be used?
   - Internal vs. External
   - Course Determination/Correction vs. Advocacy Building
   - Also determines methodology
3. What resources are available?
   - Budget
   - Human capital
   - Tools & services
   - Also determines methodology

Foundational Considerations (2/2)

- Some examples of IND's key questions:
  - How do DSN and AMMOS architectures, systems, and technologies need to evolve to better serve mission customers in the future?
    - What does the future mission customer base look like?
    - What are the key factors that are driving it?
    - How is that customer base changing in terms of parameters relevant to DSN services? To AMMOS tools and services?
  - How do SCaN's plans for integrating the DSN, NEN, and SN potentially impact the future mission customer base?
- Some examples of how IND uses the answers:
  - Production of roadmaps and implementation plans to facilitate both internal and external alignment.
  - Advocating, or maintaining the case for, proposed projects.
  - Informing SCaN-sponsored studies on the implications of various network integration options.

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Available Methodologies

(Lists are not exhaustive)

- Data Collection →
  - Established tool/system output research
  - Document & online publication research
  - Symposia/conferences
  - Expert Opinion Solicitation
    - Interviews
    - Questionnaires
    - Idea Generation/Nominal Group Technique
    - Delphi Method
- Data Analysis
  - Descriptive statistics
  - Trend analysis
  - Simulations
  - Inferential statistics
  - Case studies
  - Scenarios
  - Cost-Benefit/ROI analysis
  - Cross-Effect Matrices
  - Decision Analysis
  - System Dynamics

A viable approach will usually entail a combination of techniques.

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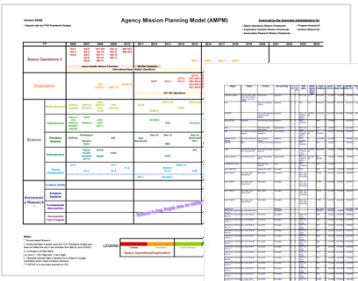
IND's Methodology

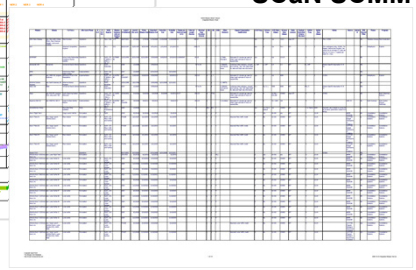
Overall approach is two-pronged:

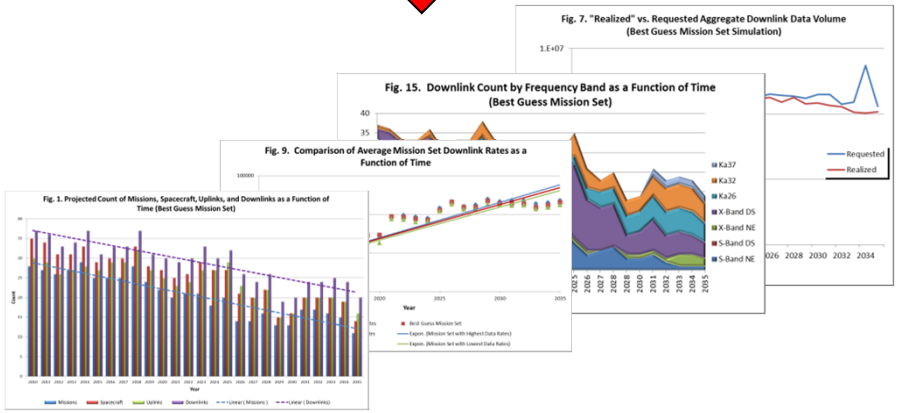
Mission Set Analysis
(What is the future mission demand?)

AMPM

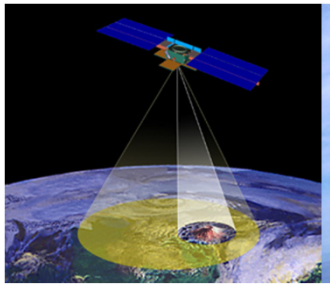


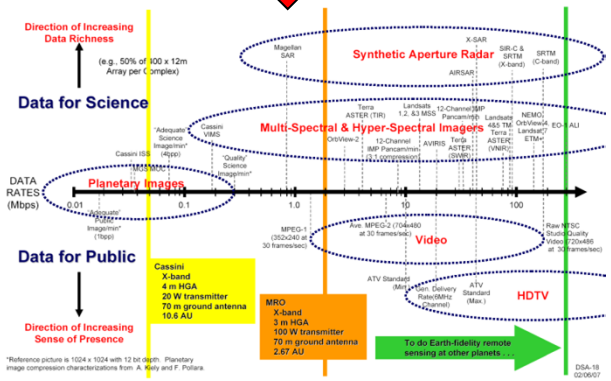
SCaN SCMM





Earth-Based Analogies
(What do capabilities at Earth suggest missions will eventually want at other planets?)





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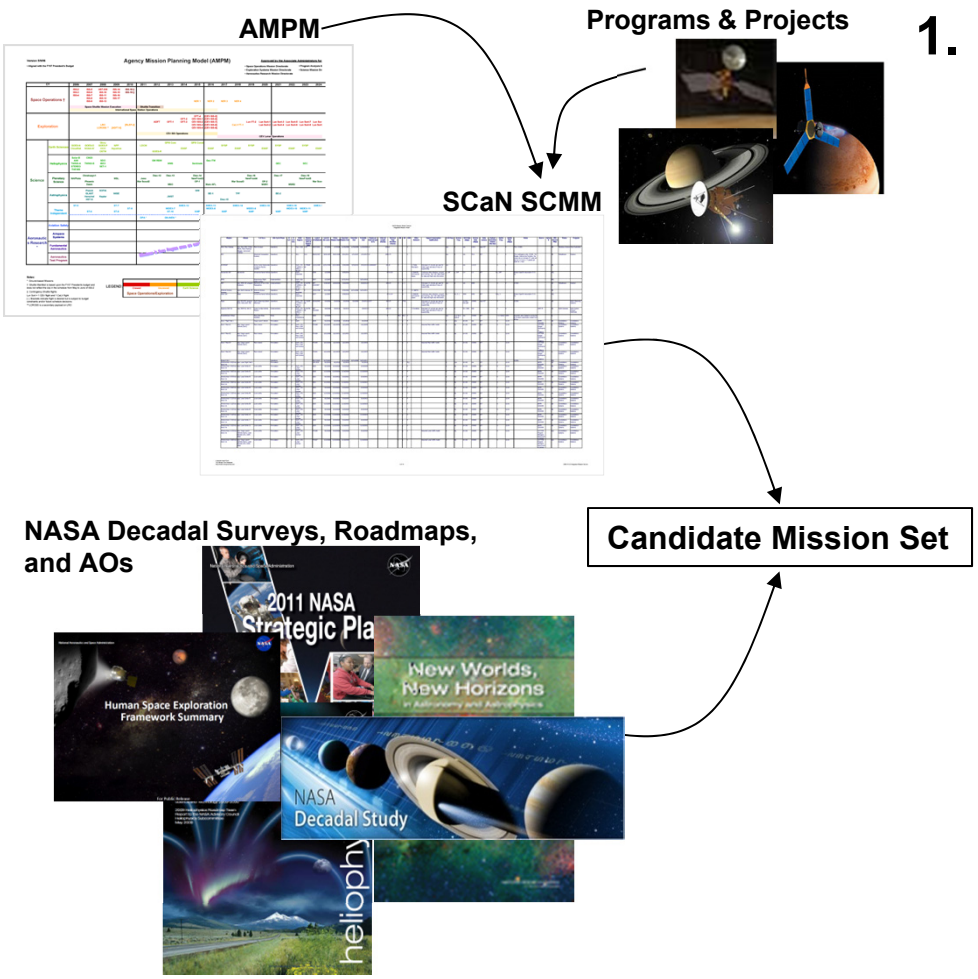
Mission Set Analysis Steps (1/8)



1. Identify the candidate missions.

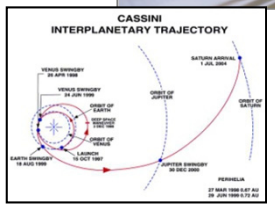
- Mission set is always changing.
- Program & Project sources supply nearer-term future mission data.
- Agency Mission Planning Manifest (AMPM) contains 20-year mission horizon that mission directorates sign off on.
- Space Communications Mission Model (SCMM) combines these sources and provides additional basic parameter data, establishing an agreed upon baseline within SCaN.
- NASA Decadal Surveys, Roadmaps, and AOs suggest candidates for generic or competitively-bid program lines.

Mission Set Analysis Steps (2/8)

Document Research: PSLAs, DSAs, Network Ops Plans, Team-X Studies, Other Mission Concept Studies

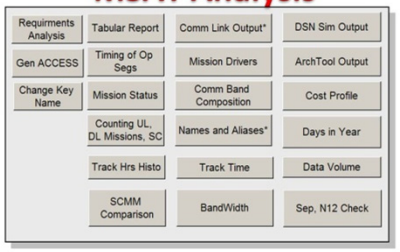
$$P_r = \frac{P_t A_t A_r f^2}{R^2 c^2}$$

Parameters Supporting Generation of Link Budgets, Spectrum Bandwidth Requirements, etc.

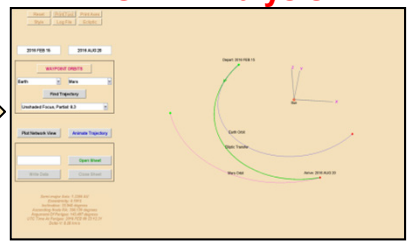


Established Tool/System Output Research: HORIZONS & NAIF trajectory files
Document Research: Study parameters supporting trajectory file generation

MSAT Analysis



OTIE Analysis

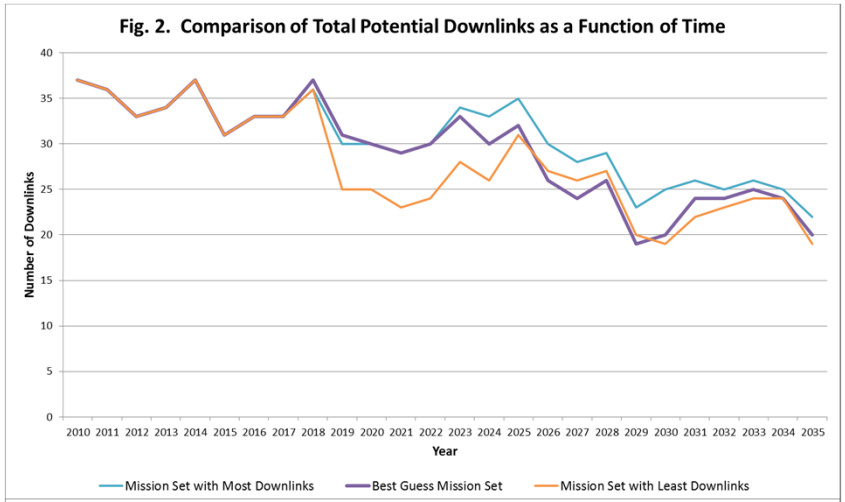


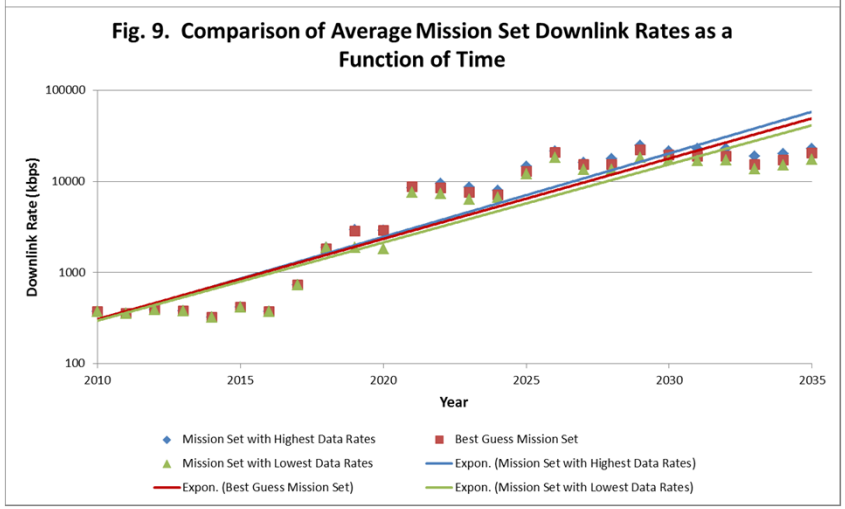
2. Research and collect data on each of the candidate missions.

- Focus on each mission's fundamental telecom, trajectory, and tracking parameters for each operational segment within the mission.
- Candidate mission parameters entered into:
  - Mission Set Analysis Tool (MSAT) for telecom trend analyses, automated link budget calculations, and associated bandwidth, G/T, and EIRP requirements generation.
  - Orbital Trajectory Inference Engine (OTIE) for automated generation of spacecraft trajectory and/or associated visibility files.

Data collection is probably the least appreciated, yet most important, aspect of data-driven strategy analysis.

Mission Set Analysis Steps (3/8)



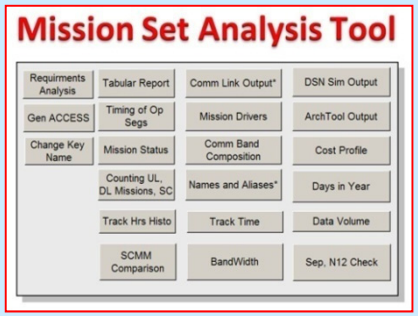


3. Analyze the data.

- For competitively-bid mission opportunities, it is extremely difficult to "divine" which mission candidate will fly in which opportunity.
- Hence, for each parameter of interest, conduct analysis with 3 different candidate mission sets:
  - "Best guess" mission set
  - Mission set that maximizes the parameter of interest
  - Mission set that minimizes the parameter of interest
- Use the SCMM Analysis Tool Suite to conduct analysis.

Mission Set Analysis Steps (4/8)

3. Analyze the data. (Continued…)



- Mission Set Analysis Tool (MSAT)
  - "Houses" all the mission data via an accompanying database.
  - Conducts link budget analysis on all of the missions.
  - Analyzes mission trends.

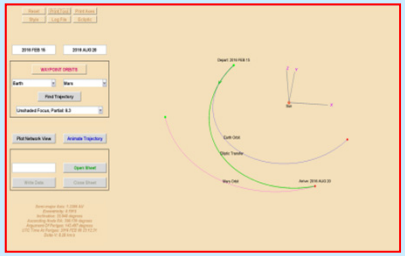
Data analysis output is dominated by easy-to-understand trend lines and descriptive statistics.

Mission Set Analysis Steps (5/8)

3. Analyze the data. (Continued…)

- Orbital Trajectory Inference Engine (OTIE)
  - Ingests trajectory files and converts them into visibility files for over 60 different ground stations.
  - Where trajectory data are scant, infers and generates the required trajectory file.
  - Optimizes gravity assist trajectories for launch date changes.
  - Analyzes aggregate mission geometry characteristics.

Orbital Trajectory Inference Engine



When not intermediate products for other tools, data analysis output is again dominated by easy-to-understand plots and descriptive statistics.

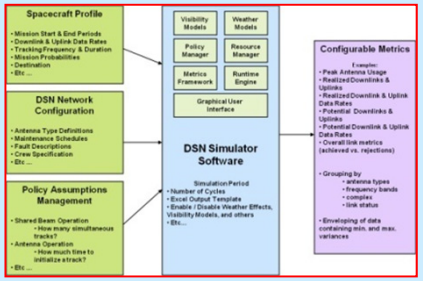
Mission Set Analysis Steps (6/8)

3. Analyze the data. (Continued…)

- DSN Simulator
  - Simulates any desired antenna architecture (including the current DSN) as a function of time.
  - Shows how a particular candidate mission set will load up on it given the link budget and tracking requirements from MSAT and the spacecraft visibility files for each station from OTIE.
  - Analyzes various “requested” vs. “realized” metrics (e.g., tracking hours, data volume, etc.) for a given architecture.
  - Enables relative loading performance comparisons between alternative antenna architectures.

Again, data analysis output is dominated by easy-to-understand plots and descriptive statistics.

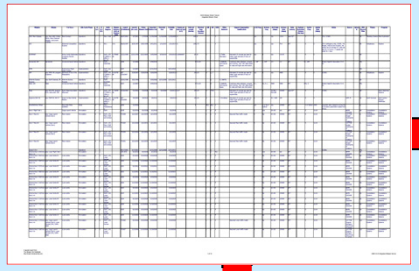
DSN Simulator



Mission Set Analysis Steps (7/8)

3. Analyze the data. (Continued…)

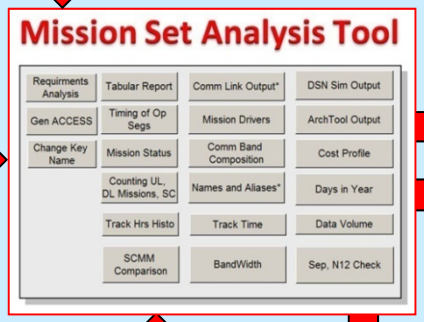
The true power of the tools comes from their synergistic application as a suite.



SCMM

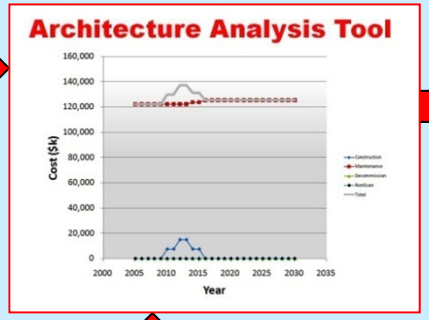
Official SCaN Mission Data

Official SCaN Mission Data

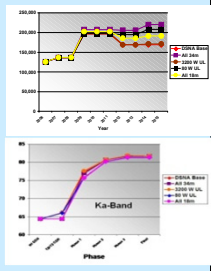


Study Architecture Parameters & Associated Cost & Schedule Data

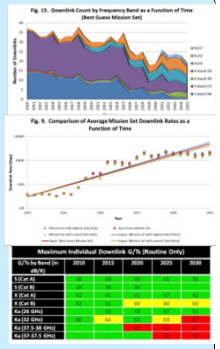
Detailed Spacecraft Telecom & Tracking Requirement Data



Architecture Cost, Schedule, and Performance



Spacecraft Equivalent Aperture & Tracking Time Requirements & Data Rates

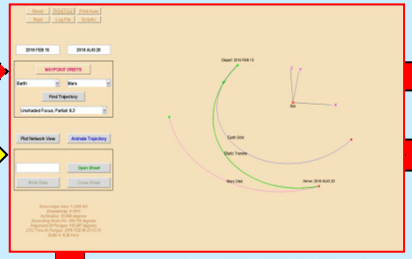


Aggregate Mission Set Trends & Requirements

Spacecraft Range Distances as a Function of Time

Spacecraft Equivalent Aperture & Tracking Time Requirements

Orbital Trajectory Inference Engine



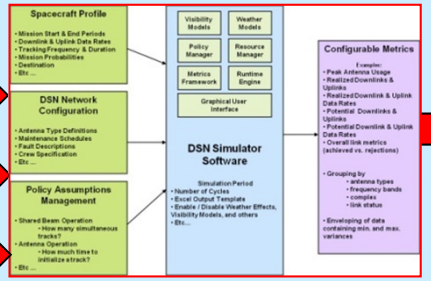
Inferential Spacecraft Trajectory Information, Trajectory Parameters, and/or Partial or Complete Trajectory Files

Aggregate Mission Set Geometry Analyses

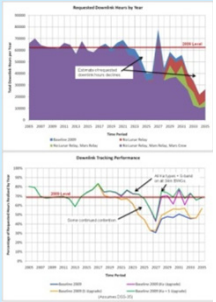
Spacecraft Rise & Set Sheets

Network Architecture & Ground Station Parameters; Planetary Ephemeris Data

DSN Simulator



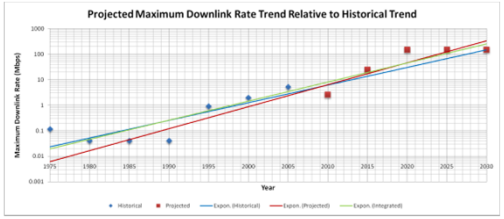
Architecture Loading & Data Traffic Implications

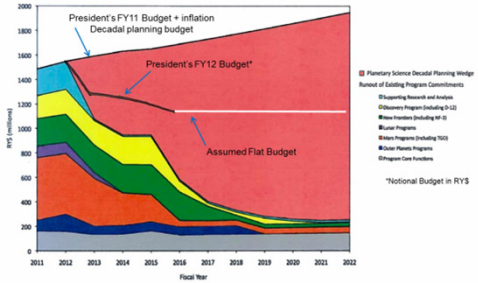


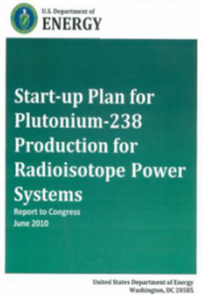
Mission Set Analysis Steps (8/8)

4. Interpret the results.

- Perform “sanity” checks.
  - Compare analysis results to historical trends and past projections.
  - Explore impacts of different future scenarios.
  - Perform sensitivity analyses.
- Provide context.
  - Fiscal environment
  - Policy environment
  - Technology issues or developments
  - Other emerging developments
- Make recommendations.







Results won’t have impact unless presented in context and used to suggest a course of action.

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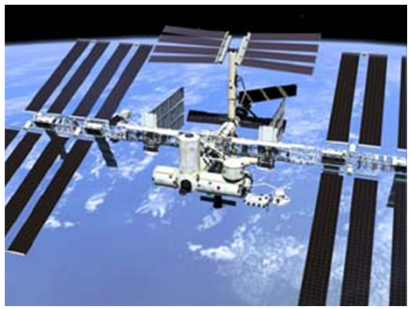
Earth-Based Analogies (1/5)

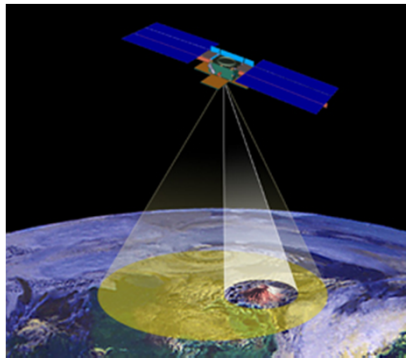
- It is inherently hard for mission concept designers to foresee and incorporate design features that exceed the current "state of the art."
- Hence, required capability projections based solely on future mission trends risk understating what will actually be needed in the far-future.
- Because technologies that are used in space are frequently used first at Earth, a particular technology's Earth-based capabilities are frequently a good indicator of what may ultimately be needed at other solar system destinations.

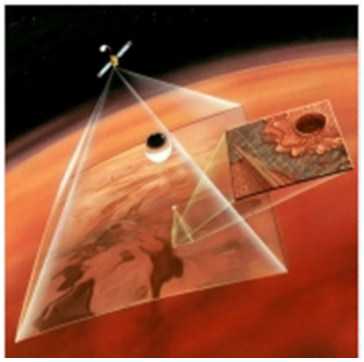


ISS was using i386 processors when the average person on the ground was using a Pentium 4 1.5 GHz processor.

Earth-Based Analogies (2/5)

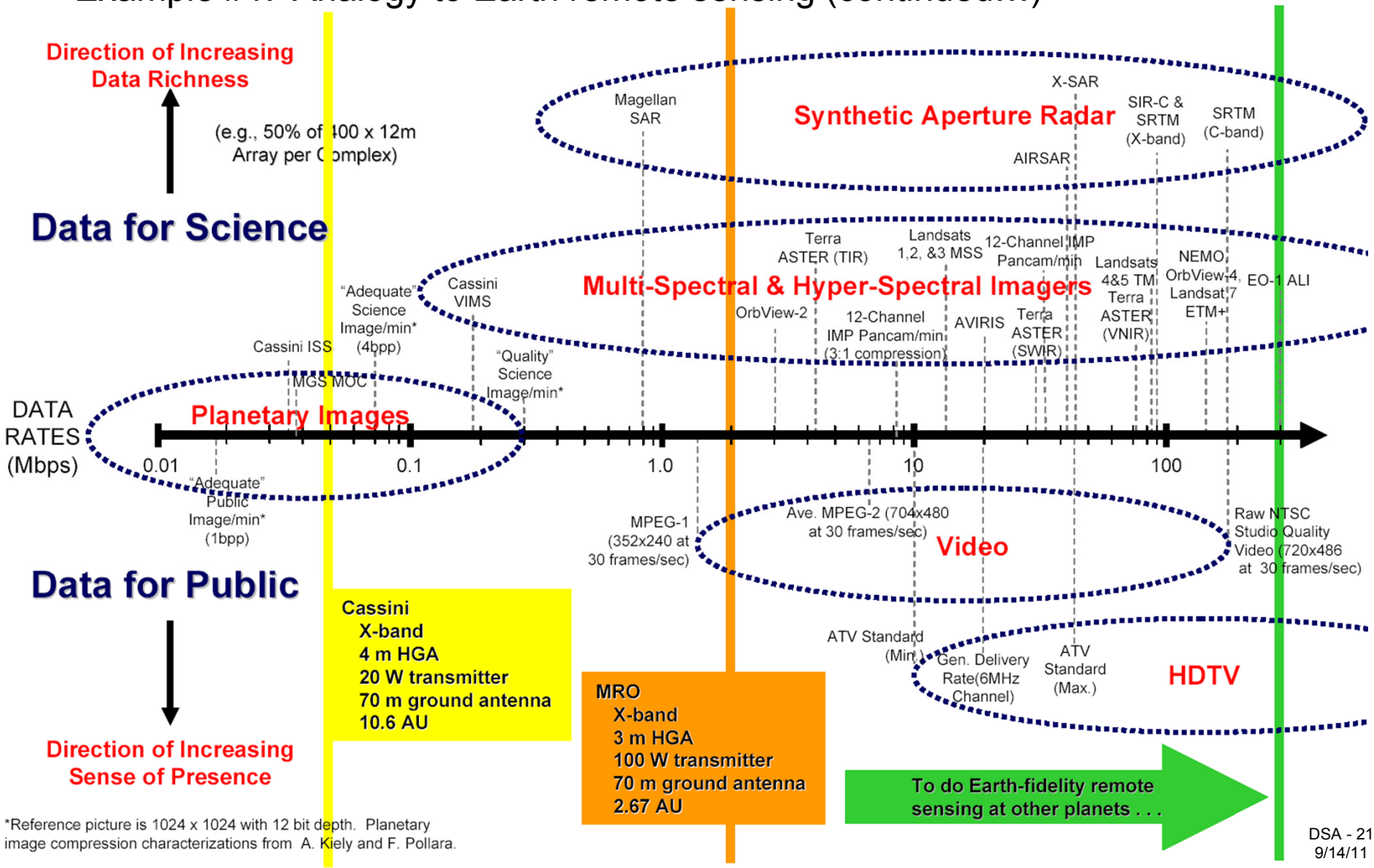
- Example #1: Analogy to Earth remote sensing
  - Remote sensing capability beyond Earth has always lagged such capability at Earth.
  - A key mission paradigm change is from preliminary reconnaissance to much higher-fidelity planetary remote sensing.
  - So, what telecommunications capability is implied by doing remote sensing at other planets with the same fidelity that we can do remote sensing at Earth today?





Earth-Based Analogies (3/5)

- Example #1: Analogy to Earth remote sensing (continued…)



*Reference picture is 1024 x 1024 with 12 bit depth. Planetary image compression characterizations from A. Kiely and F. Pollara.

Earth-Based Analogies (4/5)

- Example #2: Earth-based autonomous vehicle navigation and targeting data types as indicators of upload requirements for in situ exploration elements
  - *In situ* exploration will directly entail or depend heavily upon mobility elements.
  - Intelligent use of mobility requires guidance, navigation, & control (GN&C).
  - Mobility elements will have to negotiate obstacles faster than command from Earth will allow.
  - Earth-based analogs suggest potential solutions that depend on onboard autonomy, in conjunction with remote sensing data product uploads, for navigation & retargeting.

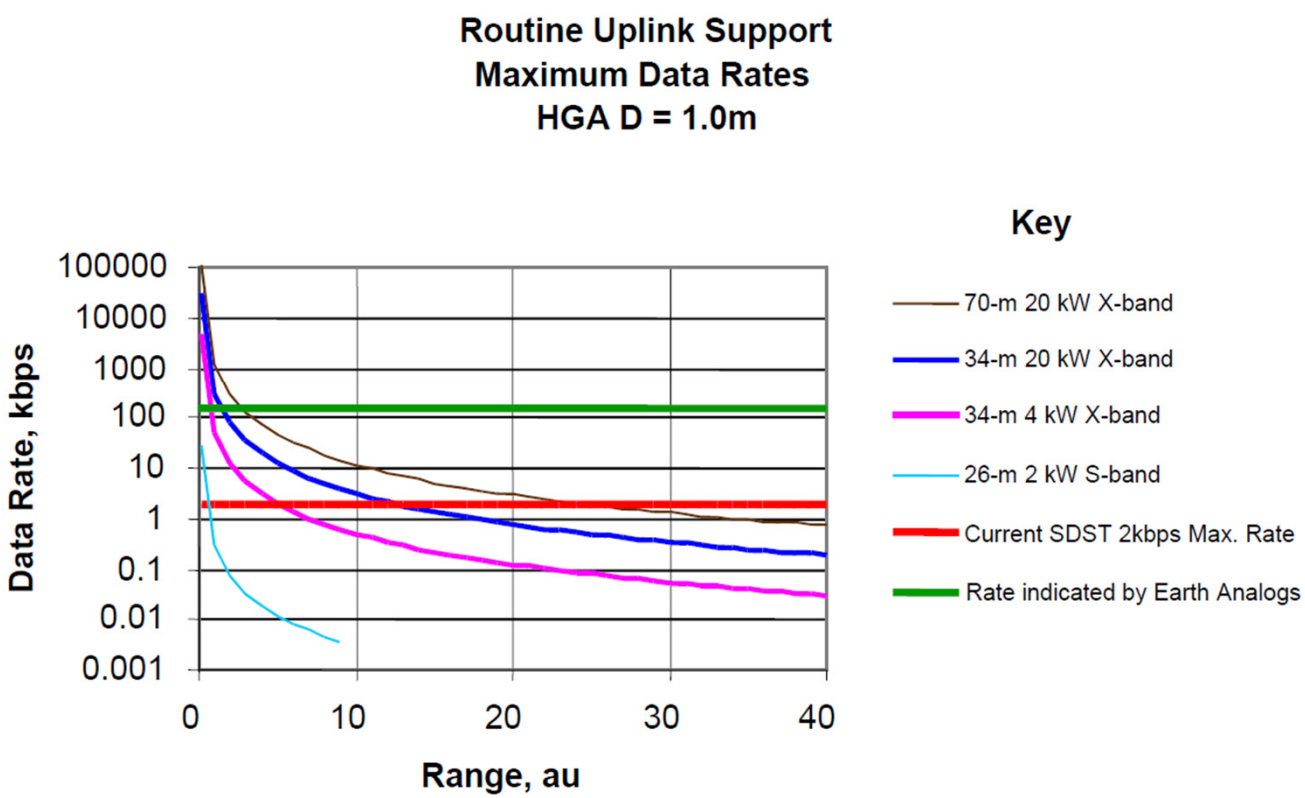
Cruise Missiles →
- Guidance via matching SAR data
- Targeting via digital scene matching

UAVs →
- Guidance via GPS-like beacon aids
- Targeting via hyperspectral signature

UGVs →
- Stereoscopic vision
- Multi-spectral terrain classification

Earth-Based Analogies (5/5)

- Example #2: Earth-based autonomous vehicle navigation and targeting data types as indicators of upload requirements for in situ exploration elements (continued…)



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Disseminating Results

- The most meaningful analysis results in the world don't do any good if they're not communicated to people who can act on them.
- The target audience depends on the foundational considerations discussed earlier.
  - What are the key questions to be answered?
  - What will be done with the answers?
- Once the purpose(s) and target audience are known, then the mechanism(s) for delivery should be identified (preferably prior to the analysis).
  - Internal vs. External
  - Briefings vs. Reports
- Within IND, we pursue multiple dissemination paths, as appropriate.
  - Briefings at internal Strategic Planning Meetings (SPMs)
  - Sections of strategic planning documents
  - Conference papers and associated briefings

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Arriving at Actionable Strategies

- Even when analysis results have been communicated to people who can act on them, it may not do any good unless those people understand what action or actions need to be taken; supply recommendations.
- Use a multi-stage dissemination process to evolve the recommendations into actionable strategies.
  - Education (initial briefings/reports)
  - Alignment (recommendation discussion meetings/strategic planning documents)
  - Advocacy Building (HQ briefings, external boards, conference papers)
- Within IND, the dissemination process discussed earlier follows this multi-stage approach.
  - Conducting Strategic Planning Meetings (SPMs) & System Engineering Working Group (SEWG) meetings to educate and then engender discussion regarding the recommendations and (for those that survive) their path(s) to implementation.
  - Working through the process of producing strategic plans, roadmaps, and implementation plans to first build internal alignment; then, external alignment.
  - Presenting in various external forums to build advocacy.

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Summary of Key Points (1/2)

- Think carefully about the questions you want to answer and what you will do with the answers before formulating your approach to data-driven strategy analysis.
  - Also, think about potential delivery mechanisms for the analysis results.
- Data requirements and analysis techniques will depend heavily on your upfront thinking; usually multiple data sources and analysis techniques will be needed.
- Data collection is probably the least appreciated, yet most important, aspect of data-driven strategy analysis; garbage in, garbage out.
  - Don't underestimate the resources required to collect good data.
- Keep the outputs of analysis tools straight-forward and understandable.
- No single tool has to do everything; just make sure that all of your tools work smoothly together to produce what you need.
- Consider employing alternative methodologies to avoid systematic biases in the analysis results.

Summary of Key Points (2/2)

- Communicate what you learn to those that can do something about it.
- Provide recommendations so that those who can do something have an idea of what to do.
- Arriving at actionable strategies frequently requires a 3-step process:
  - Educating
  - Achieving alignment
  - Building advocacy