Multi-Attribute Tradespace Exploration as an Enabler of Architecting an Extensible On-Orbit Servicing System

**Background**
- Multi-Attribute Tradespace Exploration (MATE)
- Simple, secure, flexible, rapid architecture design methodology
- Decision maker preferences aggregated into a single utility function
- Engineering trade space quantifies and evaluates each design
- Decision maker utility identifies pareto front of architectures
- Evolutionary Acquisition
  - Preplanned Product Improvement (P3I)
  - Spiral Development
- On-Orbit Servicing (OOS)
  - Upgrade software
  - Fix hardware
  - Refuel
  - Provide station keeping
  - Relocate (re-boost and end-of-life)
  - Service hardware (e.g., plug-and-play mechanisms)
  - Repair (mechanical, structural, etc.)

**Research Proposal**
- A MATE study of on-orbit servicing (OOS) architectures is proposed to address both of these needs
- OOS offers means to extend satellite lifetimes or correct the orbits of stranded satellites
- MATE strong candidate to architect an OOS system
- MATE is a flexible tool that can incorporate "lessons learned" from previous spirals as well as advances in technology
- MATE can rapidly enumerate the tradespace for each stakeholder
- MATE empowers an OOS architect to explore a multidimensional pareto efficient surface of designs

**Guiding Questions**
1) What on-orbit servicing architecture maximizes the provider’s profit?
- From the provider’s perspective, what is the best way to divide up the market? What attributes characterize each market segment?
- What design variable vector(s) represent the most profitable architecture for each market segment?
- What are the costs and benefits of designing for extensibility and market uncertainty?
- What is the expansion path for an OOS provider? In what order should an OOS provider reach out to the different market segments?
2) What value can MATE add to the staged deployment of systems with multiple stakeholders?
- How do you merge preferences of multiple stakeholders into system-of-system requirements?

**Four Classes of OOS “Functions”**
- Categorize on-orbit servicing “functions” into four unique mission types:
  - **Assess**
    - Proximity operations to assess physical state
    - Determine current position
    - Determine orientation
    - Determine operational status
  - **Restore**
    - Anything that restores satellite to beginning-of-life state
    - Restore
    - Provide station keeping
    - Fix hardware
    - Fix software
  - **Relocate**
    - Re-boost from failed launch
    - Re-boost to stable orbit
    - Orbital transfer, including constellation reconfiguration
    - End-of-life transfer into graveyard orbit
    - Remove orbital debris
  - **Augment**
    - Anything that improves upon beginning-of-life state
    - Upgrade hardware
    - Upgrade software

**Each mission has its own multi-attribute utility (MAU) function...**

**Mapping Design Vectors to Missions**

**Technology and Policy Aspect**
- Possibility of lack of feasible OOS market raises interesting policy question
- Combine OOS analysis from the provider’s perspective with customer reservation prices calculated by MIT graduate student Andrew Long
- OOS as a public good?
  - Defined as a product that cannot or will not be produced for profit due to diffuse, beneficial externalities

**Four* Classes of OOS “Forms”**
- Categorize on-orbit servicing “forms” into four design vectors:
  - **Design Vector 1**
    - **Eye Ball**
    - Microsatellites for proximity inspection
  - **Design Vector 2**
    - **Space Tug**
    - Tow truck to move mass on orbit
  - **Design Vector 3**
    - **Servicer**
    - Preplanned refueling and plug ‘n’ play upgrades
  - **Design Vector 4**
    - **Servicer Plus**
    - All-purpose vehicle: inspect, move, repair, upgrade

**Work Plan**
- **Spring 2005**
  - Complete literature review and outline thesis
  - Present "Challenges for a GEO Space Tug System" at SPIE Defense & Security Symposium
  - Begin coding OOS model/simulation
- **Fall 2005**
  - Complete model/simulation
  - Conduct MIST interviews to obtain OOS multi-attribute utility functions
  - Experiment with different categories of utility, portfolio theory and other valuation techniques
- **Summer 2005**
  - Test use of MATE with two design vectors (satellite + micro-UAV)
  - Present “Multi-Attribute Tradespace Exploration as an Enabler of Tactical Reconnaissance System Design” at AIAA Space 2005
- **Spring 2006**
  - Complete assessment of extendibility between architectures
  - Write thesis
  - Submit to conference and journal

---

Matt Richards (mgr@mit.edu), Research Assistant

Systems Engineering Working Group

Donna Rhodes (rhodes@mit.edu), Research Advisor