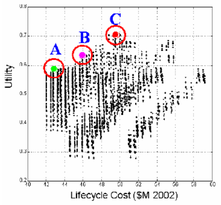
Multi-Attribute Tradespace Exploration as an Enabler of Architecting an Extensible On-Orbit Servicing System

Background

- **Multi-Attribute Tradespace Exploration (MATE)**
  - Simple, accurate, flexible, rapid architecture design methodology
  - Decision maker preferences aggregated into a single utility function
  - Parametric models enumerate tradespace of designs
  - Decision maker utility identifies pareto front of architectures
- **Evolutionary Acquisition**
  - Preplanned Product Improvement (P3I)
  - Spiral Development
- **On-Orbit Servicing (OOS)**
  - Upgrade software
  - Inspect
  - Refuel
  - Provide station keeping
  - Relocate (re-boost and end-of-life)
  - Upgrade hardware (e.g., plug-and-play electronics)
  - 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**

Motivation

- **Need for robust, flexible space systems**
  - **Users have low tolerance for failure**
  - **User needs change rapidly**
  - **Satellites abandoned because there is no means to repair/refuel**
- **Need design methodology to enable multi-stakeholder spiral development**
  - **Space systems: civil, commercial, military, and intelligence users**
  - **In first spiral, OOS provider may focus on one group of stakeholders**
  - **In following spirals, OOS provider may seek to develop a "product family" of servicing vehicles to tap the entire servicing market**

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"

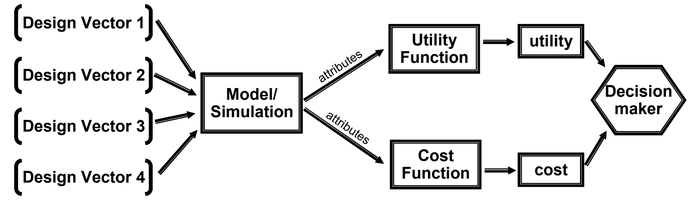
Categorize on-orbit servicing "functions" into four unique mission types:

Assess	Restore
• Proximity operations to assess physical state ▪ Determine current position ▪ Determine orientation ▪ Determine operational status	• Anything that restores satellite to beginning-of-life state ▪ Refuel ▪ Provide station keeping ▪ Fix hardware ▪ Fix software
Relocate	**Augment**
• 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	• Anything that improves upon beginning-of-life state ▪ Upgrade hardware ▪ Upgrade software

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

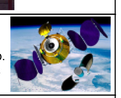
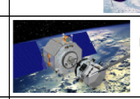
Four* Classes of OOS "Forms"

Categorize on-orbit servicing "forms" into four design vectors:



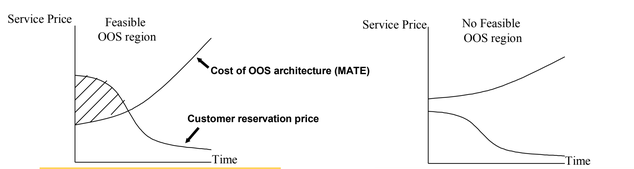
	"Form"	Description
Design Vector 1	Eye Ball	Microsatellite for proximity inspection
Design Vector 2	Space Tug	Tow truck to move mass on orbit
Design Vector 3	Servicer	Preplanned refueling and plug 'n play upgrades
Design Vector 4	Servicer Plus	All-purpose vehicle: inspect, move, repair, upgrade

Mapping Design Vectors to Missions

Design Vector \ Mission Type	Assess	Relocate	Restore	Augment	Example
Eye Ball	X				 NASA - AerCam Sprint
Space Tug	X	X	?		Orbital Recovery Corp. - ConeXpress 
Servicer (Preplanned)	X	X	?	?	 DARPA - Orbital Express
Servicer Plus	X	X	X	X	NASA + DARPA - Robonaut 

Technology and Policy Aspect

Possibility of lack of feasible OOS market raises interesting policy question



Feasible OOS Market
(Provider's breakeven price is lower than the customer's reservation price)

No Feasible OOS market
(Provider's breakeven price is higher than the customer's reservation price)

- **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**

Work Plan

Spring 2005	Fall 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	• 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	**Spring 2006**
• 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	• Complete assessment of extensibility between architectures • Write thesis • Submit to conference and journal

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