Design and Evaluation of an Orbital Debris Remediation System

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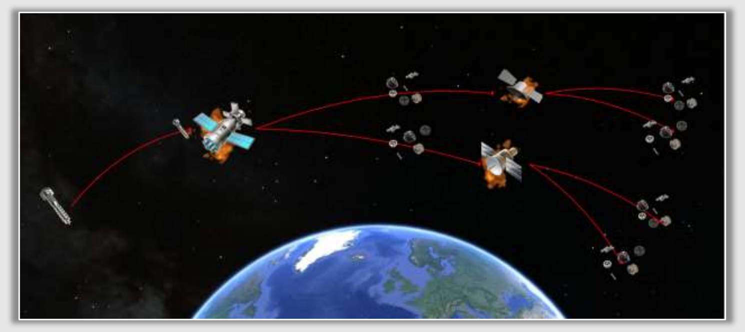
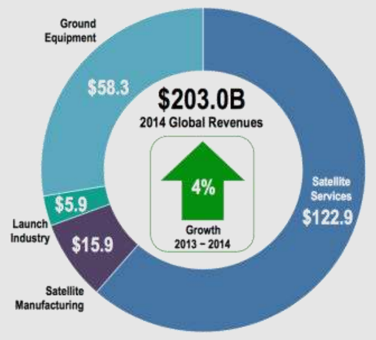
Context

Space debris and collisions form a positive feedback loop that propagates more and more debris throughout the space environment. This puts the entire space economy, worth hundreds of billions of dollars, at risk.

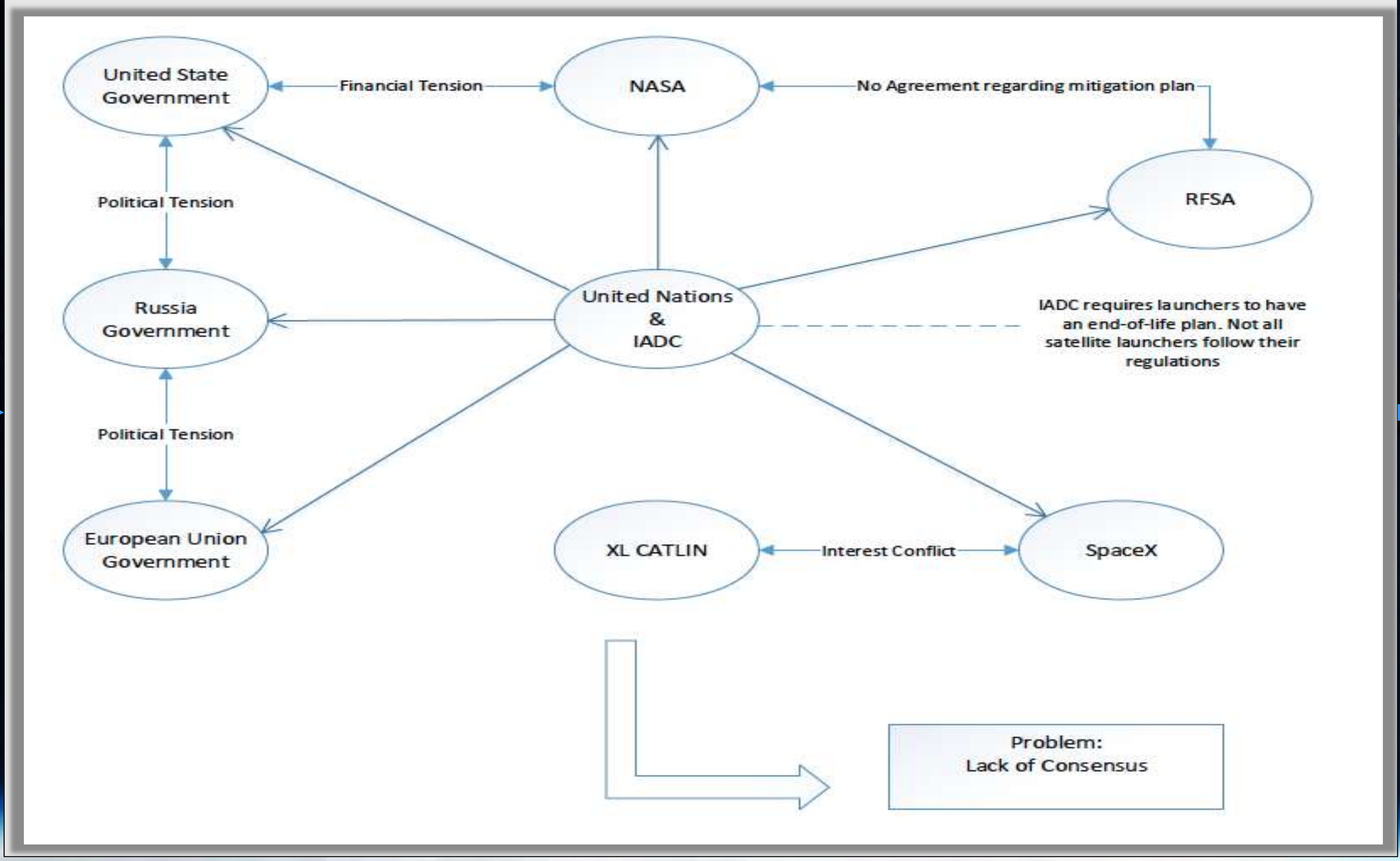




There are many proposed remediation solutions, but there is no consensus on which solution to use and thus none of them have been implemented. The first step to any remediation effort is to bridge this gap.

Problem:
Lack of Consensus

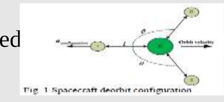
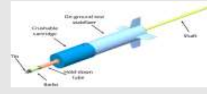
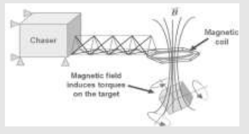
Stakeholders and Need



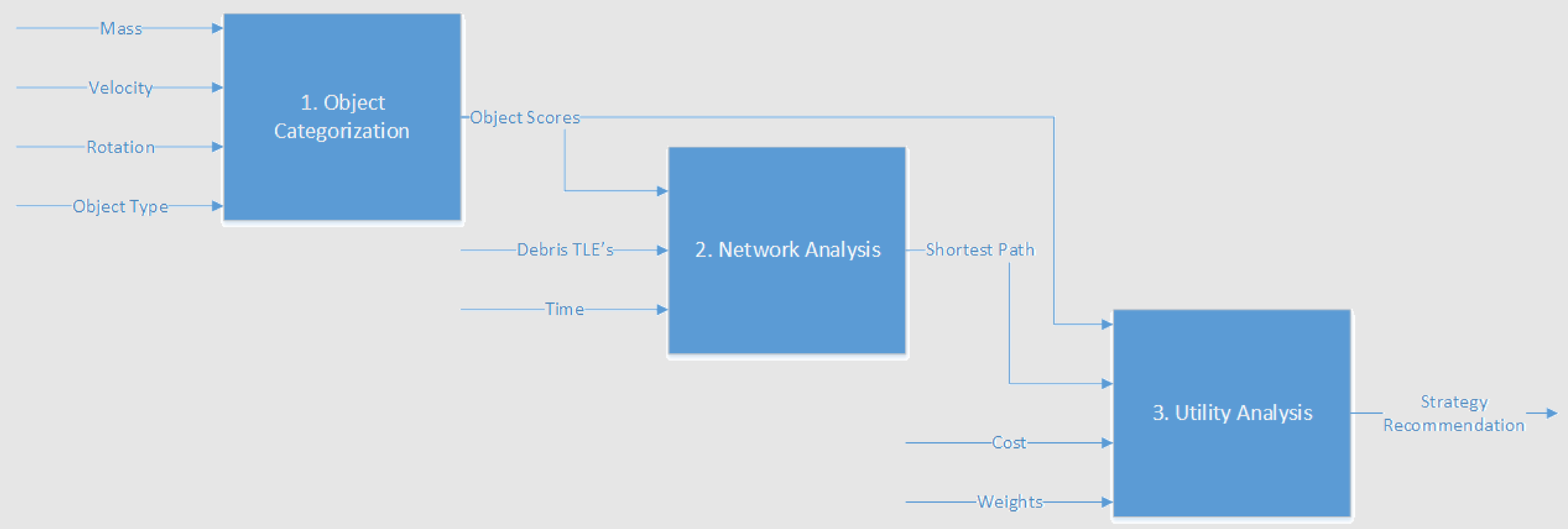
Active Debris Removal (ADR)

Concept of Operations:

1. Identify target object
2. Maneuver and rendezvous with target
3. Grapple with target and de-tumble (if necessary)
4. Remove the object from orbit

ADR Alternatives	Concept	TRL	Cost
Robotic arm (with de-orbit kit) 	Physically grab the debris object using a robotic arm and perform a maneuver to change the object's orbit.	6 - 7	High
Throw Net 	Throw a net towards a debris object and pulls the object along a tether. The net entangles the objects due to weights or a closing mechanism.	6 - 7	Low
COBRA IRIDES	Use plume impingement from a hydrazine monopropellant propulsion system to impart momentum on a target debris either to change its orbit or its attitude.	5 - 6	Medium
Three Coordinated Electromagnetic Spacecraft 	With the application of inter-spacecraft electromagnetic force, a disabled satellite with functional magnetorquer can be removed in a non-contacting manner without propellant expenditure or complicated capture mechanisms.	2 - 4	High
Harpoon 	Shoot a tethered harpoon into the object. After the harpoon penetrates the object, the bars at the point are opened to keep itself sticking in the object. Then perform a maneuver to change the object's orbit.	6 - 7	Medium
Eddy Currents 	It is based on the computation of the Magnetic Tensor which depends on how the conductive mass is distributed throughout the debris object, using the open cylindrical shell and flat plates. No mechanical contact with the target is required since an active de-tumbling phrase is based on eddy currents.	3 - 4	High

Method of Analysis



1. Object Categorization

It analyzes the effectiveness of each ADR designs for all types of object

Take mass, velocity, rotation and objects type as input and output the object scores for each ADR design.

Calculate mass using Linear Decreasing:

V(X) = 1− (Max-X/Max− Min)

Calculate velocity and rotation using Exponential Decreasing:

V(X) = e^− λx

2. Network Analysis

Take position data and calculate the delta-v required to maneuver between an interceptor (an ADR design) and a target

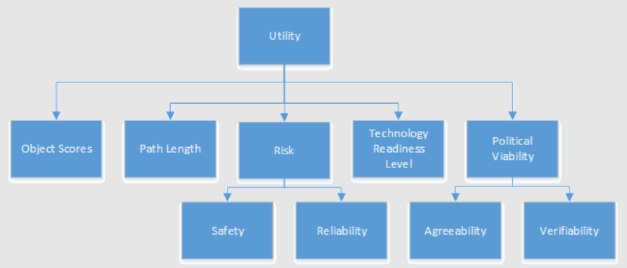
Merge this data with the object scores from part 1.

Use maneuvers as arcs in a time-sensitive network, with object scores and delta-v costs as the objective function and constraints

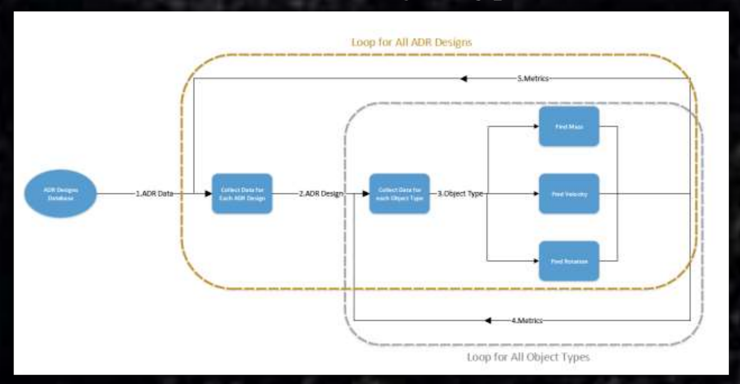
Choose next target via:

$$\max\{{objectScore_i}/{\Delta V_i}, i = potential\ targets\}$$

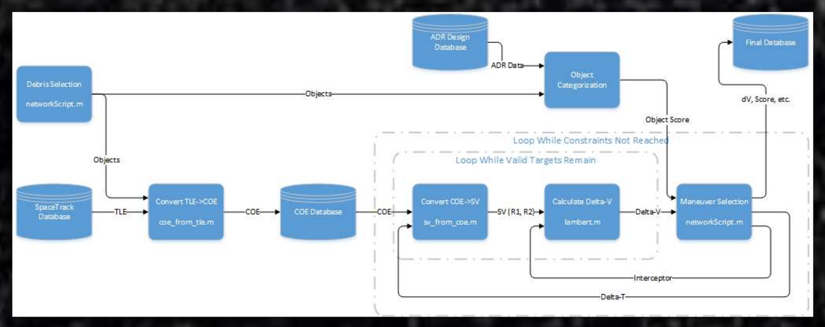
3. Utility Analysis



General Algorithm
For all ADR designs:
For all object types:
Find mass, velocity and rotation
Choose next object type
Choose next ADR design
For all objects:
Find mass, velocity and rotation
Determine object scores
Choose next object type



General Algorithm
For all interceptors:
For all potential targets:
Find delta-v cost
Choose best target
Iterate clock
Update positions
Choose next interceptor



Preliminary Results

Using a series of MATLAB functions, we have constructed a delta-v cost calculator, the main "engine" of our network analysis.

The exhaustive computations involved in the overall project (combinations of hundreds of debris objects) are extensive and involved. For our preliminary results, we test our algorithms with a limited sampling of objects.

>>Read in TLE data
>>Read in parameters from DOE
>>OUTPUT:
>>Deploy NET to remediate object 00011 at time 0
>>Deploy NET to remediate object 01584 at time 543
>>Deploy NET to remediate object 01314 at time 674
>>Deploy HARPOON to remediate object 04964 at time 721
>>etc…

Future Work

Throughout Winter Break and the Spring semester we will continue to review and refine our model.

While we have made an effort to narrow the field and propose a best strategy for ADR development and deployment, we would be remiss to ignore competing debris remediation strategies, as ADR is only one option. Other possibilities include Just-In-Time Collision Avoidance (JCA), or more abstract political solutions, such as expanded property rights.

To fully explore and expand upon our work, and particularly in order to truly fill the current gap (lack of consensus), further examination of high-level strategies is required.

In a brief snapshot, below are some competing concepts, each of which has pros and cons:

	Description	Cost	Risk
ADR	This is the method that we dealt with in this project. ADR is a long-term, expensive, but theoretically permanent, solution. By permanently removing debris, it can no longer pose a threat.	$100's of millions to billions per collision avoided	Most well-established technically, still untested under live conditions
JCA	A competitor to ADR, JCA proposes to circumvent debris risk by predicting and dodging collision events as they occur. CONOPS: Identify, react, deflect, prevent.	$10's of millions to $10's of billions per collision avoided	Lower acceptance in the space debris community (even less consensus) Does not solve the long-term problem
Property Rights	By allocating orbits to individuals and corporations, almost as if they were land, governments foist the costs (and benefits) of space use from public organizations to private companies. In theory, the incentive to protect your own goods on your own property would drive the owners to handle the debris problem.	$0 (ignoring administrative overhead)	Entirely untested High potential for failure Does not truly account for total costs, simply shifts them around via free market forces