Systems Engineering Advancement Research Initiative

System of Systems Architecture: The Case of Space Situational Awareness

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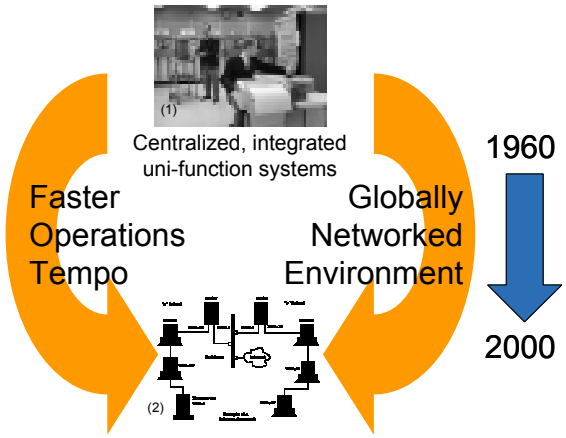
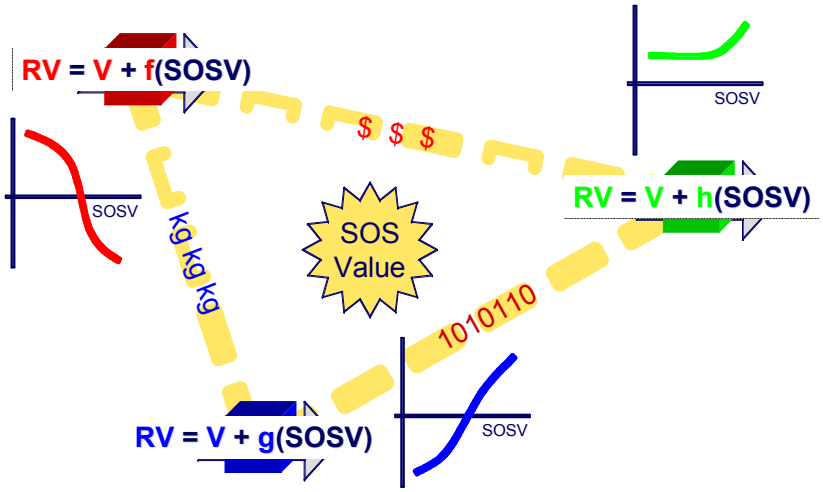
Systems of Systems

- Emerged from the **growth of network technologies** and the **need for more agile** and nuanced **system response**
- **Collection of systems** that **work together** through SOS interfaces to generate value that can't be produced in isolation
- Demonstrate **operational and managerial independence**



(1) http://www.electrohype.org/press/pionjar/IBM_System360_Mod_50.jpg
(2) http://www.washington.edu/R870/img/Network.gif



- **Value** in SOS is a **two part problem**
- Each constituent system's stakeholders care about certain **needs that are local** to them
- They also have **needs** that can **address by** participating in **the SOS**
- **Joining the SOS**, however, can also **impact local value** generation
- Managing the SOS therefore requires **finding the right balance between local and SOS level needs**

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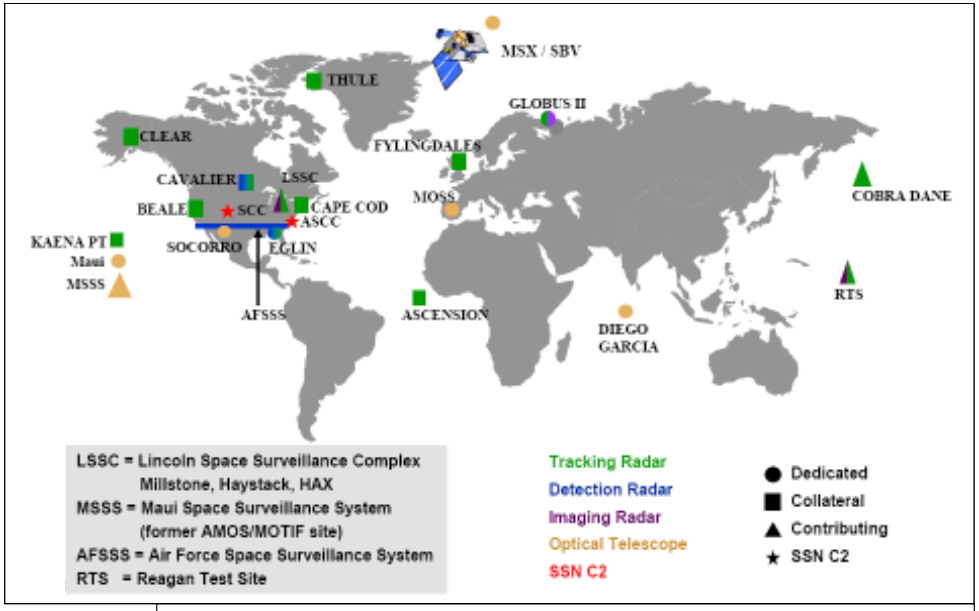
Space Situational Awareness



Graphic: G. Shepherd

Dedicated – space surveillance is primary mission
Collateral – belong to AFSPC but have primary mission other than space surveillance (e.g., launch support, early warning)
Contributing – report to another Air Force Major Command or are under to AFSPC to provide space surveillance information

Shepherd, G., "U.S. Space Surveillance System," *Improving our Vision: Approaches for Shared Space Situational Awareness*, Colorado Springs, CO, Sept. 2006.

- Space Situational Awareness (SSA) is the surveillance and characterization of objects in the space environment
- Requires multiple sensing assets and complex coordination across geography
- Several nations current accomplish this mission through varied means
- International cooperation is an area of increasing interest among the SSA community

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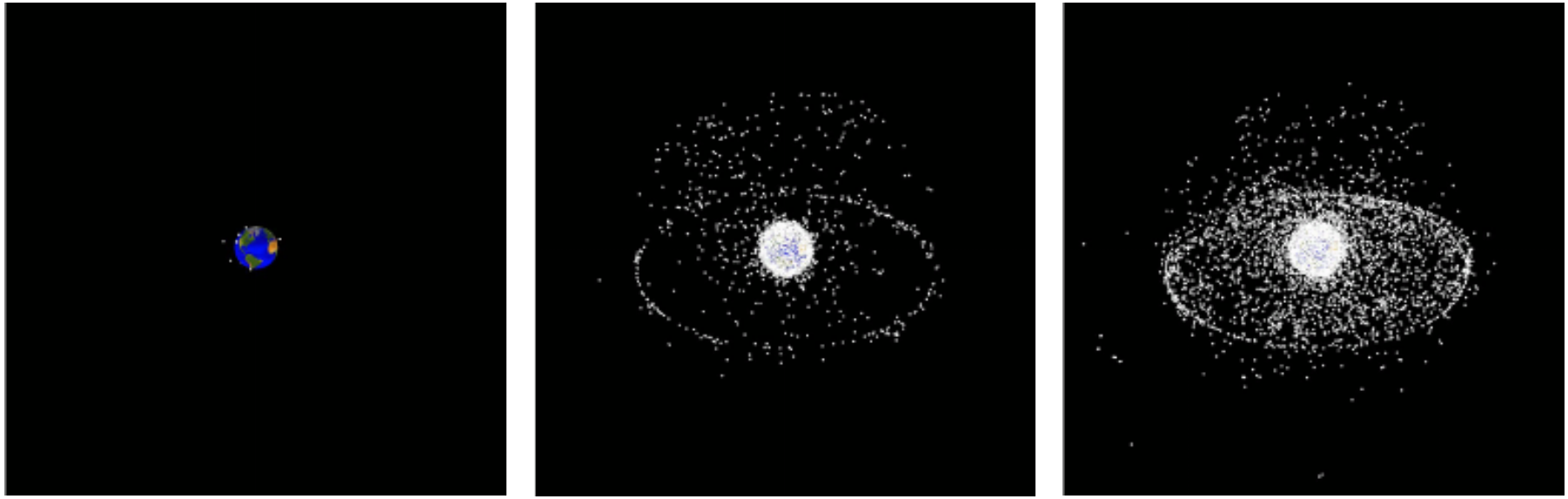
Orbital Debris: A growing threat

- In-orbit collision risk has always existed, but exponential growth in number of space objects increases risk
- Prime objective of a commercial operator is to maintain spacecraft functionality
  - Minimizing collision risk is paramount
- Need for space surveillance to conduct hazard analyses and to inform hardening/maneuver strategies

1960 **1985** **2006**



Cataloged objects >10 cm in diameter

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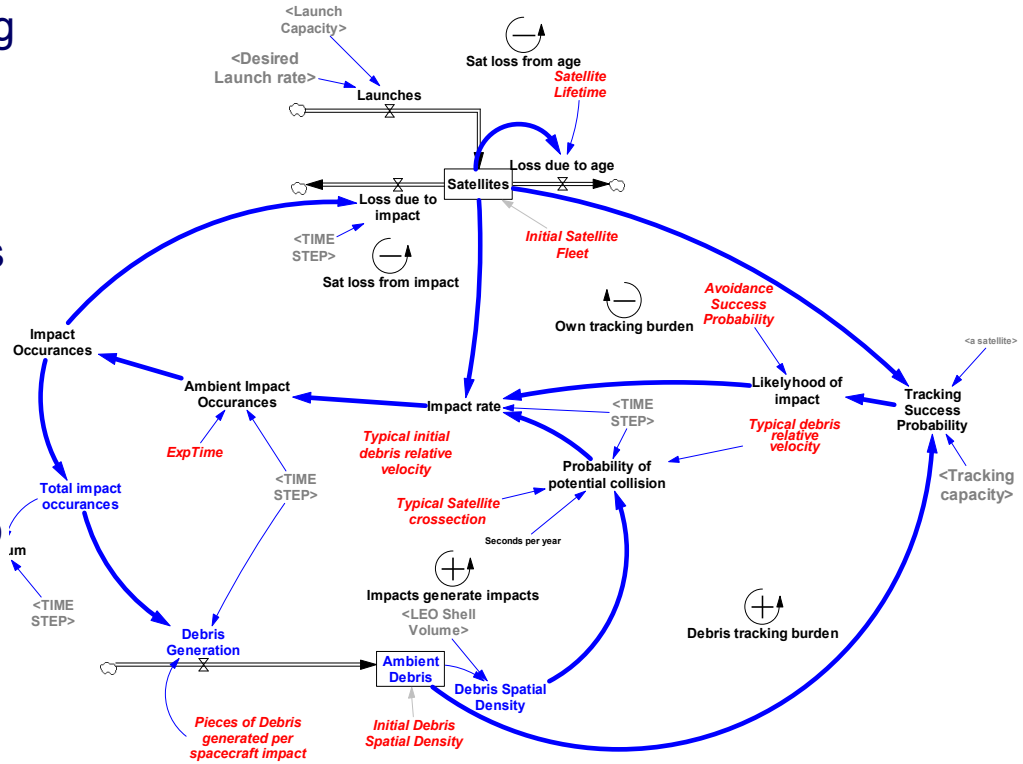
Model of international cooperation for SSA to reduce the danger posed by orbital debris

- **System dynamics model**
- **Interactions between spacecraft and debris** (shown at right) modeled assuming simple ideal gas model of debris
- Economic decisions of **purchasing and operating spacecraft** (leads to Launch Rate at top of diagram)
- **Purchasing of sensors** by nations (leads to national debris tracking capability at right of diagram)
- **Two generic nations** are included
- Model allows nations to **share sensor data**
- Sharing **reduces collision risk** leading to **economic benefit**
- Sharing also can **create dependence upon other nations'** sensors that may **hurt national security**
- Sensor **purchasing/sharing decisions** use a utility function that **balances the economic drive to share with the security need to be self-reliant**



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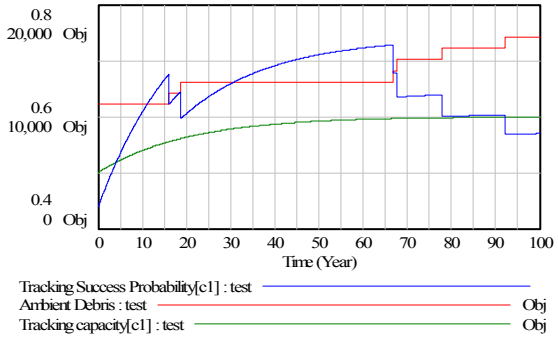
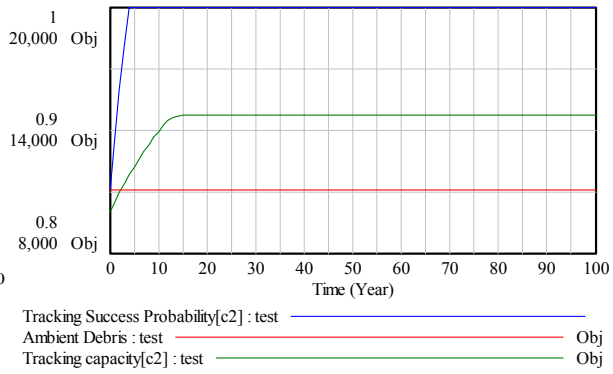
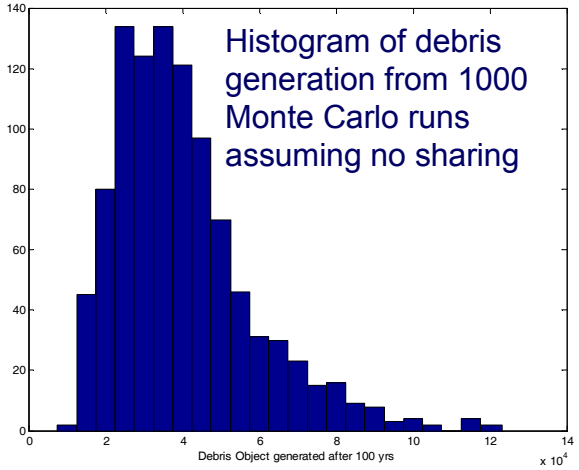
Preliminary Results

No sharing



Full sharing





- Assumed both **nations have identical value functions** (equally weighing economic and security concerns) and **identical initial conditions** (sensing capability and satellite fleet)
- Game theoretic analysis of the level of sensor sharing reveals that **full sharing** by both nations is the pure strategy **Nash equilibrium**
- This equilibrium is, however, **not socially efficient** as both nations could **do better if they limited their sharing**
- Argues for the existence of a mixed strategy equilibrium and/or the **need for a coordination mechanism**

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Ongoing Work

- Further improve debris model by including effects of rocket bodies and explosions and better handle spacecraft retirement
- Relax assumptions that nation have identical value functions
- Explore the inclusion of an operationally responsive space capability to allow for smaller but possibly less reliable spacecraft
- Explore coordination mechanisms and mixed strategy equilibrium to see if socially efficient policy options can be found

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