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CONSORTIUM FOR SPACE MOBILITY AND ISAM CAPABILITIES

ISAM CAPABILITY TAXONOMY

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REVISION AND HISTORY PAGE

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1. Acronyms

Acronyms	Meaning
AM	Additive Manufacturing
DSO	Dynamic Space Operations
FMC	Forced Motion Circumnavigation
GEO	Geosynchronous Orbit
HEO	Highly Elliptical Orbit
HW	Hardware
ISAM	In-space Servicing, Assembly, and Manufacturing
ISRU	In-Situ Resource Utilization
LEO	Low-Earth Orbit
NMC	Natural Motion Circumnavigation
RPO	Rendezvous and Proximity Operations
RSO	Resident Space Object
SC	Spacecraft
SMA	Structural Manufacturing and Assembly
SML	Space Mobility and Logistics
SV	Space Vehicle
SW	Software

Table 1. Table of used acronyms

2. Lexicon

ISAM-adjacent	A function or technology that does not service, assemble, or manufacture, but that would be present in the same space economy as ISAM functions and missions
ISAM Capability[CL]	The integration of ISAM Functions to enable an ISAM Mission
ISAM Function[CL]	Application of one or more ISAM Technologies to perform a specific action, task, or activity
ISAM Mission[CL]	An activity carried out to achieve operational outcomes/effects with ISAM Capabilities
ISAM-relevant	In support of, but not exclusive to, an ISAM Function or Mission
ISAM Use Case[CL]	Baseline or alternative scenarios where ISAM Capabilities are employed to achieve an ISAM Mission or realize an ISAM Mission opportunity
ISAM-unique	Exclusive to an ISAM Function or Mission
Taxonomy[MW]	The study of the general principles of scientific classification: systematics
CONFERS Lexicon	A satellite servicing lexicon created by the CONFERS Technical Committee that contains definitions for various ISAM terms

[MW] Merriam-Webster Dictionary
[CL] COSMIC Lexicon

3. Introduction

This document presents a comprehensive framework containing twelve In-space Servicing, Assembly, and Manufacturing (ISAM) capability areas in a taxonomy. The capability areas leverage the organization of NASA's ISAM State of Play document, where each capability area in the taxonomy is a distinct activity that an ISAM mission would perform to achieve its objectives. Leveraging this existing structure reduces potential discrepancies among resources and confusion in the community.

This capability taxonomy serves as a baseline document for other COSMIC products to reference when defining ISAM capabilities, and it will serve as a foundational layer for future COSMIC products. The taxonomy standardizes the terminology for ISAM activities to facilitate internal and external communication. The identification of use cases, decomposition, and competencies in each capability area will serve to enhance future COSMIC products that will be used broadly by the community.

4. Capability Taxonomy

In 2023, NASA published the ISAM State of Play[1], a document that identified "11 capability areas that describe the functions or activities that would be performed in space using In-Space Service, Assembly, and Manufacturing (ISAM)." The structural manufacturing and assembly capability has been separated in its two components; the resulting 12 capabilities and their acronyms have been tabulated in Table 2.

#	Capability	Acronym
1	Inspection and Metrology	IM
2	Parts and Goods Manufacturing	PGM
3	Planned Repair, Upgrade, Maintenance, and Installation	PR
4	Refueling and Fluid Transfer	RFT
5	Relocation	Rel
6	Robotic Manipulation	RM
7	Rendezvous & Proximity Operations (RPO), Capture, Docking, and Mating	RPO
8	Recycling, Reuse, & Repurposing	R^3
9	Structural Assembly (formerly in SMA)	SA
10	Surface Infrastructure	SI
11	Structural Manufacturing (formerly in SMA)	SM
12	Unplanned or Legacy Repair and Maintenance (A)	UR

Table 2. Table of ISAM capabilities.

The capabilities have been mapped to the Assembly-Service-Manufacturing triad with the goal to identify commonalities; the Venn diagram is shown in Figure 1.

Each capability area is discussed in the following sections with the goal to answer the question, "What does an organization need to be able to competently demonstrate the respective capability?" Moreover, the answers to the question are categorized into ISAM-unique, ISAM-relevant, and ISAM-adjacent.

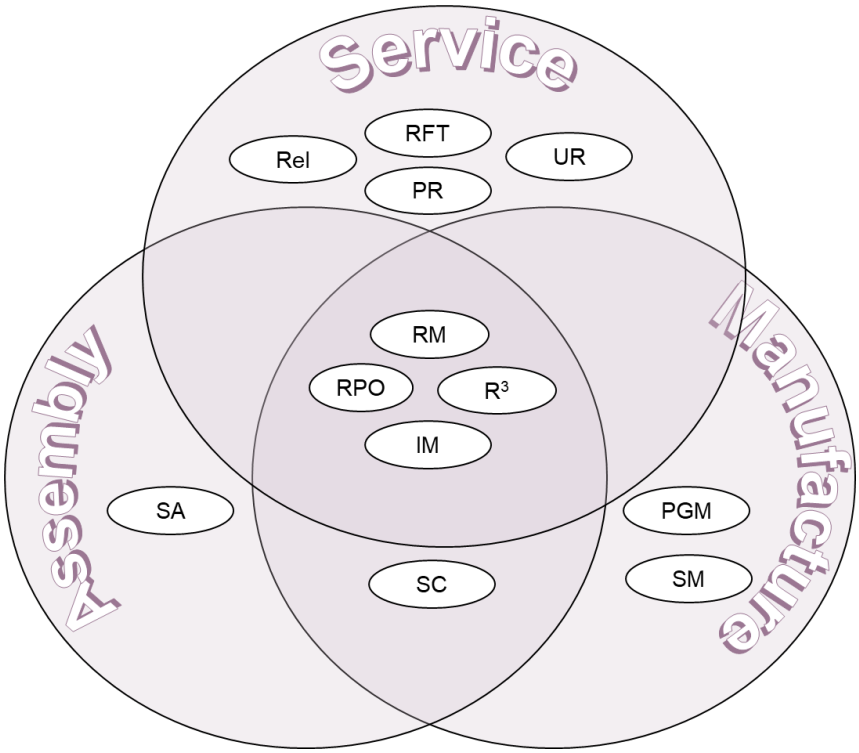


Figure 1. Service-Assembly-Manufacturing triad and the capabilities identified in ISAM State of Play[1].

5. Inspection and Metrology (IM)

5.1 Description

Inspection and Metrology (IM) involves observation of systems in space to understand and quantify their configuration, size and shape, surrounding environment, or other features of interest. It includes free-flyer inspection, non-destructive evaluation, close (robotic) inspection, and space situational awareness.

5.2 Use Cases

- Verification:
  - Deployment of components stowed during launch and transit.
  - Deployed configuration of the client.
  - Calibration and alignment of components on the client.
  - Confirm/quantify partial and final results of in-space manufacturing or assembly.

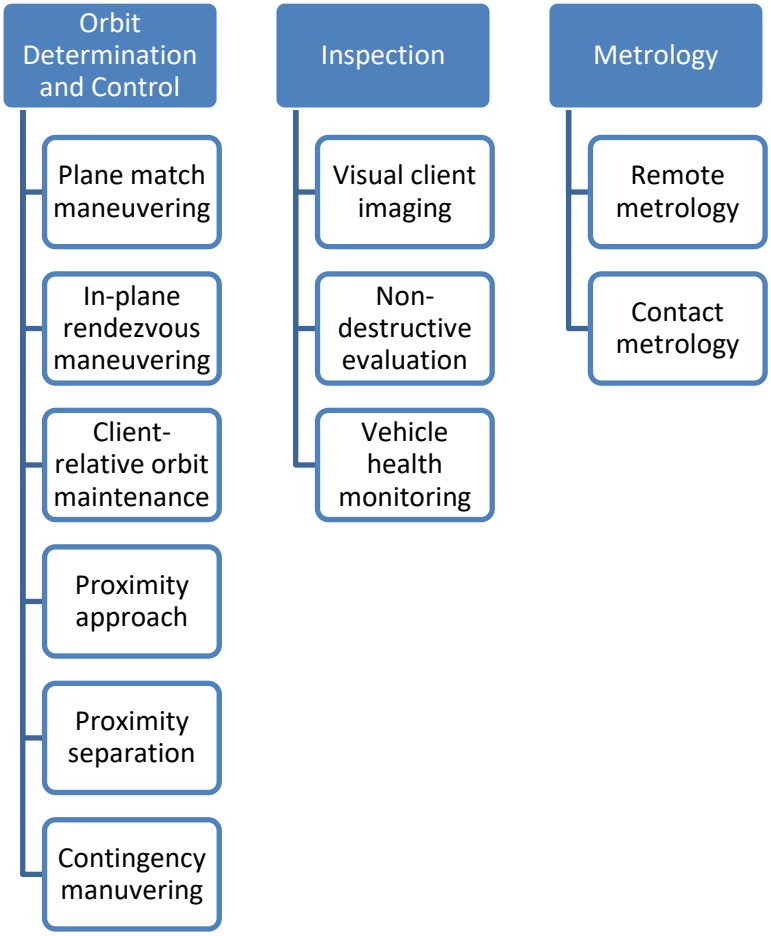
- Monitor client:
  - Client operations.
  - Near-space environment of the client.
  - Client health.

- Assessment of client:
  - Client damage.
  - Client maintenance and repair needs.
  - Service readiness.
  - Relocation readiness.

- Perform:
  - Anomaly detection.
  - Diagnostics.

- Other services for the client:
  - Protection and security (sentinel, bodyguard).

5.3 Taxonomy



5.4 Competencies required/desired to demonstrate IM

	Orbit determination and control		Inspection		Metrology	
	Inertial	Relative	Remote	Contact	Remote	Contact
ISAM-adjacent	●					
ISAM-relevant		●	●	●	●	●
ISAM-unique						

6. Parts and Goods Manufacturing (PGM)

6.1 Description

Parts and Goods Manufacturing (PGM) involves producing parts, originals and spares, subsystems, and components for use in space, on Earth, or on a lunar or planetary surface. It includes internal (to a habitat) and external manufacturing with multiple materials and sizes.

6.2 Use Cases

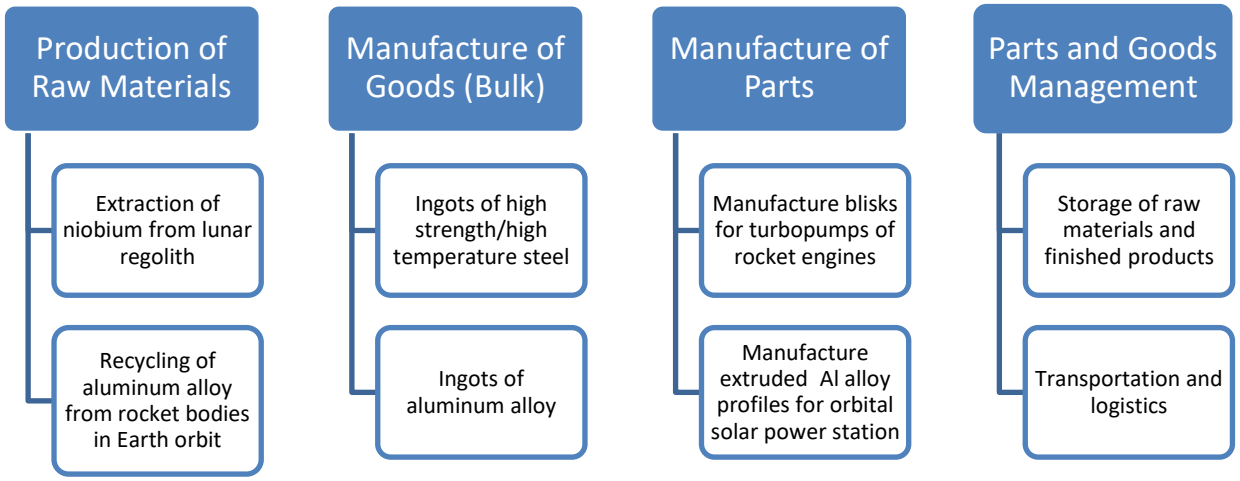
- Including parts and goods made in space for space and planetary surfaces or made in space for use on Earth.

- Manufacture of parts:
  - Made in space:
    - For use in space.
    - For use on the surface of any celestial body (including Earth).

  - Made on the surface of celestial bodies other than Earth:
    - For use in space.
    - For use on the surface of any celestial body (including Earth).

- Manufacture of goods (materials and consumables):
  - Solids: single crystals, fibers, filaments, etc.
  - Liquids: water, methanol, cognac, etc.
  - Power generation and energy storage.

6.3 Taxonomy



6.4 Competencies required/desired to demonstrate PGM

	Production of Materials		Manufacture of Goods		Manufacture of Parts		Parts and Goods Management	
	Extraction	Recycling	Casting	Recycling	Machining	Welding	Storage	Transport
ISAM-adjacent	●						●	
ISAM-relevant		●	●	●	●	●		●
ISAM-unique								

7. Planned Repair, Upgrade, Maintenance, and Installation (PR)

7.1 Description

Planned Repair, Upgrade, Maintenance, and Installation (PR) involves adding or replacing components on a client space object that is prepared to receive those components. These operations are performed to repair or upgrade that component, perform a maintenance swap-out, or install a new component that expands the capability of the spacecraft. It includes systems with modular interface connections and payload/component swap-out or upgrade.

7.2 Use Cases

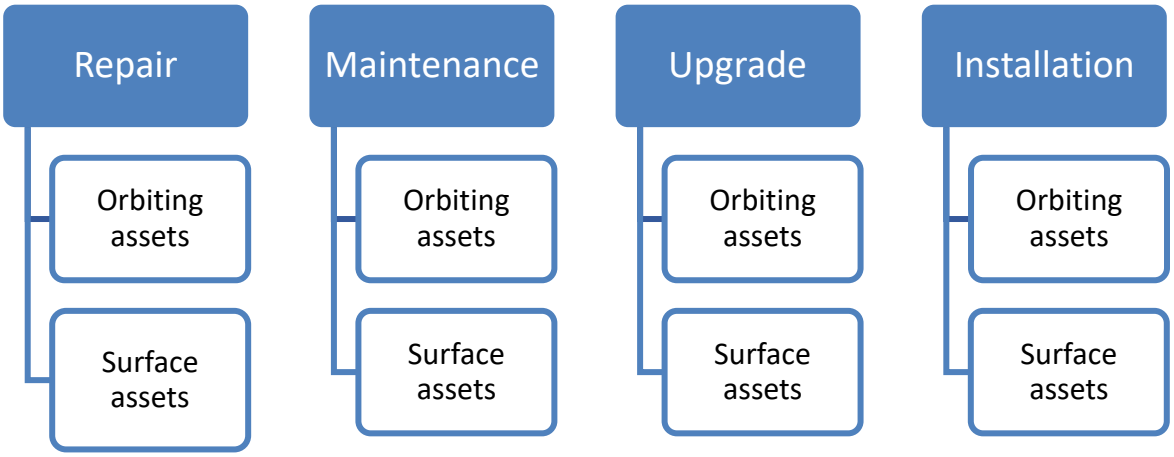
- Repair of:
  - Orbiting assets, e.g., spacecraft, space stations, etc.
  - Surface assets, e.g., rovers, habitats, other infrastructure, etc.

- Maintenance
  - Orbiting assets, e.g., spacecraft, space stations, etc.
  - Surface assets, e.g., rovers, habitats, other infrastructure, etc.

- Upgrade
  - Orbiting assets, e.g., spacecraft, space stations, etc.
  - Surface assets, e.g., rovers, habitats, other infrastructure, etc.

- Installation
  - Orbiting assets, e.g., spacecraft, space stations, etc.
  - Surface assets, e.g., rovers, habitats, other infrastructure, etc.

7.3 Taxonomy



7.4 Competencies required/desired to demonstrate PR

	Repair		Maintenance		Upgrade		Installation	
	Orbiting	Surface	Orbiting	Surface	Orbiting	Surface	Orbiting	Surface
ISAM-adjacent								
ISAM-relevant								
ISAM-unique	●	●	●	●	●	●	●	●

8. Refueling and Fluid Transfer (RFT)

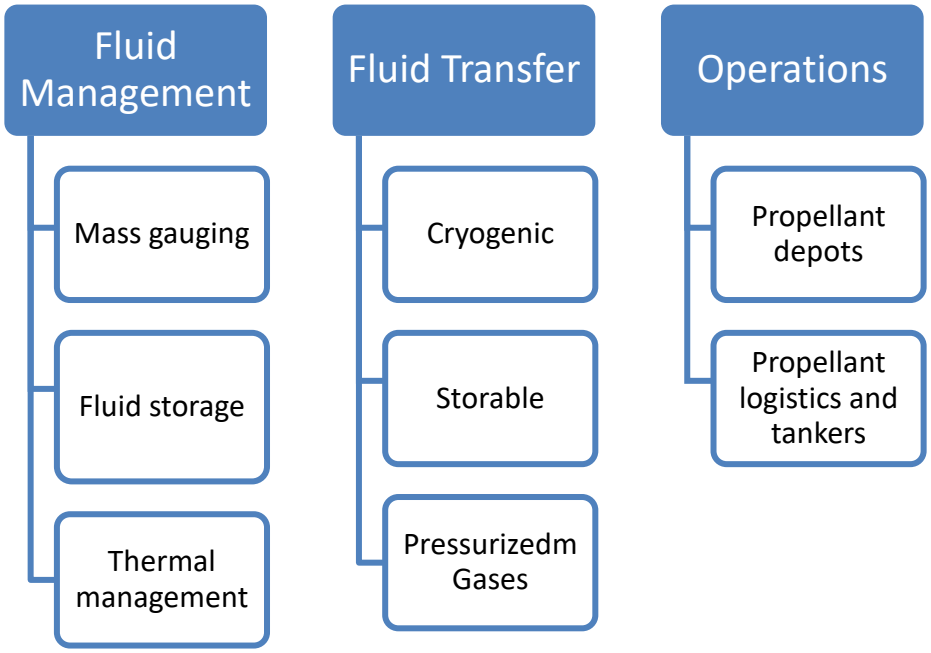
8.1 Description

Refueling and Fluid Transfer (RFT) involves transferring fluid from one spacecraft to another. Includes cryogenic and non-cryogenic propellants/fluids and transfer in orbit or on a lunar or planetary surface.

8.2 Use Cases

- Mars Transit Vehicle fueling before departure and between missions.
- Lunar lander refueling.
- Habitat consumable replenishment.
- Mission extension of LEO/GEO satellites.
- Dynamic space operations.
- Refueling crewed space stations/Gateway.
- Increase payload mass delivery (e.g., Starship refueling).

8.3 Taxonomy



8.4 Competencies required/desired to demonstrate RFT

	Fluid Management			Fluid Transfer			Operations	
	Mass gauging	Fluid storage	Thermal management	Cryogenic	Storable	Pressurized gases	Propellant depots	Propellant logistics & tankers
ISAM-adjacent	●	●	●					
ISAM-relevant								
ISAM-unique				●	●	●	●	●

9. Relocation (Rel)

9.1 Description

Relocation (Rel) involves one spacecraft maneuvering another space object into a new orbit or orientation. This includes boosting, repositioning, end-of-life disposal, debris removal, attitude control, and station keeping.

9.2 Use Cases

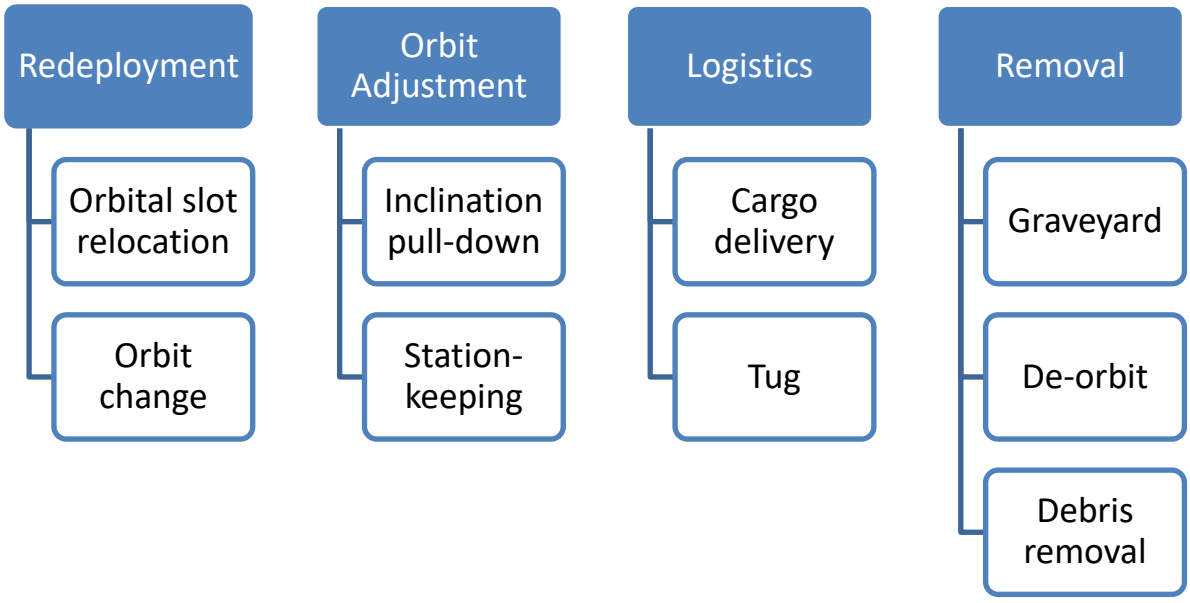
- Removal:
  - From orbit – case by case that contributes to the remediation of the orbital environment.
  - End-of-life (maneuver to graveyard and maneuver to deorbit including splashdown).

- Redeployment (e.g., bigger delta V than orbit adjustment):
  - Orbital slot relocation.
  - Change in orbit.

- Orbit adjustment (smaller delta V than redeployment):
  - Deconflict an orbit or set of (close) orbits.
  - Inclination pull-down.
  - Station keeping.
  - De-Tumble.
  - Reorient spacecraft to generate power with its solar panels.

- Logistics – moving resources from one location to another:
  - Last mile delivery.
  - Cargo delivery.
  - Transfer from space station to space station or vehicle to vehicle.
  - Tug from launch to operational location.

9.3 Taxonomy



9.4 Competencies required/desired to demonstrate Rel

	Redeployment		Orbit Adjustment		Logistics		Removal		
	Orbital slot relocation	Orbit change	Inclination pull-down	Station-keeping	Cargo delivery	Tug	Grave-yard	De-orbit	Debris removal
ISAM-adjacent					●	●			
ISAM-relevant	●	●	●	●			●	●	●
ISAM-unique									

10. Robotic Manipulation (RM)

10.1 Description

Robotic Manipulation (RM) is the precise actuation of a well-characterized robotic system that physically interacts with objects in a given workspace. This process of robotic manipulation can include a variety of variables including methods of mechanical actuation, sensing, end-effector design, and motion planning.

10.2 Use Cases

- Orbital multibody operations (These use cases are agnostic of cooperative and non-cooperative and prepared and unprepared space vehicles (SV)):
    - Resident Space Object (RSO) inertial properties characterization.
    - Detumbling an RSO.
    - Capture/gaining custody of an RSO.
    - Docking with an RSO.

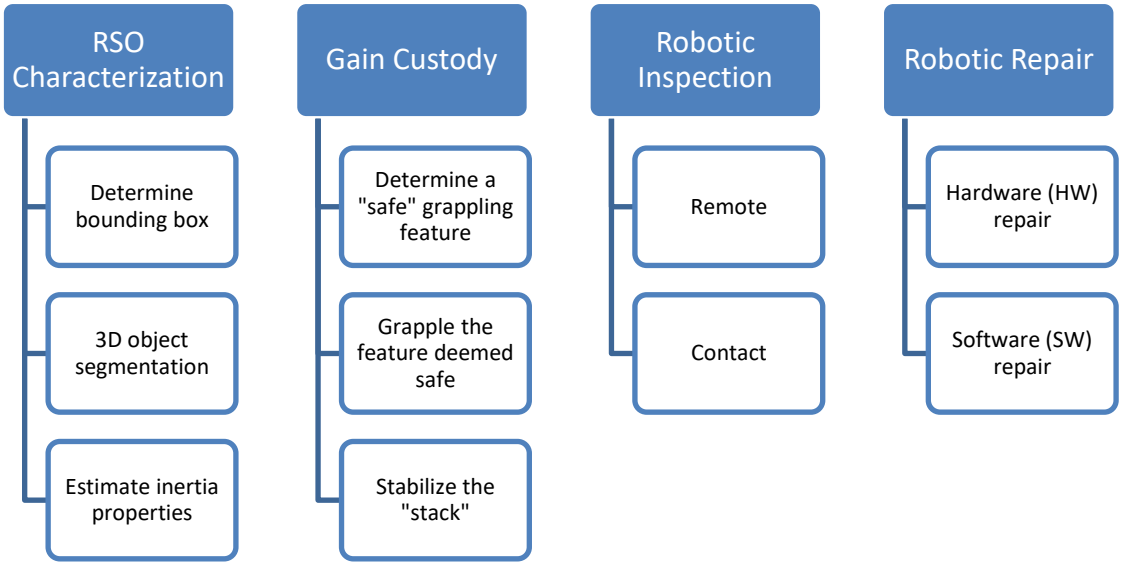
- Servicing:
    - Module/Component replacement.
    - Inspection via physical probe.
    - Precise inspection.
    - Internal satellite inspection and precision repair.
    - Refueling.
    - Repair (via manipulation, welding, printing, etc.).

- Assembly:
    - Unpacking.
    - Component transportation.
    - Component joining.
    - In-situ structural testing and quality control.

- Manufacturing:
    - Precision Additive Manufacturing (AM).
    - Conformal printing.
    - Welding.

- Surface:
    - In-Situ Resource Utilization (ISRU).
    - Drilling.
    - Sample collection.
    - Surface construction.
    - Surface traversal.

10.3 Taxonomy



10.4 Competencies required/desired to demonstrate RM

	RSO Characterization			Gain Custody			Robotic Inspection		Robotic Repair	
	Bounding box	3D object segmentation	Estimate inertia props	Determine safe grapple	Grapple	Stabilize stack	Remote	Contact	HW repair	SW repair
ISAM-adjacent										●
ISAM-relevant					●	●	●	●	●	
ISAM-unique	●	●	●	●						

11. Rendezvous & Proximity Operations (RPO), Capture, Docking, and Mating

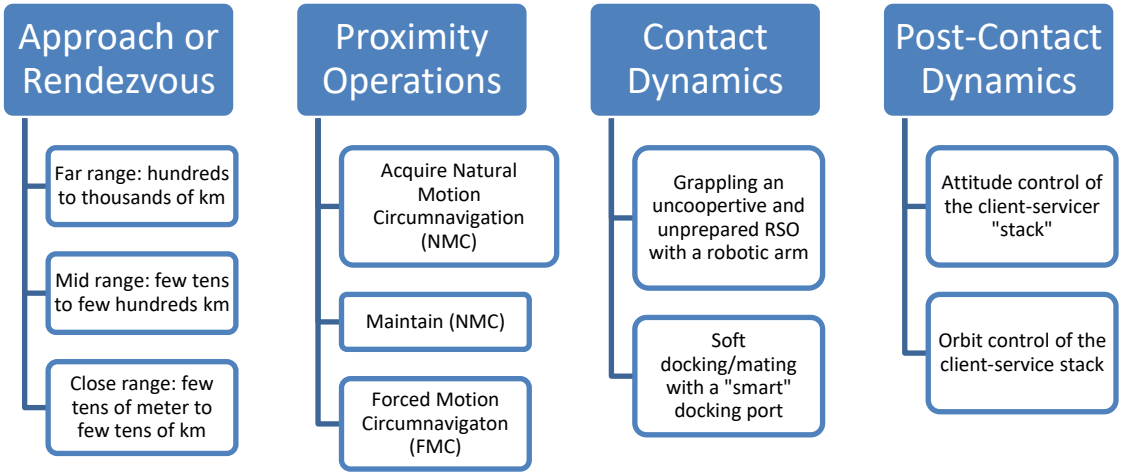
11.1 Description

Rendezvous & Proximity Operations (RPO), Capture, Docking, and Mating involves the maneuvers between two or more space objects, at least one of which is controlled, with the objective of bringing those objects into proximity with each other up to and through physical contact and docking. This includes crewed or autonomous maneuvers and actions.

11.2 Use Cases

- Mars orbit: fully automated and autonomous RPO between a sample return capsule and the earth return module.
- Servicer spacecraft that swaps on-orbit replaceable units to update the avionics of a prepared and cooperative client.
- Terminal approach: Execution of RPO is necessary for a satellite to position itself within the capture envelope of a refueling or docking interface, or the workspace of an RM for capture.
- Inspection: RPO path planning allows for movement around a target object in a relatively close proximity, allowing for optical inspection and observation. This can include things like inspection for damage, or tumble rate estimation.
- Life Extension: RPO is necessary to provide life extension services, either by reconstitution with refuel and repair, or replacement/addition/augmentation of systems through servicing (i.e. thruster “backpacks”).

11.3 Taxonomy



11.4 Competencies required/desired to demonstrate RPO

	Approach/Rendezvous			Proximity Operations			Contact Dynamics		Post-Contact Dynamics	
	Far	Mid	Close	NMC	Maintain NMC	FMC	Remote	Contact	Att. ctrl	Orb. ctrl
ISAM-adjacent										
ISAM-relevant	●	●	●	●	●	●	●	●	●	●
ISAM-unique										

12. Recycling, Reuse, and Repurposing (R^3)

12.1 Description

Recycling, Reuse, and Repurposing (R^3) involves the use of materials and spacecraft components already in space in a new spacecraft. It includes recycling the material from old spacecraft parts for new manufacturing feedstock and reusing old spacecraft parts as-is in new spacecraft.

12.2 Use Cases

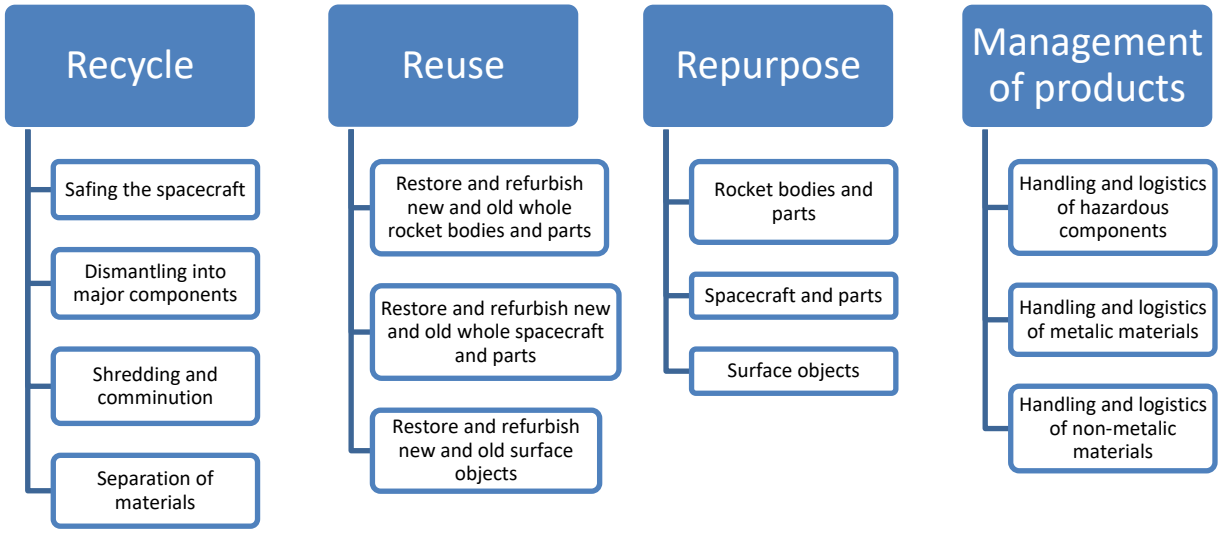
- Recycle aluminum alloy, steel, other alloys, and metals into feedstock for space smelters.

- Recycle non-metallic materials into:
    - Feedstock for manufacture.
    - Propellant and fluids.

- Reuse:
    - Upper stages and rocket bodies.
    - Spacecraft.
    - Surface objects.

- Repurpose:
    - Large structures such as rocket bodies into habitats, shelters, and depots.
    - Spacecraft.
    - Surface objects.

12.3 Taxonomy



12.4 Competencies required/desired to demonstrate R^3

	Recycle				Reuse			Repurpose			Mgmt/Logistics		
	Safing	Dismantling	Shred	Sep.	Rocket bodies	Spacecraft	Surf.	Rocket bodies	Spacecraft	Surf.	Hazard	Metal	Non-metal
ISAM-adjacent													
ISAM-relevant											●	●	●
ISAM-unique	●	●	●	●	●	●	●	●	●	●			

13. Structural Assembly (SA)

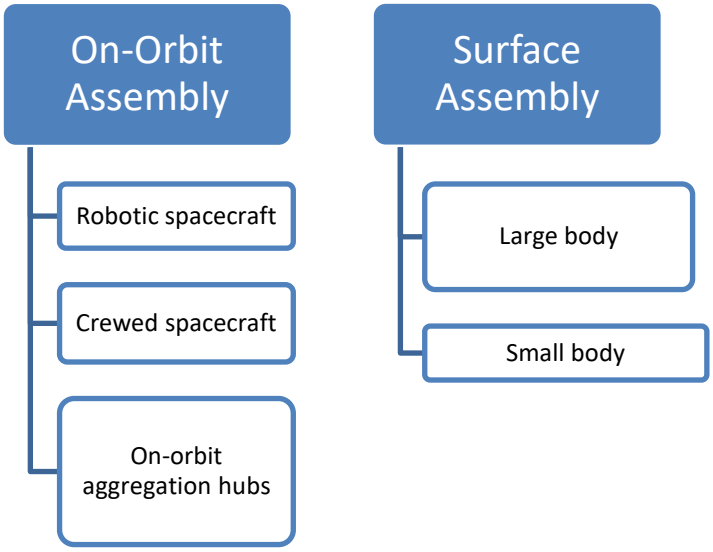
13.1 Description

Structural Assembly (SA) involves assembling structures in space to create spacecraft components or subsystems. It includes assembly of structures with various interfaces, joining approaches, and precision.

13.2 Use Cases

- On-orbit assembly:
    - Robotic spacecraft:
        - Large observatories.
        - Solar power stations.
        - Large scale antennas.
        - Persistent platforms.
        - Modular spacecrafts.
    - Crewed spacecraft:
        - Orbiting space stations.
        - Exploration spacecraft.
        - Generational spaceships.
    - On-orbit aggregation hubs:
        - Construction of manufacturing facilities (e.g., spacecraft, components).
        - Construction of components warehouses.
- Assembly on surface:
        - Large body surface – heavy gravity (e.g., Moon, Mars).
        - Small body surface – low and variable gravity (e.g., asteroid, Phobos).

13.3 Taxonomy



13.4 Competencies required/desired to demonstrate SA

	On-Orbit Assembly			Surface Assembly	
	Robotic SC	Robotic SC	Aggregation hubs	Large body	Small body
ISAM-adjacent					
ISAM-relevant				●	●
ISAM-unique	●	●	●		

14. Surface Infrastructure

14.1 Description

Surface Infrastructure (SI) involves excavating, constructing, and outfitting structures and infrastructure on a planetary surface. It includes horizontal (e.g., landing pads, roads) and vertical (e.g., power, habitation) construction, using regolith to build, and assembly of erected structures. It includes the mobility and logistics.

14.2 Use Cases

- Horizontal construction:
  - Roads.
  - Pads.
  - Berms.

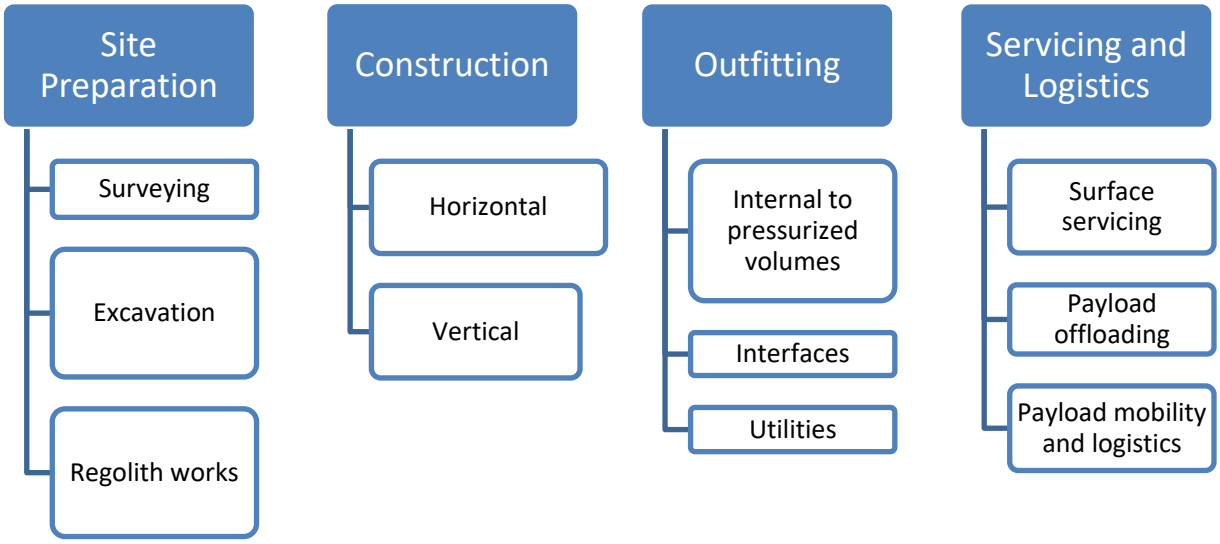
- Vertical construction:
  - Habitats.
  - Towers.

- Excavation.

- Surface Logistics.

- Surface Servicing.

14.3 Taxonomy



14.4 Competencies required/desired to demonstrate SI

	Site Preparation			Construction		Outfitting			Servicing & Logistics		
	Survey	Excavate	Regolith works	Horizontal	Vertical	Internal	Interfaces	Utilities	Servicing	Offloading	Logistics
ISAM-adjacent	●	●	●							●	●
ISAM-relevant				●		●	●	●			
ISAM-unique					●				●		

15. Structural Manufacturing (SM)

15.1 Description

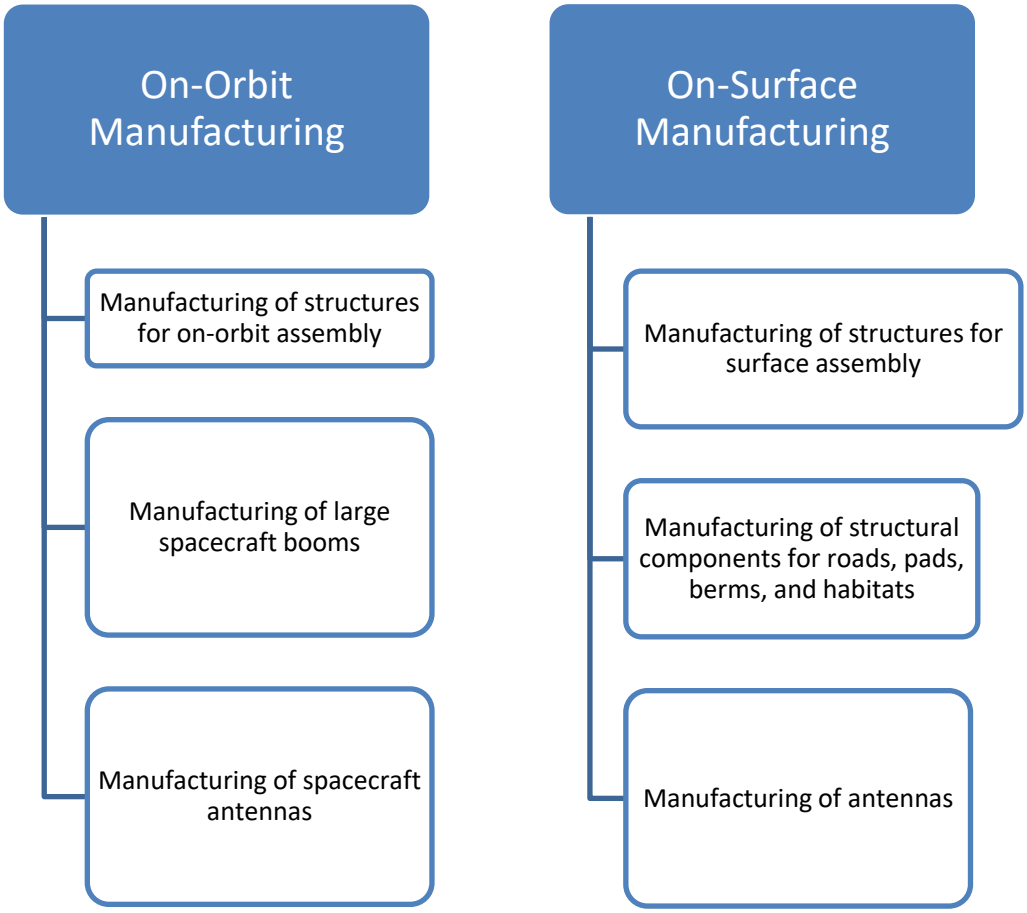
Structural Manufacturing (SM) involves fabricating structures in space to create spacecraft components or subsystems. It includes multiple manufacturing processes (e.g., 3-D printing, extruding) and assembly of structures with various interfaces, joining approaches, and precision.

15.2 Use Cases

- On-orbit:
  - Manufacturing of structures for on-orbit assembly.
  - Manufacturing of large spacecraft booms.
  - Manufacturing of spacecraft antennas.

- On Surface:
  - Manufacturing of structures for surface assembly.
  - Manufacturing of structural components for roads, pads, berms, and habitats.
  - Manufacturing of antennas.

15.3 Taxonomy



15.4 Competencies required/desired to demonstrate SM

	Additive Manufacturing Techniques				Casting	Forging	Pultrusion
	3D-printed plastics	Wire arc additive manufacturing (WAAM)	Directed energy deposition (DED)	Powder bed sintering			
ISAM-adjacent							
ISAM-relevant	●	●	●	●	●	●	●
ISAM-unique							

16. Unplanned or Legacy Repair and Maintenance (UR)

16.1 Description

Unplanned or Legacy Repair and Maintenance (UR) involves adding or replacing capability on a client space object that was not intended to receive repair or maintenance services after launch. It may include complex operations to access interfaces and make new connections.

16.2 Use Cases

Use Cases for Unplanned Repair (LEO + GEO + HEO + Planetary Body)

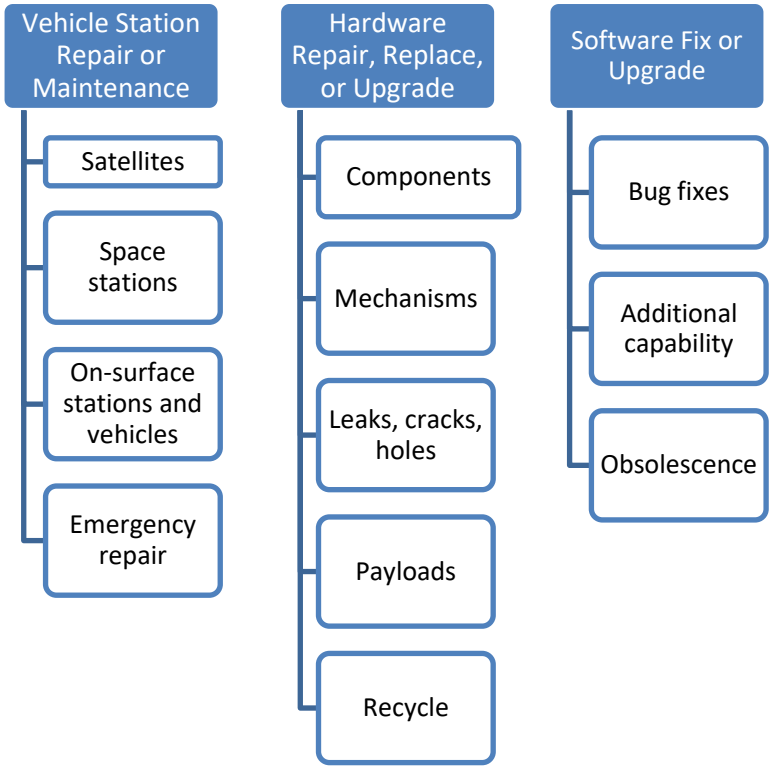
- Hardware Repair, Replace, or Upgrade:
  - Broken Electronics/comms.
  - Mechanism failure, including stuck solar arrays or deployable antennas or booms.
  - Propulsion leaks.
  - Ripped blankets.
  - Cracks, holes, leaks, etc., repairable by welding technology if metal or by other techniques.
  - Payload or science instrument replace, addition, or upgrade.

- Vehicle or Station Repair or Maintenance:
  - Rover repair.
  - Rocket repair.
  - Satellite repair: repairable, updateable, recyclable.
  - Structure or Station repair (LEO or lunar surface).
  - Micrometeoroid and small debris impacts (Meteorite, orbital debris/collision damage).

- Age/Obsolescence Emergency vs. Non-Emergency Repairs.

- Types of damage:
  - Radiation.
  - Solar wind volatile.
  - Exposure to earth or other atmospheres.
  - Other harsh space environment damage.

16.3 Taxonomy



16.4 Competencies required/desired to demonstrate UR

	Vehicle or Station Repair				Hardware Repair, Replace, or Upgrade					Software Fix or Upgrade		
	Satellites	Space stations	On-surface	Emergency repair	Components	Mechanisms	Leaks, cracks, and holes	Payloads	Recycle	Bug fixes	Additional capability	Obsolescence
ISAM-adjacent										●	●	●
ISAM-relevant		●	●				●					
ISAM-unique	●			●	●	●		●	●			

17. References

1. Arney, Dale, et al. In-Space Servicing, Assembly, and Manufacturing (ISAM) State of Play. s.I.: NASA, 2023.