

## ORION-AI: Orbital Resource Intelligence & Operations Network

Objective: To develop an AI-powered solution that optimizes in-orbit resource management and supports autonomous spacecraft operations during both crewed and uncrewed missions in Low Earth Orbit (LEO) and lunar orbit.

Problem Statement: Space missions demand constant monitoring and management of critical resources such as fuel, power, oxygen, and data bandwidth. Traditionally, these tasks rely heavily on Earth-based control, which introduces latency and operational inefficiencies — especially for long-duration missions and those extending to cislunar space. With the advent of more complex missions like NASA's Gateway, the need for onboard, real-time, autonomous systems becomes crucial. ORION-AI addresses this need through an integrated, intelligent framework that reduces dependence on ground control and enhances mission resilience.

Use Case Example: On NASA's Lunar Gateway, ORION-AI predicts when the life support system will require recalibration. It autonomously adjusts power distribution to conserve energy and alerts the crew 12 hours in advance — enabling both proactive crew decision-making and autonomous system adaptation. This highlights ORION-AI's dual role as a decision-support tool and an autonomous operations assistant.

### System Architecture Overview:

ORION-AI is built on a robust, scalable architecture designed for the unique challenges of space environments:

- Edge AI modules onboard spacecraft for real-time processing and decision-making
- Federated learning for continual improvement across missions while maintaining data privacy
- Secure satellite-to-cloud synchronization to support mission analytics without high-bandwidth dependency
- Digital twin compatibility to ensure seamless integration with NASA's Artemis and Gateway mission planning environments

### Expected Benefits:

- Up to 30% reduction in unplanned system downtime
- Enhanced mission safety and crew efficiency
- Reduced reliance on Earth communications through local AI-based decisions
- Flexible, scalable deployment across a wide range of mission types — from ISS support to future Mars transit vehicles

## Detailed Solution Plan

### System Components and AI Integration

Component	Technology	Function
Dynamic Scheduler	Reinforcement Learning	Allocates power, comms, and bandwidth based on priority and predicted demand. Optimizes solar array positioning and battery cycling.
Resource Predictor	Predictive Analytics	Forecasts consumption trends for oxygen, power, fuel, and data storage.
Health Monitoring	Computer Vision + Anomaly Detection	Uses internal and external cameras to detect wear, corrosion, and anomalies in hardware components.
Knowledge Engine	Knowledge Graphs	Enables semantic reasoning across subsystems and enhances coordination between AI modules.
Crew Command Interface	AI Natural Language Assistant	Offers intelligent recommendations and visual alerts for review by crew or ground teams.
Maintenance Assistant	Embedded in CV and analytics pipelines	Detects early signs of equipment fatigue and suggests preemptive maintenance actions.

### System Architecture Details

- Edge AI Inference Module: Deployed onboard to minimize decision latency and ensure autonomous operation even in communication-limited environments.
- Federated Learning Node: Allows ORION-AI to learn across different missions and spacecraft without centralized data storage, ensuring system evolution while maintaining privacy.
- Secure Data Relay: Facilitates encrypted transmission between the spacecraft and mission control centers, enabling analytics without excessive data drain.
- Digital Twin Integration: Allows real-time mirroring of mission operations within simulation environments for training, validation, and rehearsal.

### Operational Workflow Example

1. Environmental sensors detect a decline in oxygen regeneration efficiency.
2. ORION-AI forecasts a threshold breach within 18 hours.
3. Non-critical power usage is autonomously reduced to conserve oxygen reserves.

Jessica Navarro

ITAI 2372

NASA AI Project

4. The Crew Command Assistant flags the issue with suggested recalibration procedures.
5. If no action is taken within 6 hours, ORION-AI activates backup oxygen systems, as authorized by mission protocol.

This workflow demonstrates ORION-AI's proactive, self-corrective capability, which significantly reduces mission risk.

To ensure the reliability, adaptability, and safety of ORION-AI, a comprehensive multi-phase testing strategy will be employed:

#### 1. Simulation Testing

- **Digital Twin Integration**  
Leverage NASA's Artemis and Gateway digital twins to test AI behavior in realistic mission simulations.
- **Scenario Bank**  
Validate system response to conditions such as solar flares, battery failures, supply delays, and comms blackouts.

#### 2. Hardware-in-the-Loop (HIL) Testing

- **Edge Device Testing**  
Evaluate system performance on ruggedized space-grade hardware under simulated vacuum, thermal, and radiation conditions.
- **Sensor Fusion Validation**  
Confirm that data streams from CV cameras, environmental sensors, and telemetry inputs are processed accurately and robustly.

#### 3. Crew-in-the-Loop Testing

- **Human Factors Simulation**  
Assess user interface effectiveness and cognitive load impact on astronauts using ORION-AI's recommendations and alerts.
- **Failure Recovery Drills**  
Simulate mission anomalies and evaluate ORION-AI's response, including detection, diagnostics, and autonomous mitigation.

#### 4. Performance Metrics

Metric	Target
Prediction Accuracy (resources)	$\geq 92\%$
Autonomous Response Time	$\leq 500$ ms onboard decision latency
Bandwidth Savings	$\geq 20\%$ compared to manual operation
Unplanned Downtime Reduction	$\geq 30\%$
Hardware Fault Detection Rate	$\geq 95\%$ within critical systems

By integrating cutting-edge AI technologies with space-tested systems engineering, ORION-AI represents a transformative approach to intelligent space operations. It empowers future missions with self-reliance, adaptability, and enhanced crew support.