



Standard for Classification of Space Cargo

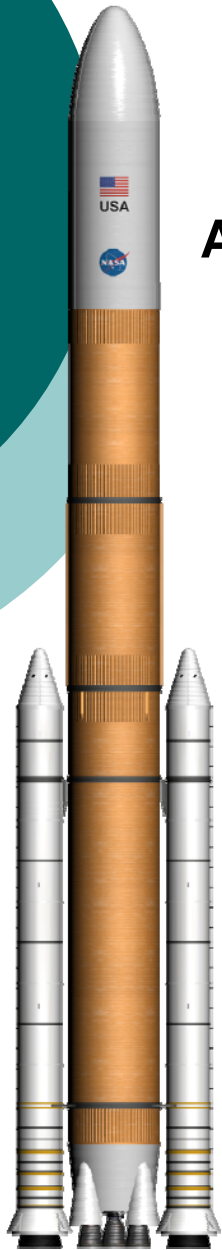
Report to the Commercial Space Group
September, 2009

Background

- Outgrowth of multi-year (2004-2007) study entitled *"Interplanetary Supply Chain Management and Logistics Architectures"* performed jointly by MIT/JPL/USA
- Study results are documented in:
 - Gralla, E. Shull, S., et al., *"A Modeling Framework for Interplanetary Logistics,"* AIAA-2006-7229
 - Shull, S. Gralla, E., et al., *"The Future of Asset Management for Human Space Exploration: Supply Classification and an Integrated Database,"* AIAA-2006-7232
 - NASA/TP—2007—214725, *SpaceNet v1.3 User's Guide*, January 2007
 - Grogan, P., Armar, N., *"A Flexible Architecture and Object-Oriented Model for Space Logistics Simulation,"* AIAA-2009-6548

0.1% launched mass = 100% value

Ares-V



Ares-I



- Mass fractions (approx.)
 - Propellant 93%
 - Vehicle Dry Mass 6.9%
 - Everything Else 0.1%
 - Crew, Consumables, Spares, Exploration Items, Other
- Direct exploration value is generated by 0.1% of launched mass
 - fixed crew & cargo capacity per launch, vehicles are given (more or less)
 - What to launch? How often? When?
 - How do we tradeoff between consumables (endurance), spares (system availability) and exploration items (value)?
 - Need to focus on operations & supply items

Previous Space Exploration Paradigms

- Apollo Program
 - 6 Lunar Surface Missions (1969-1972)
 - Each Mission self-contained (no space logistics network)
 - Carry-along all supplies
 - “backpack model”
 - based on forecast
 - Optimized for short-term lunar stays ~ 3 days
- Space Shuttle & ISS
 - Shuttle Operations 1981-
 - ISS is a single facility at LEO node (since 2000)
 - Logistics based on regular re-supply
 - Shuttle
 - Progress, Soyuz
 - Planned: ATV, HTV
 - based on actual demand
 - Actual up and down mass capacity is different than planned

“Carry-Along”

“Scheduled Resupply”

What is the next logistics paradigm?

Key Logistics Questions for Exploration

- What is the most appropriate supply chain strategy for Earth-Moon-Mars exploration?
 - pre-positioning, carry-along, resupply, hybrids?
 - role of commercial relationships (“make-or-buy” analysis)
- For what, when and where is it cost-effective to establish an on-orbit or surface depot?
 - for spares, consumables, fuel?
 - before, during, after lunar outpost buildup?
 - in LEO, LLO, (EML1)?
- What is the effect of commonality between elements of Constellation (Orion, Altair, EDS,...) on...
 - DDT&E and production cost, sparing, system availability?
- How do uncertainties impact logistics and exploration capability?
 - component failures, launch failures, stochastic consumption rates
- What is the net effect of ISRU?
 - on total launch mass, on system cost, on campaign risk



Project Objectives

- Develop a framework, simulation model, databases, and metrics needed to do trade studies and address key logistics questions
- Unify several disciplines
 - Astronautical engineering/planetary orbital mechanics
 - Supply chain management
 - Traditional logistics engineering
 - Real-time inventory and stowage operations (ISO)
- Validate concepts, methods, and tools using terrestrial examples
- Rediscover and distill logistics lessons learned (or not learned)
- Reach out to the space logistics community and next generation of space explorers/workforce

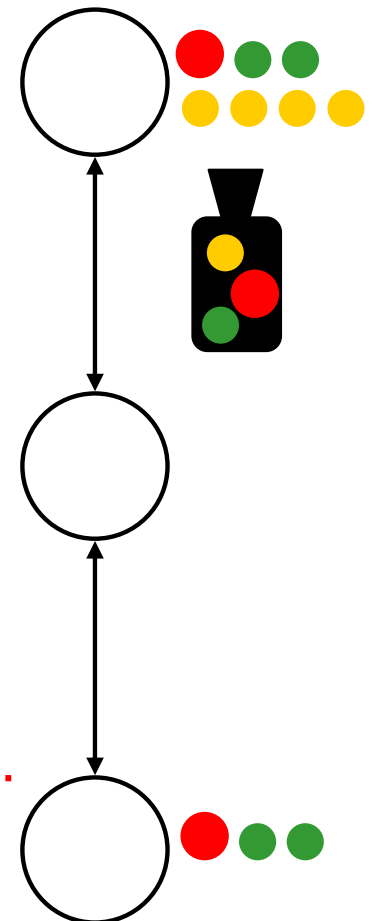
Challenges

Why is designing an interplanetary supply chain a challenge?

- Three domains
 - Earth, In-Space, Planetary Surfaces
- Network characteristics
 - Tradeoff between time-of-flight and mass on arcs (ΔV)
 - Time-varying arcs (Moon 28 day cycle, Mars 25 month cycle)
 - Discrete nature of mass flows (chunking of cargo at launch)
 - "Small quantity logistics" (< 5 missions/year)
- Multiple Levels of Nesting
 - Stacks
 - Elements (=Launchers, Modules, Vehicles, Habitats)
 - Carriers
 - Cargo (Crew & Supplies)

Building Blocks

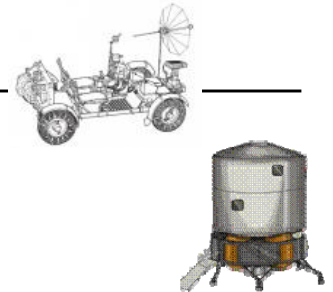
- **Nodes**
 - Surface, Orbital, Lagrangian
 - **Supplies**
 - Classes of Supply
 - **Elements**
 - Propulsive, Non-Propulsive
- Building Blocks**
- **Network (Time-Expanded)**
 - Time Discretization, Orbit Dynamics
 - **Processes**
 - Wait, Transport, Proximity Ops, Transfer, Exploration
- Put them together...**



Supplies

○ **Supplies** are the **items** that move through the network

- Consumables, spares, equipment, vehicles, etc.
- How to *classify* supply items?



Supply Classification: Some Examples

Table 2: NATO Class of Supply [5]

Class Description

I Items of subsistence, e.g. food and forage, which are consumed by personnel or animals at an approximately uniform rate, irrespective of local changes in combat or terrain conditions.

II Supplies for which allowances are established by tables of organization and equipment, e.g., clothing, weapons, tools, spare parts, vehicles.

III Petroleum, oil and lubricants (POL) for all purposes, except for operating aircraft or for use in weapons such as flamethrowers, e.g. gasoline, fuel oil, greases, coal and coke. (Class IIIa - aviation fuel and lubricants)

IV Supplies for which initial issue allowances are not prescribed by approved issue tables. Normally includes fortification and construction materials, as well as additional quantities of items identical to those authorized for initial issue (Class II) such as additional vehicles.

V Ammunition, explosives and chemical agents of all types

Supply Classification: Some Examples

Table 3: U.S. Military Class of Supply [6]

Class Supplies

I – Rations Subsistence, gratuitous health and comfort items.

II – Expendables Clothing, individual equipment, tentage, organizational tool sets and kits, hand tools, unclassified maps, administrative and housekeeping supplies and equipment.

III – POL Petroleum, fuels, lubricants, hydraulic and insulating oils, preservatives, liquids and gases, bulk chemical products, coolants, deicer and antifreeze compounds, components, and additives of petroleum and chemical products, and coal.

IV – Barrier Materials Construction materials, including installed equipment, and all fortification and barrier materials.

V – Ammunitions Ammunition of all types, bombs, explosives, mines, fuzes, detonators, pyrotechnics, missiles, rockets, propellants, and associated items.

VI – Sundry Personal demand items (such as health and hygiene products, soaps and toothpaste, writing material, snack food, beverages, cigarettes, batteries, and cameras—nonmilitary sales items).

VII – Major End Items Major end items such as launchers, tanks, mobile machine shops, and vehicles.

VIII – Medical Medical materiel including repair parts peculiar to medical equipment.

IX – Repair Parts Repair parts and components to include kits, assemblies, and subassemblies (repairable or non-repairable) required for maintenance support of all equipment.

X – Material to support nonmilitary programs

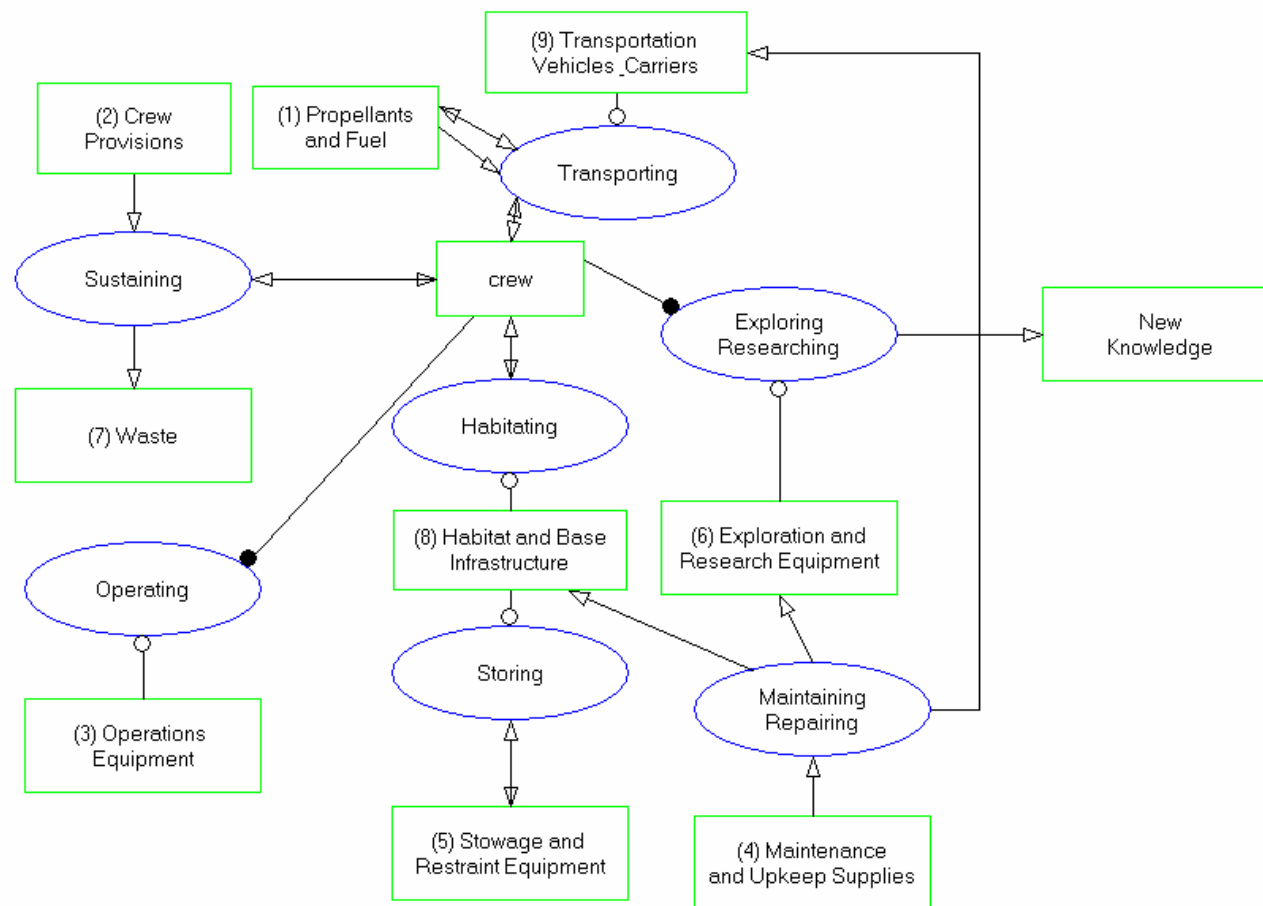
Material to support nonmilitary programs such as agriculture and economic development (not included in Classes I through IX).

Miscellaneous Water, salvage, and captured material.

Supply Classification: ISS CCART

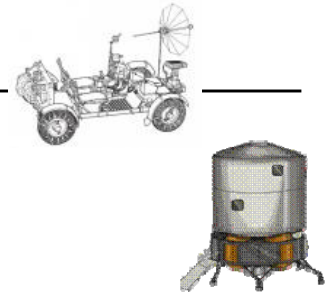
1. CREW PROVISIONS	5. STATION SYSTEMS SUPPORT
1.1 Joint Crew Provisions	5.1 US Station Systems
clothing	I/A tools: utility light, tape
hygiene	maintenance spares: O-rings
care packages	ECLSS: LIOH canisters
1.2 Crew Provisions/Food	Extravehicular Robotics (EVR)
US food containers	5.2 Russian Station Systems
Russian food containers	I/A tools
utensils	maintenance spares
2. CREW DAILY OPERATIONS	ECLSS: LIOH canisters
2.1 Joint Crew Daily Operations	dust collector cartridge
office supplies	5.3 FGB Station Systems
2.2 US Crew Daily Operations	FGB I/A tools
computers	FGB Maintenance spares
vacuum cleaners	6. EVA
film cassette	6.1 US EVA
batteries	EVA suits and consumables
2.3 Russian Crew Daily Operations	EVA tools
laptops	6.2 Russian EVA
dust collectors	EVA Orlan suits and consumables
photo equipment/consumables	EVA tools
electrical power system	7. USERS/PAYLOADS
3. INTEGRATED MEDICAL SYSTEM	JAXA utilization
3.1 US ISS Medical Equipment	ESA utilization
microbial air sampler	8. WASTE MANAGEMENT
blood pressure/electrocardiograph	black polyliner bags
defibrillator resupply kit	crumb bags
crew care packages	solid waste container
3.2 Russian ISS Medical Equipment	9. SOTO
medical first aid kits	10. INGRESS/DOCKING EQUIPMENT
dosimeter (radiation)	11. VISITING VEHICLES/CARRIES
cardiorecorder Accessory kit	11.1 Shuttle hardware
4. WATER TRANSFER	11.2 Soyuz equipment
EDVs	12. STATION ASSEMBLY/ OUTFITTING INTERNAL - MODULES/HARDWARE
CWCs	13. STATION ASSEMBLY/ OUTFITTING EXTERNAL ELEMENT and TRUSS HARDWARE
	14. MULTIPLE CATEGORIES

Supply Classification: Object Process Diagram for Generic Exploration



Supplies

- **Supplies** are the **items** that move through the network
 - Consumables, spares, equipment, vehicles, etc.
 - How to *classify* supply items?
- **Functional classes of supply**
 - What needs to be done? What are essential functions?
 - Organize by functional classes, regardless of
 - material, owner, NASA center, etc.
- **Basis for supply item modeling**
 - Model 'demand' for each supply class
 - Unified relational database for exploration



Classes of Supply

1. Propellants and Fuels



6. Exploration and Research



2. Crew Provisions



7. Waste and Disposal



3. Crew Operations



8. Habitation and Infrastructure



4. Maintenance and Upkeep



9. Transportation and Carriers



5. Stowage and Restraint



10. Miscellaneous



Fundamental Concepts: Classes of Supply

Ten Classes of Supply (CoS) with subclasses defined as needed for inventory management and modeling purposes

1. Propellants
2. Crew Provisions *Food, Clothes, Hygiene Items, Oxygen, Etc.*
3. Crew Operations *Laptops, EVA, Health Eqmt and Consumables, Safety and Comm Eqmt, Etc.*
4. Maintenance and Upkeep *Spares, Maintenance Tools, Batteries, Filters, Etc.*
5. Stowage and Restraint *Crew Transfer Bags Etc.*
6. Exploration Items *Field Equipment, Science instruments, Etc.*
7. Waste and Waste Management Equipment
8. Infrastructure
9. Carriers and Propulsion Modules
10. Miscellaneous

Major End-Items

- Largely based on functional groupings and nomenclature from CCART breakdown

Tiered Subclasses

Table Name: Supply Classes		Table Theme:	Identifies Classes and Subclasses of Supply		
Supply Class ID	Supply Class Name	Supply Class Description	Parent Supply Class ID	Supply Class Level	Comments
	1 Propellants and Fuels			1	
	2 Crew Provisions			1	
	3 Crew Operations			1	
	4 Maintenance and Upkeep			1	
	5 Stowage and Restraint			1	
	6 Exploration and Research			1	
	7 Waste and Disposal			1	
	8 Habitation and Infrastructure			1	
	9 Transportation and Carriers			1	
	10 Miscellaneous	Public educations and outreach material, flags, etc.		1	
	101 Cryogenics	Liquid oxygen, liquid hydrogen, etc.	1	2	
	102 Hypergols	Hydrazine, nitrogen tetroxide, etc.	1	2	
	103 Nuclear Fuel	Uranium, Plutonium, etc.	1	2	
	104 Petroleum Fuels	Aviation Gas, Diesel, LNG,...	1	2	
	105 Other Fuels	Water/ethylene-glycol, etc.	1	2	
	201 Water and Support Equipment	Potable water, distilled water, tanks, valves, flow meters	2	2	
	202 Food and Support Equipment	Dehydrated foods, canned foods, produce, cooking, eating utensils	2	2	
	203 Gases	Oxygen, nitrogen, argon	2	2	
	204 Hygiene Items	Toothpaste, soap, toilet paper, etc.	2	2	
	205 Clothing	T-Shirts, jumper suits, sweaters, underwear, socks,...	2	2	
	206 Personal Items	CD-players, books, photos, Sleeping bags	2	2	
	301 Office Equipment and Supplies	Stationary, user manuals, instructions	3	2	
	302 EVA Equipment and Consumables	Space Suits, CO2 filters, EVA tools	3	2	
	303 Health Equipment and Consumables	Medical kit, medications, treadmill, telemedicine equipment	3	2	
	304 Safety Equipment	Gas masks, fire extinguishers, contamination protection items, etc.	3	2	
	305 Communications Equipment	mobile transmitters, antennas, UHF shortwave radio, walkie talkie etc	3	2	
	306 Computers and Support Equipment	laptops, USB sticks, printers	3	2	
	401 Spares and Repair Parts	ORU spares, replacement parts,...	4	2	
	402 Maintenance Tools	Multi-function tool kits, Volt-meters,...	4	2	
	403 Lubricants and Bulk Chemicals	Alcohols, refrigerants, etc.	4	2	
	404 Batteries	AA, C, D batteries, NiCd rechargeables, other mobile power sources	4	2	
	405 Cleaning Equipment and Consumables	Vacuum bags, detergents, filters, etc.	4	2	
	501 Cargo Containers and Restraints	Cargo Transfer Bags (CTB), containers, bungees, fasteners, etc.	5	2	
	502 Inventory Management Equipment	Bar code readers, RFID equipment, etc.	5	2	
	601 Science Payloads and Instruments	Spectrometers, gravimeters, experiments, drills	6	2	
	602 Field Equipment	Generic tools (rock hammers...), cameras, TV equipment, etc.	6	2	
	603 Samples	Cores, rocks, regolith, atmospheric gas samples	6	2	
	701 Waste	Various trash, urine, fecal matter, ..	7	2	
	702 Waste Management Equipment	Compactor, toilets, holding tanks	7	2	
	703 Failed Parts	Failed parts (ORUs, SRUs)	7	2	
	801 Habitation Facilities	Habitats, incl. thermal, ECLSS, structural subsystems	8	2	
	802 Surface Mobility Systems	Pressurized and open rovers	8	2	
	803 Power Systems	Photovoltaic, RTG, nuclear power plants	8	2	
	804 Robotic Systems	Robotic assistants, robotic scouts, construction/maintenance systems	8	2	
	805 Resource Utilization Systems	Regolith scooping system, LOX generation plant, CH4 generation,...	8	2	
	806 Orbiting Service Systems	In-space communication relay spacecraft, navigation aids	8	2	
	901 Carriers, Non-propulsive Elements	Pressurized and unpressurized cargo carriers, crew compartments	9	2	
	902 Propulsive Elements	Launch vehicles, in-space propulsion elements, descent and ascent stages	9	2	



Proposed Schedule of Key Events

- Submitted AIAA Standards Project Proposal Form, December 2008
- Approval of Outline at SLTC meeting, January 2009
- First full draft for SLTC review delayed to January 2010
- Release for public review, Spring 2010



Related Documents

- DoD, NATO, and ISS (CCART) COS in use
- ECSS (European Cooperation for Space Standardization) documents
 - Integrated Logistics Support (ECSS-M-70A, April 1996)
 - Availability Analysis (ECSS-O-ST-30-09C, July 2008)
- AIAA/ANSI Standard Terminology for Space Structures (S-001-1991)
- Draft AIAA Lexicon of Space Logistics Terminology

Outline for AIAA Class of Supply (COS) Standard

Forward (Background including version change log, who worked on it)

Introduction (Purpose)

Trademarks

1 Scope

2 Tailoring

3 Applicable Documents

4 Vocabulary

4.1 Acronyms and Abbreviated Terms

4.2 Terms and Definitions

5 Class of Supply Model

5.1 'Functional' Basis for Model

5.2 Other Models (DoD, NATO, ...)

5.3 Classes of Supply (shows the ten COS at Level I and contains shall statements)

5.3.1 Class 1 (Propellants and Fuels)

5.3.2 Class 2 (Crew Provisions)

5.3.3 Class 3 (Crew Operations)

5.3.4 Class 4 (Maintenance and Upkeep)

5.3.5 Class 5 (Stowage and Restraint)

5.3.6 Class 6 (Exploration and Research)

5.3.7 Class 7 (Waste and Disposal)

5.3.8 Class 8 (Habitation and Infrastructure)

5.3.9 Class 9 (Transportation and Carriers)

5.3.10* Class 10 (Miscellaneous)

*[For each class and its
Level II subclasses, content
is defined and examples are given]*

Annex A Recommended Applications (Informative)

* The number of classes may be other than ten, and the Class #'s may be ordered differently in the final version.



Participation

- SOLE
- NASA Office of the Chief Engineer
- Commercial Space Group?
- Any volunteers?