AN INTEGRATED ECONOMIC MODEL FOR ISRU IN SUPPORT OF A MARS COLONY—INITIAL STATUS REPORT

Caltech/Jet Propulsion Laboratory (JPL)
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School of Mining Engineering
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September 1, 2015

Team

- **Caltech / Jet Propulsion Laboratory**
  - Dr. Robert Shishko, Principal Systems Engineer / Economist
  - Rene Fradet, Deputy Director for Engineering & Science Directorate
  - Others (Mars Program Chief Engineer, Foundry A Team, ISRU SMEs . . .)

- **University of New South Wales, Australia (Self-funded)**
  - Dr. Serkan Seydam, School of Mining Engineering, Principal Investigator
  - Prof. Andrew Dempster, School of Electrical Engineering and Telecommunications / Director, Australian Centre for Space Engineering Research (ACSER)
  - Dr. Jeff Coulton, Australian School of Business

- **MIT (*)**
  - Professor Oli deWeck, Department of Aero/Astro

Three Giant Leaps

Scope of This Research

2014

Orion ETF-1

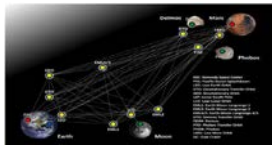
2030's-2040's

First Human Landing On Mars

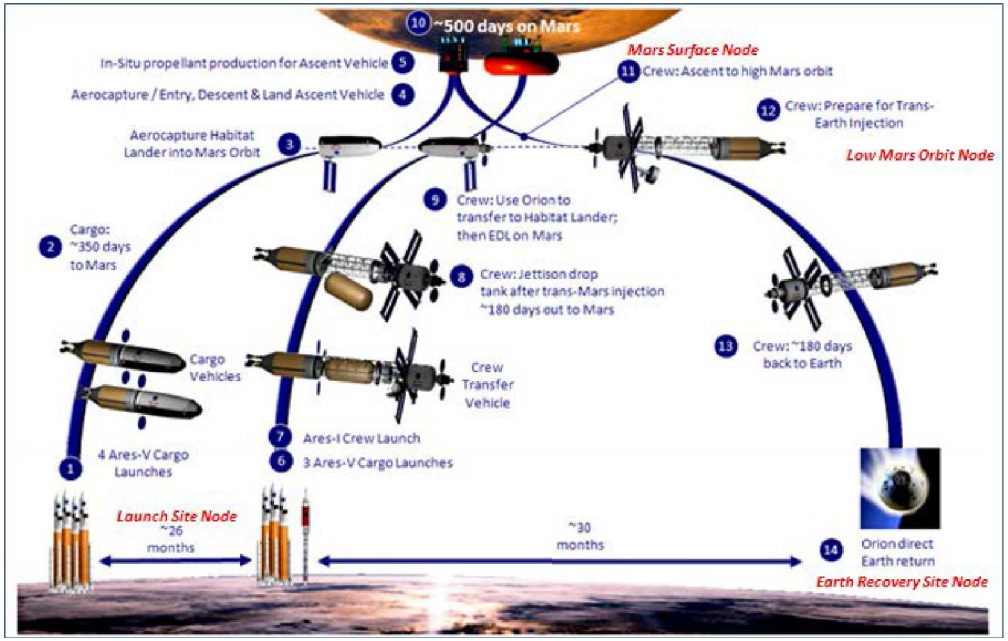
2040's-2050's

Establishment Of A Mars Colony

2050's - ?

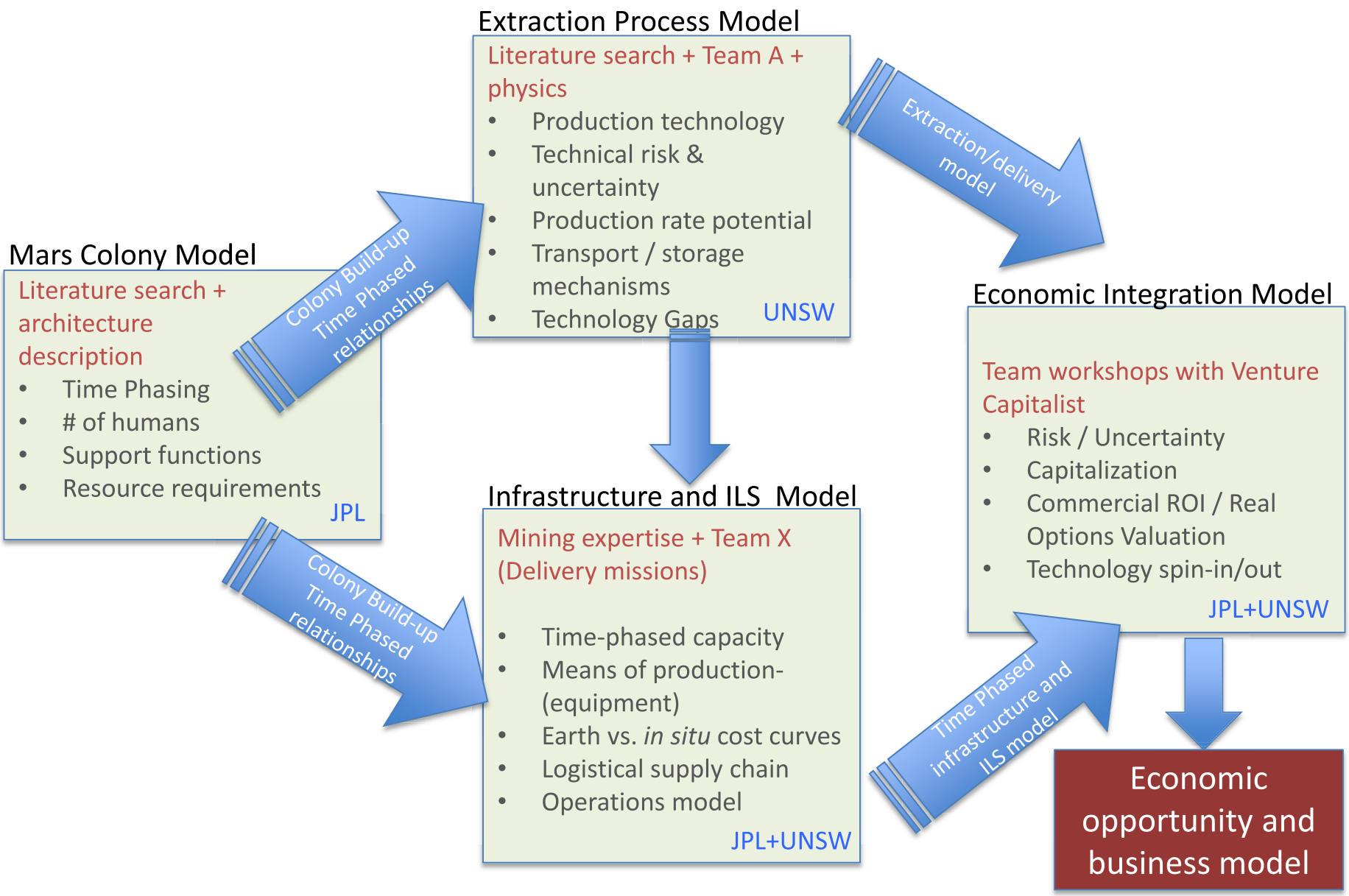


Economic Viability



Stakeholders	Concerns
National Space Agencies	Public Support; Safety
Private Enterprises	Profitability
Science Communities	Science Opportunities
Space Enthusiasts/Influencers	Frequent Progress
Colonists	Survival; Sustainability

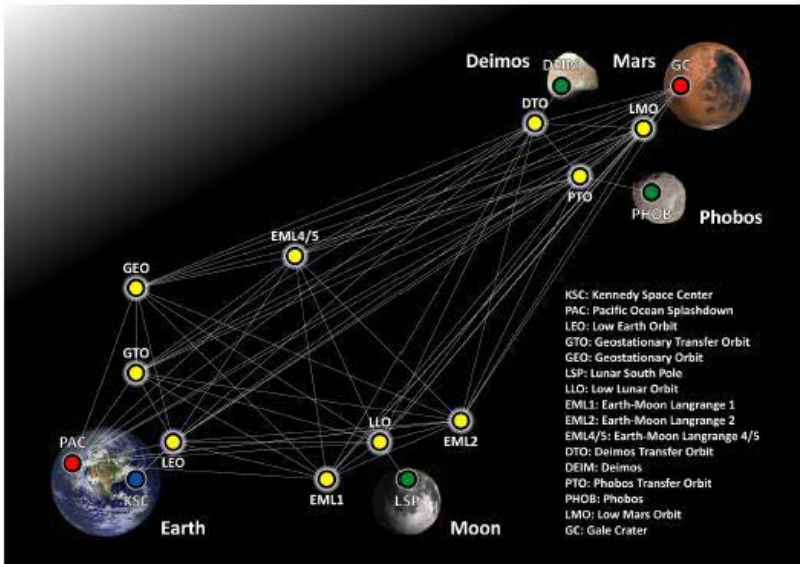
Research Objective



Mars Colony Architecture Model (MCAM)

- Data model based on DoDAF 2.02 with "for-purpose" extensions
- MCAM Key Constructs
  - Operational Nodes (Surface Locations, Orbits, Lagrange Points)
  - Systems (Transport, Mining, Habitation, etc.)
  - Operational Activities/Functions
  - Resources (People, Material, Information, etc.)
  - Milestones
  - Needlines
  - Operational Resource Flows
  - System Resource Flows
  - Measures (Mass, Capacity, Reliability, etc.)
  - Performer Classes
  - Rules (Standards)

Types and Subtypes Permeate

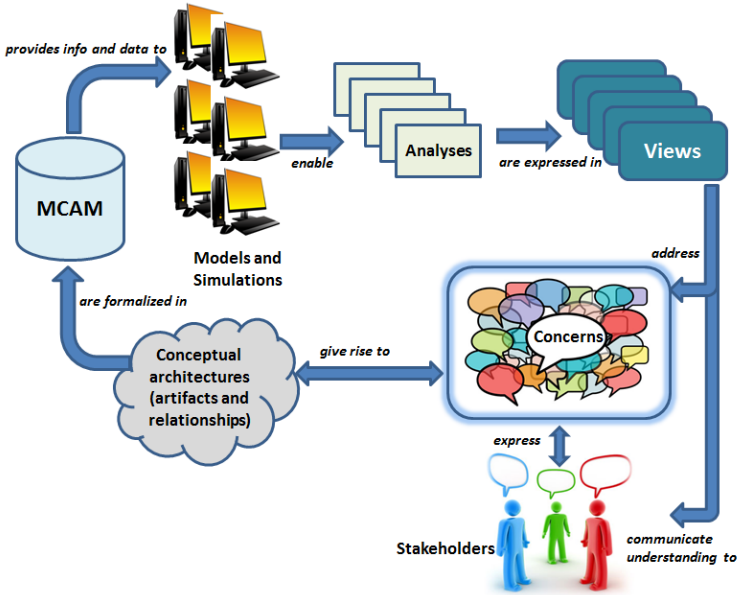


- "For-purpose" extensions permit quantitative analyses
- Key quantitative relationships are needed for ISRU (i.e., extraction output (kg) of mining operations based on technology, number of mining systems deployed, number of persons by personnel type, etc.)

Mars Colony Architecture Model (MCAM)

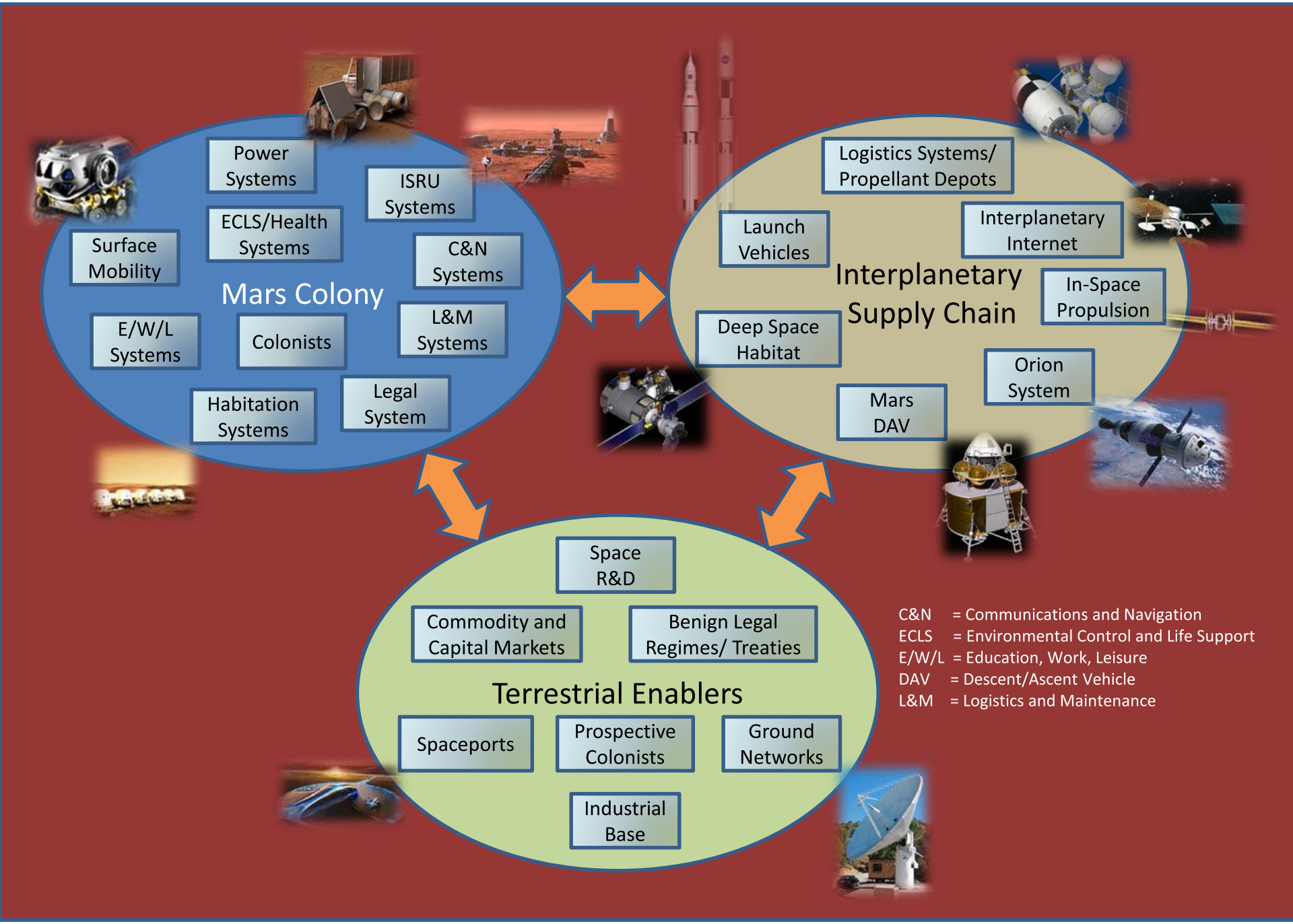
- MCAM's purpose is to support an exploratory investigation of various architectures, CONOPS, and representative scenarios

- MCAM Use Case



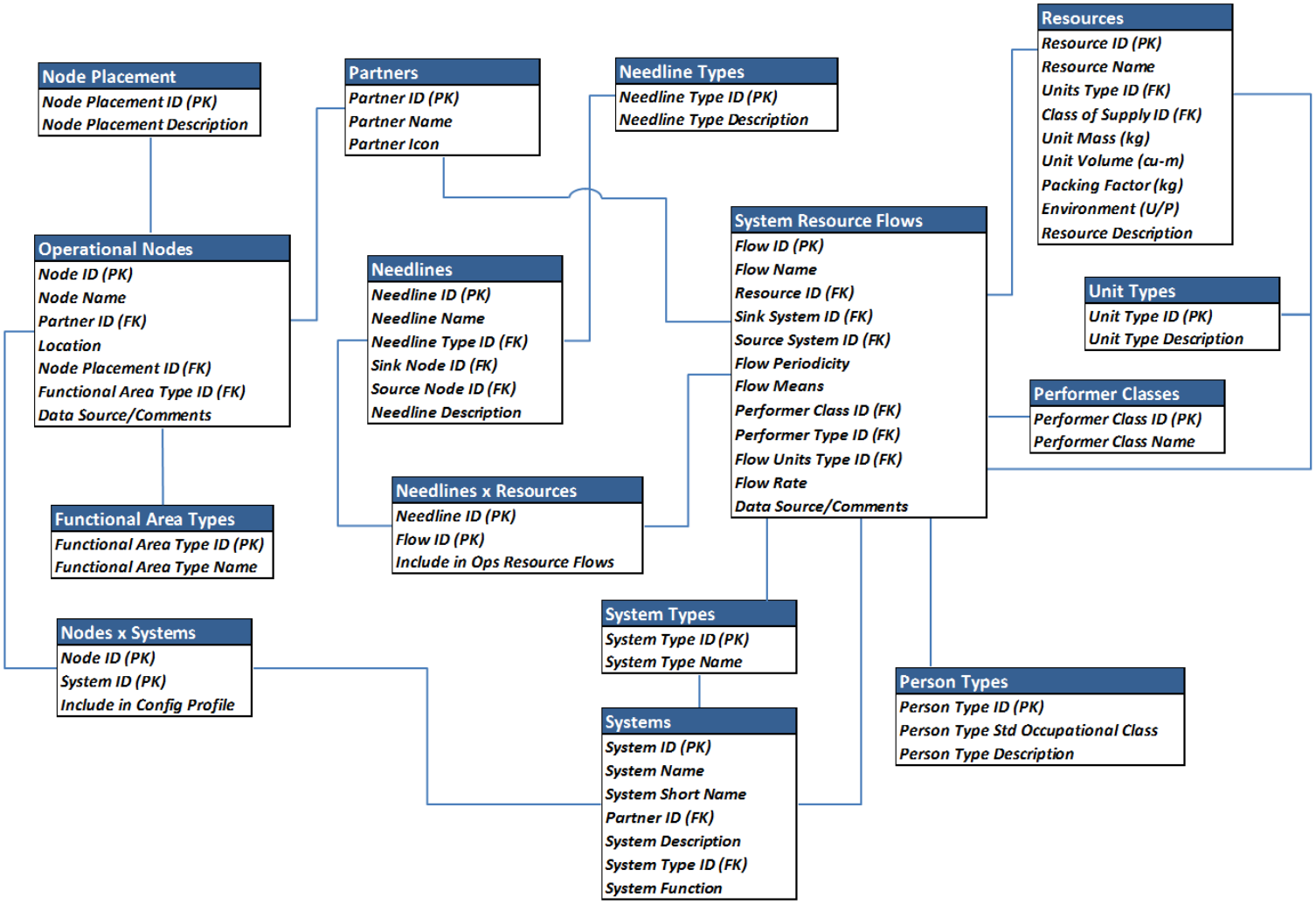
- Some guiding criteria for MCAM
  - Consistency
  - Compactness (brevity and conciseness are important, but must support the analytical models)
  - Auditability

CONTEXT DIAGRAM


Mars Colony
Power Systems
ISRU Systems
ECLS/Health Systems
Surface Mobility
C&N Systems
E/W/L Systems
Colonists
L&M Systems
Habitation Systems
Legal System
Interplanetary Supply Chain
Logistics Systems/ Propellant Depots
Launch Vehicles
Interplanetary Internet
In-Space Propulsion
Deep Space Habitat
Orion System
Mars DAV
Terrestrial Enablers
Space R&D
Commodity and Capital Markets
Benign Legal Regimes/ Treaties
Spaceports
Prospective Colonists
Ground Networks
Industrial Base
C&N = Communications and Navigation
ECLS = Environmental Control and Life Support
E/W/L = Education, Work, Leisure
DAV = Descent/Ascent Vehicle
L&M = Logistics and Maintenance

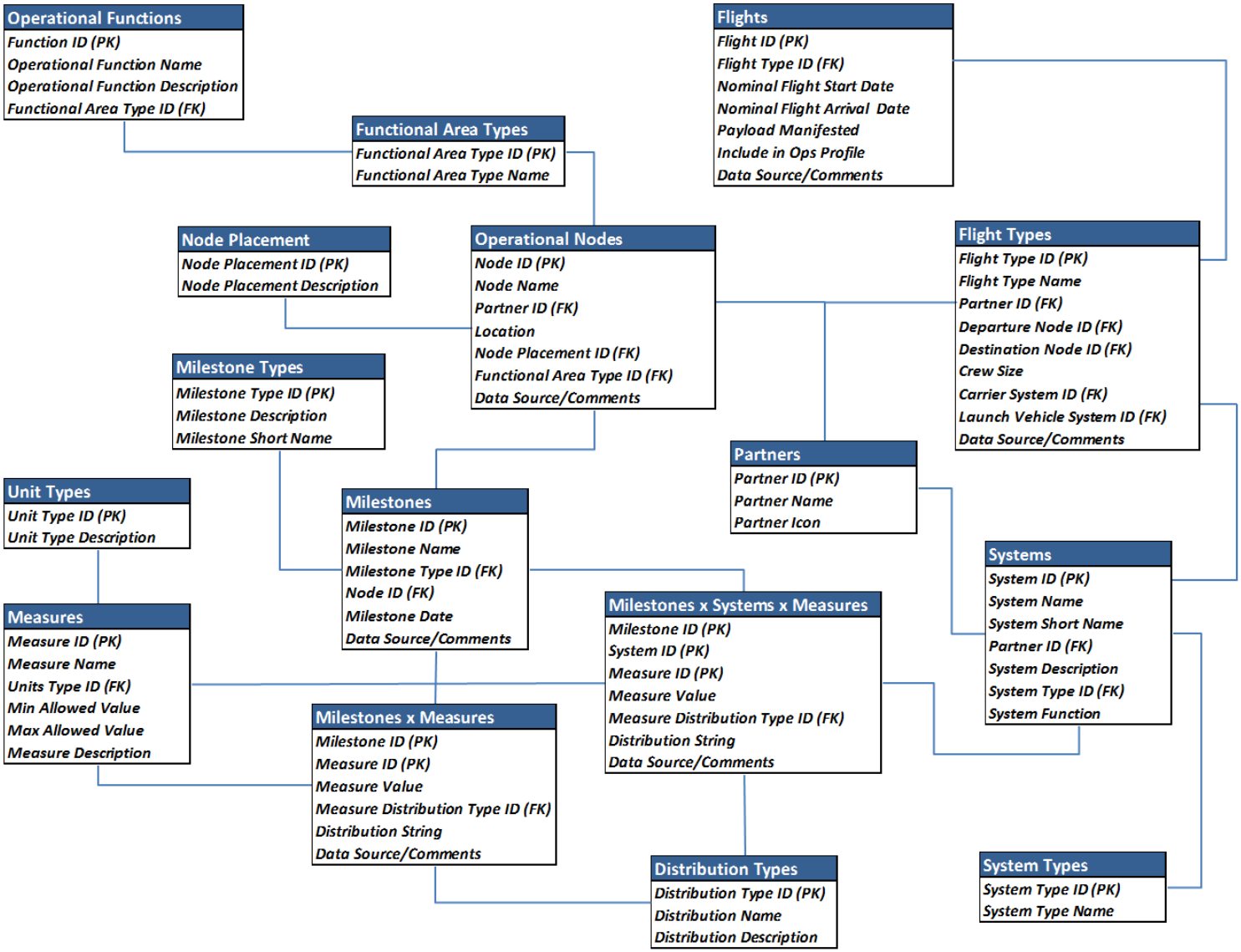
Mars Colony Architecture Model (MCAM)

Entity-Relationship Diagram (System Resource Focus)



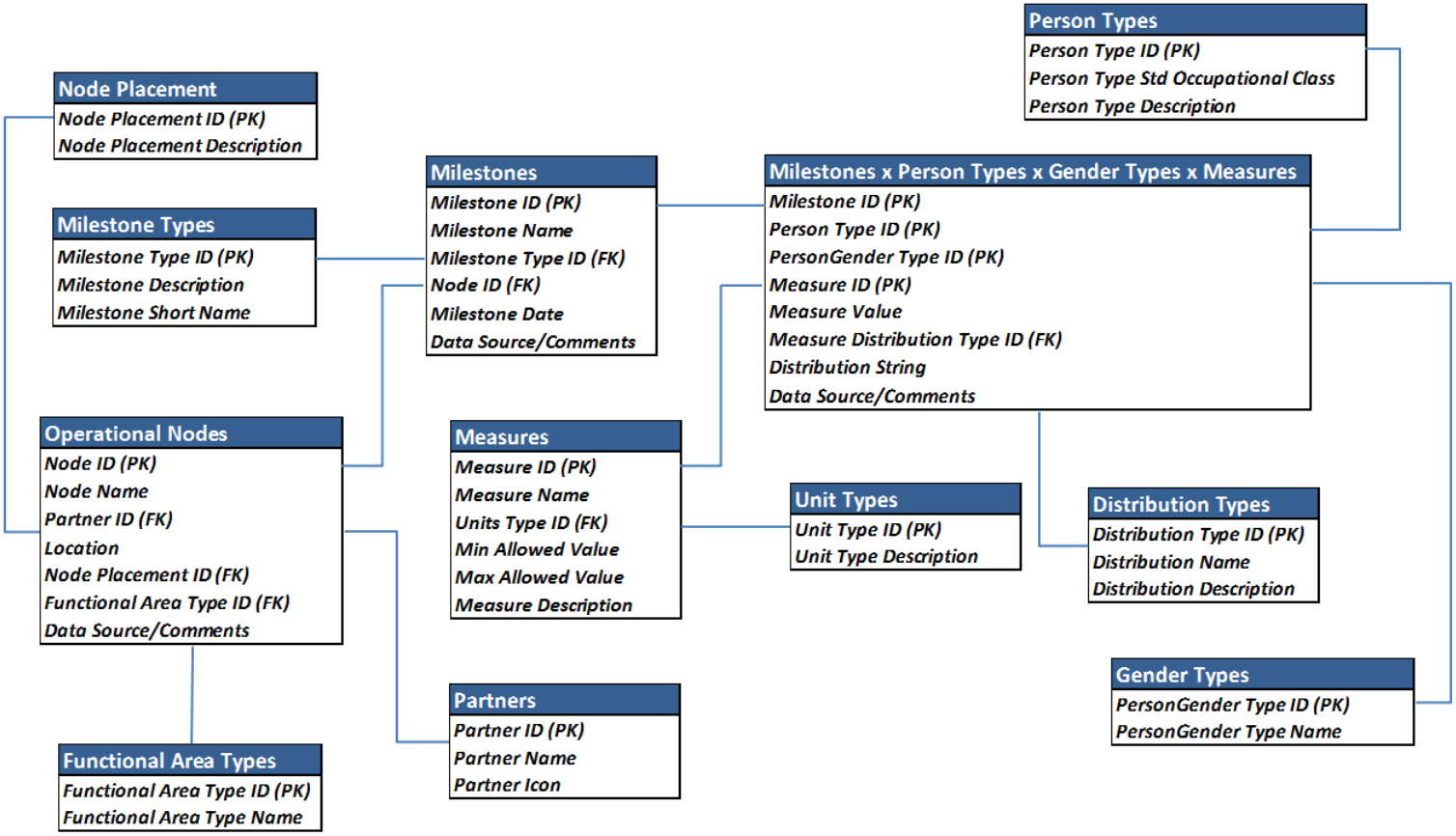
Mars Colony Architecture Model (MCAM)

Entity-Relationship Diagram (Operations Focus)



Mars Colony Architecture Model (MCAM)

Entity-Relationship Diagram (Human Activities Focus)



Mars Colony Architecture Model (MCAM)

Views Enabled by MCAM

DoDAF Views	Description
AV-1	Provides scope, overview, key assumptions for the architecting effort
AV-2	Defines the architecture artifacts (operational nodes, systems, etc.)
CV-1	Communicates the strategic vision regarding capability development
OV-2	A graphic that shows 'needlines' between operational nodes
OV-3	Breaks needlines into component classes (various resources)
OV-5a	Describes functions/activities (ops functions, mining functions, etc.)
SV-1	A graphic shows a solution space generally in terms of an integrated SoS
SV-3	A matrix shows system interfaces
SV-5b	Maps systems back to functions/activities
SV-6	Describes the physical flows from one system to another
PV-2	Describes the deployment timing for systems

EXAMPLE

Mars Colony Architecture Model (MCAM)

Nodes Table (as part of AV-2)

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California Institute of Technology

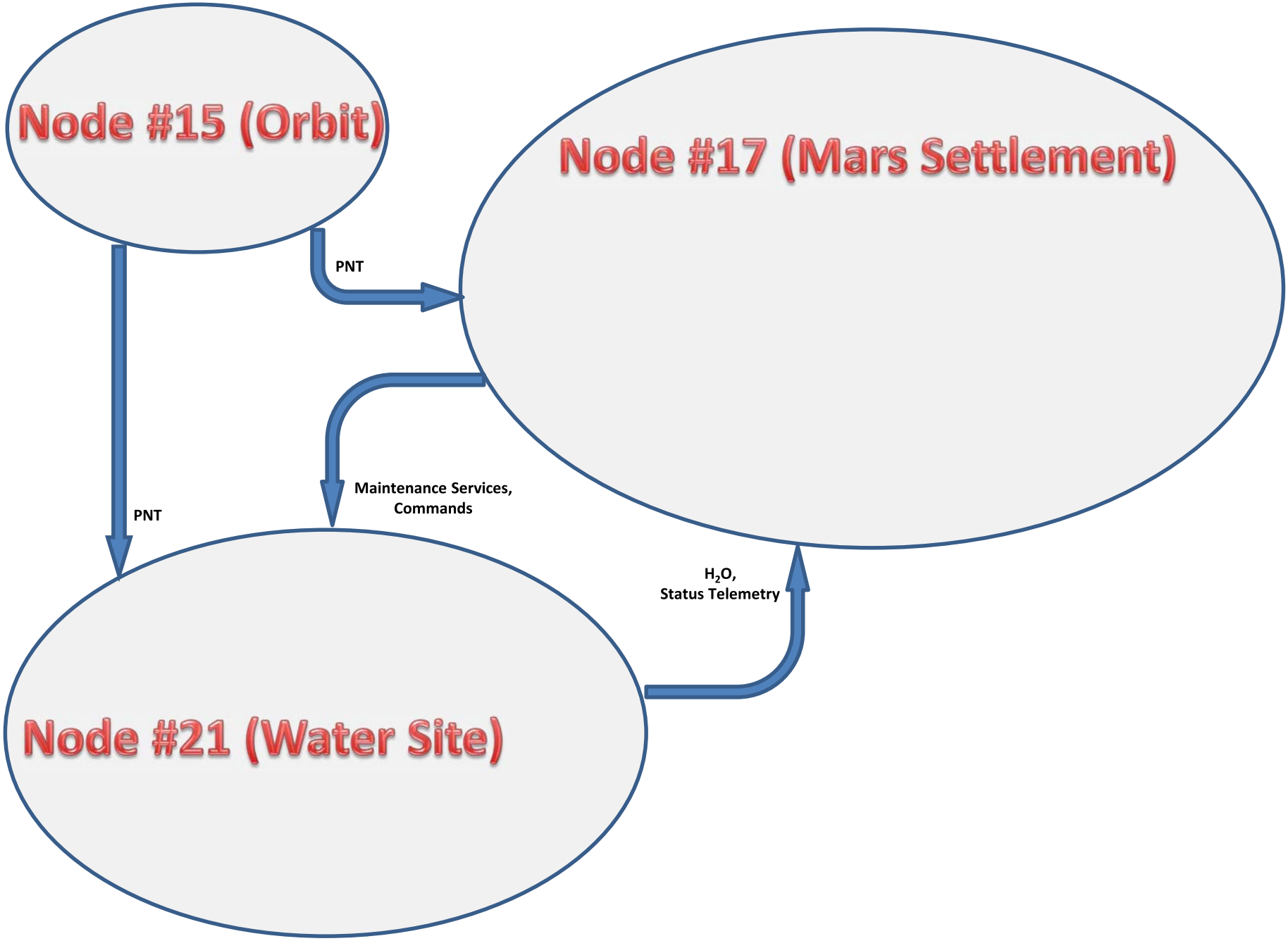
UNSW AUSTRALIA

Node ID	Node Name	Partner ID	Location	Node Placement ID	Node Placement Description	Functional Area Type ID	Functional Area Description	Data Source/Comments
0	Disposal	0	Various	1	Terrestrial	12	Other	
1	Orion Recovery Site	1	Various	1	Terrestrial	4	Ground Ops	
2	DSN Ground Station	0	Goldstone, Madrid, and Canberra	1	Terrestrial	6	Communications and Tracking	
3	HEO Mars Transfer Orbit	0	200 km x 340,000 km, highly elliptical	2	CisLunar	8	Rendezvous	Earth departure to Mars
4	LEO Rendezvous Orbit	0	300 km alt circular 28.5 deg	2	CisLunar	8	Rendezvous	
5	NASA Program Office	1	JSC	1	Terrestrial	1	Management	
6	Mission Control Center, Hou	1	JSC	1	Terrestrial	3	Mission Ops	
7	Training Center, Hou	1	JSC	1	Terrestrial	3	Mission Ops	
8	Mission Control Center, Mos	2	Moscow, Russia	1	Terrestrial	3	Mission Ops	
9	Training Facility, FP	2	Star City, Russia	1	Terrestrial	3	Mission Ops	
10	Launch Facility, KSC	1	KSC	1	Terrestrial	4	Ground Ops	
11	Launch Facility, Baik	2	Baikonur, Khazakstan	1	Terrestrial	4	Ground Ops	
12	Launch Facility, Kou	3	Kourou, French Guiana	1	Terrestrial	4	Ground Ops	
13	Launch Facility, Tan	4	Tanegashima, Japan	1	Terrestrial	4	Ground Ops	
14	Logistics Facility	1	KSC	1	Terrestrial	5	Integrated Logistics Support	
15	Mars Comm Relay Orbit	0	1 sol orbit at altitude = 17,030 km	4	Deep Space	6	Communications and Tracking	Areostationary orbit
16	Mars Parking Orbit	0	250 km x 33,793 km	4	Deep Space	8	Rendezvous	
17	Mars Settlement Site A	0	Isidis Planitia 12°54'N 87°00'E	5	Mars Surface	7	Settlement	SP-2009-566 ADD, Human Exploration of Mars DRA 5.0 Addendun
18	Mars Settlement Site B	0	N. Amazonis Planitia 35°00"N 145°00'W	5	Mars Surface	7	Settlement	Website http://marsbase.org/location, accessed 27 Feb 2015
19	Mars Settlement Site C	0	Utopia Planitia 42°00'N 150°00'E	5	Mars Surface	7	Settlement	Website http://marsbase.org/location, accessed 27 Feb 2015
20	Mars Settlement Site D	0	Isidis Basin 18°30'N 77°30'E	5	Mars Surface	7	Settlement	Website http://marsbase.org/location, accessed 27 Feb 2015
21	Mars Water Mining Site	0	Panchaia Rupes 64°14'N 146°00'E	5	Mars Surface	9	ISRU-Type 1 (Volatiles)	Thierry de Roche, UNSW, School of Mining, 2015
22	Distant Retrograde Lunar Orbit	0	70,000 km alt from lunar surface, near circul	2	CisLunar	8	Rendezvous	Asteriod Redirect Mission (ARM) Feasibility Study, v2.0, 24 May 20
23	Low Lunar Orbit (LLO)	0		2	CisLunar	8	Rendezvous	
24	Geostationary Orbit (GEO)	0	35,786 km alt, circular	2	CisLunar	8	Rendezvous	
25	Geostationary Transfer Orbit (GTO)	0	185 km x 35,786 km alt	2	CisLunar	8	Rendezvous	
26	Earth-Moon Langrange Point 1 (EML1)	0		2	CisLunar	8	Rendezvous	
27	Earth-Moon Langrange Point 2 (EML2)	0		4	Deep Space	8	Rendezvous	
28	Earth-Moon Lagrange Point 4/5 (EML4/	0		2	CisLunar	8	Rendezvous	
29	Lunar South Pole	0	Shackleton Crater region	3	Lunar Surface	9	ISRU-Type 1 (Volatiles)	
30	Lunar Transfer Orbit	0		2	CisLunar	8	Rendezvous	
31	Phobos Transfer Orbit	0		4	Deep Space	8	Rendezvous	
32	Low Phobos Orbit	0		4	Deep Space	8	Rendezvous	
33	Phobos Site of Interest	0		4	Deep Space	9	ISRU-Type 1 (Volatiles)	
34	Deimos Transfer Orbit	0		4	Deep Space	8	Rendezvous	
35	Low Deimos Orbit	0		4	Deep Space	8	Rendezvous	
36	Deimos Site of Interest	0		4	Deep Space	9	ISRU-Type 1 (Volatiles)	
37	Low Mars Orbit	0		4	Deep Space	8	Rendezvous	
38	High Mars Orbit	0		4	Deep Space	8	Rendezvous	
39	Mars Settlement Site E	0	Henry Crater 10°54'N 10°42'E	5	Mars Surface	7	Settlement	Project Aldrin-Purdue Final Report, April 9, 2015
40	Mars Settlement Site F	0	Elysium Planitia 3°00'N 154°00'E	5	Mars Surface	7	Settlement	Project Aldrin-Purdue Final Report, April 9, 2016
41	Mars Settlement Site G	0	Casius Quadrangle 35°00'N 75°00'E	5	Mars Surface	7	Settlement	Project Aldrin-Purdue Final Report, April 9, 2017
42	Mars Settlement Site H	0	Arcadia Planitia 50°00'N 173°00'E	5	Mars Surface	7	Settlement	Project Aldrin-Purdue Final Report, April 9, 2018
43	S1L1 Orbit	0		4	Deep Space	8	Rendezvous	Project Aldrin-Purdue Final Report, April 9, 2019

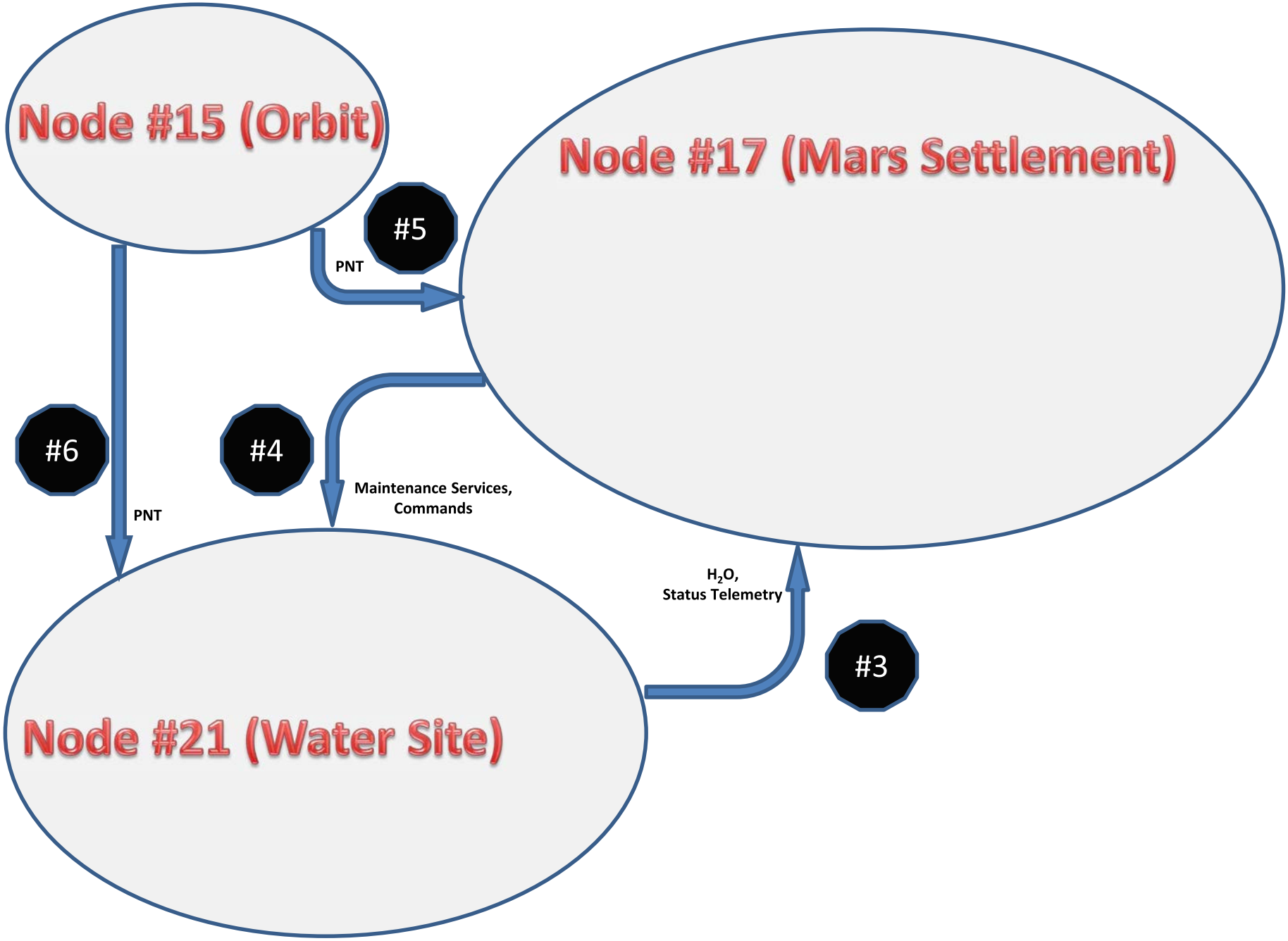
Node #15 (Orbit)

Node #17 (Mars Settlement)

Node #21 (Water Site)


Node #15 (Orbit)
Node #17 (Mars Settlement)
Node #21 (Water Site)
PNT
PNT
Maintenance Services,
Commands
H_2O,
Status Telemetry

OV-2 Diagram


Node #15 (Orbit)
Node #17 (Mars Settlement)
Node #21 (Water Site)
#5
PNT
#6
PNT
#4
Maintenance Services,
Commands
H_2O,
Status Telemetry
#3

OV-2 Diagram

Mars Colony Architecture Model (MCAM)

Needlines Table (as part of AV-2)

Needline ID	Needline Name	Needline Type ID	Needline Type Description	Sink Node ID	Sink Node Name	Source Node ID	Source Node Name	Needline Description
1	HEO-HMO	1	Logistics (LOG)	38	High Mars Orbit	3	HEO Mars Transfer Orbit	
2	Colony-DSN	6	General Communications (COMM)	2	DSN Ground Station	17	Mars Settlement Site A	
3	Water Mining-Colony	1	Logistics (LOG)	17	Mars Settlement Site A	21	Mars Water Mining Site	Water from ISRU systems
4	Colony-Water Mining	1	Logistics (LOG)	21	Mars Water Mining Site	17	Mars Settlement Site A	Maintenance services for ISRU systems
5	Positioning Satellites-Colony	5	Positioning, Navigation, and Timing (PNT)	17	Mars Settlement Site A	15	Mars Comm Relay Orbit	
6	Positioning Satellites-Water Mining	5	Positioning, Navigation, and Timing (PNT)	21	Mars Water Mining Site	15	Mars Comm Relay Orbit	

Mars Colony Architecture Model (MCAM)

Resources Table (as part of AV-2)

Jet Propulsion Laboratory
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Resource ID	Resource Name	Units Type ID	Units Type	Class of Supply ID	Unit Mass (kilograms)	Unit Volume (cubic meters)	Packing Factor (kilograms)	Environment (U/P)	Resource Description
0	Information	32	Gb						
1	Labor	39	workhours						
2	Water	8	kg	201	1	0.001			
3	Oxygen	8	kg	203	1				
4	Hydrogen	8	kg	203	1				
5	Carbon Dioxide	8	kg	203	1				
6	Electric Power, DC	31	watts						
7	Mars Icy Regolith	8	kg		1				
8	Lunar Ice/Icy Regolith	8	kg		1				
9	Food from Plant Sources	8	kg	202	1				
10	Food from Animal Sources	8	kg	202	1				
11	Nitrogen	8	kg	203	1				
12	Methane	8	kg	104	1				

Mars Colony Architecture Model (MCAM)

Systems Table (as part of AV-2)

Jet Propulsion Laboratory
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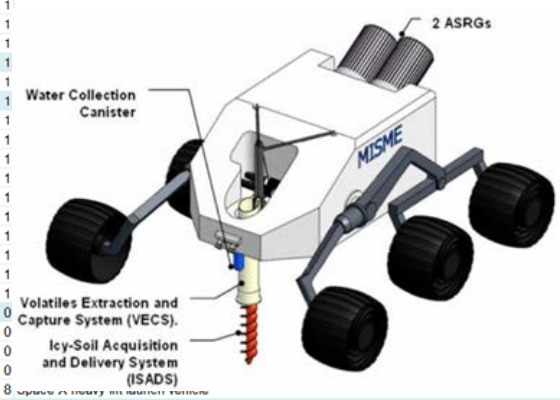
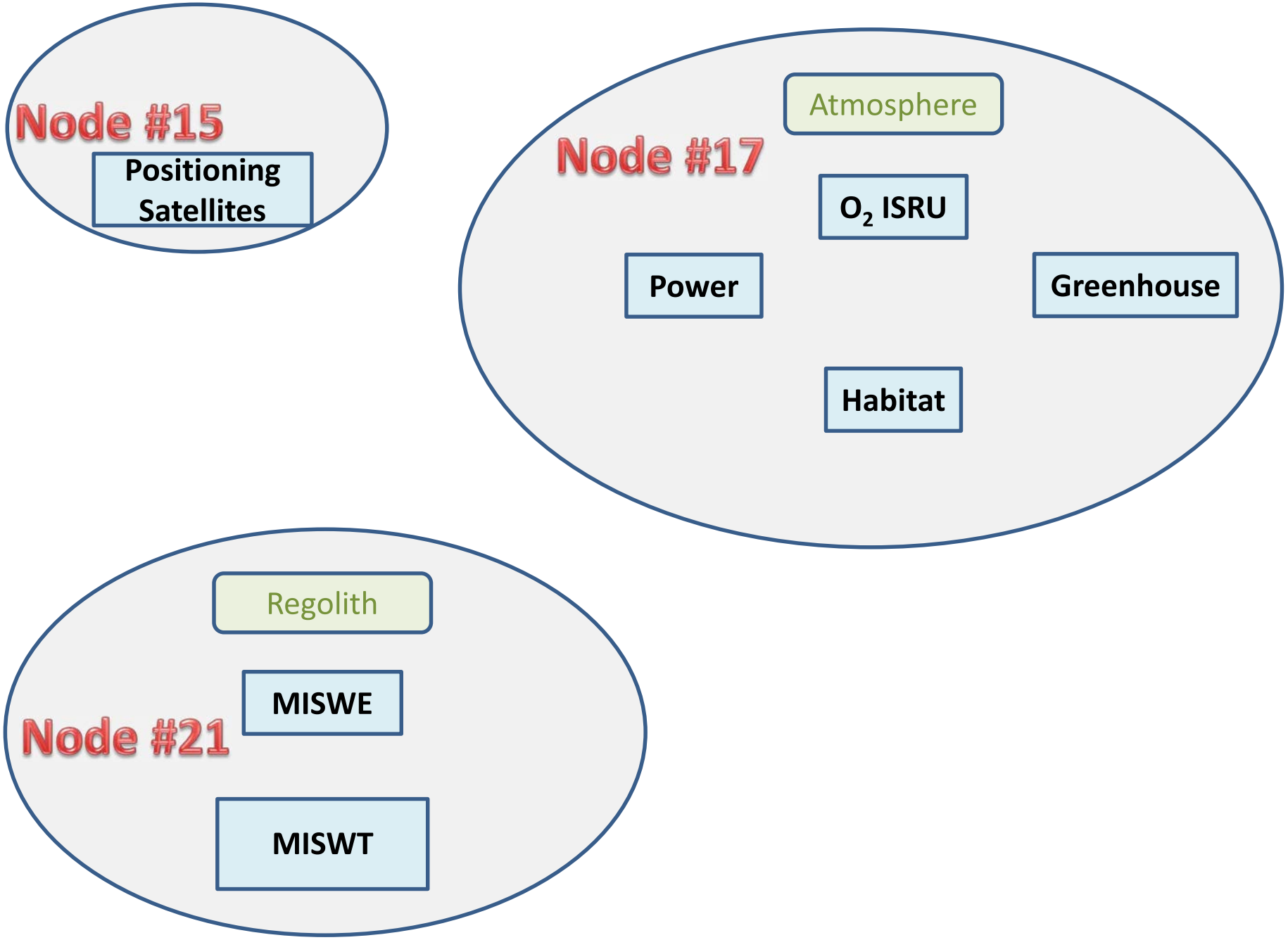
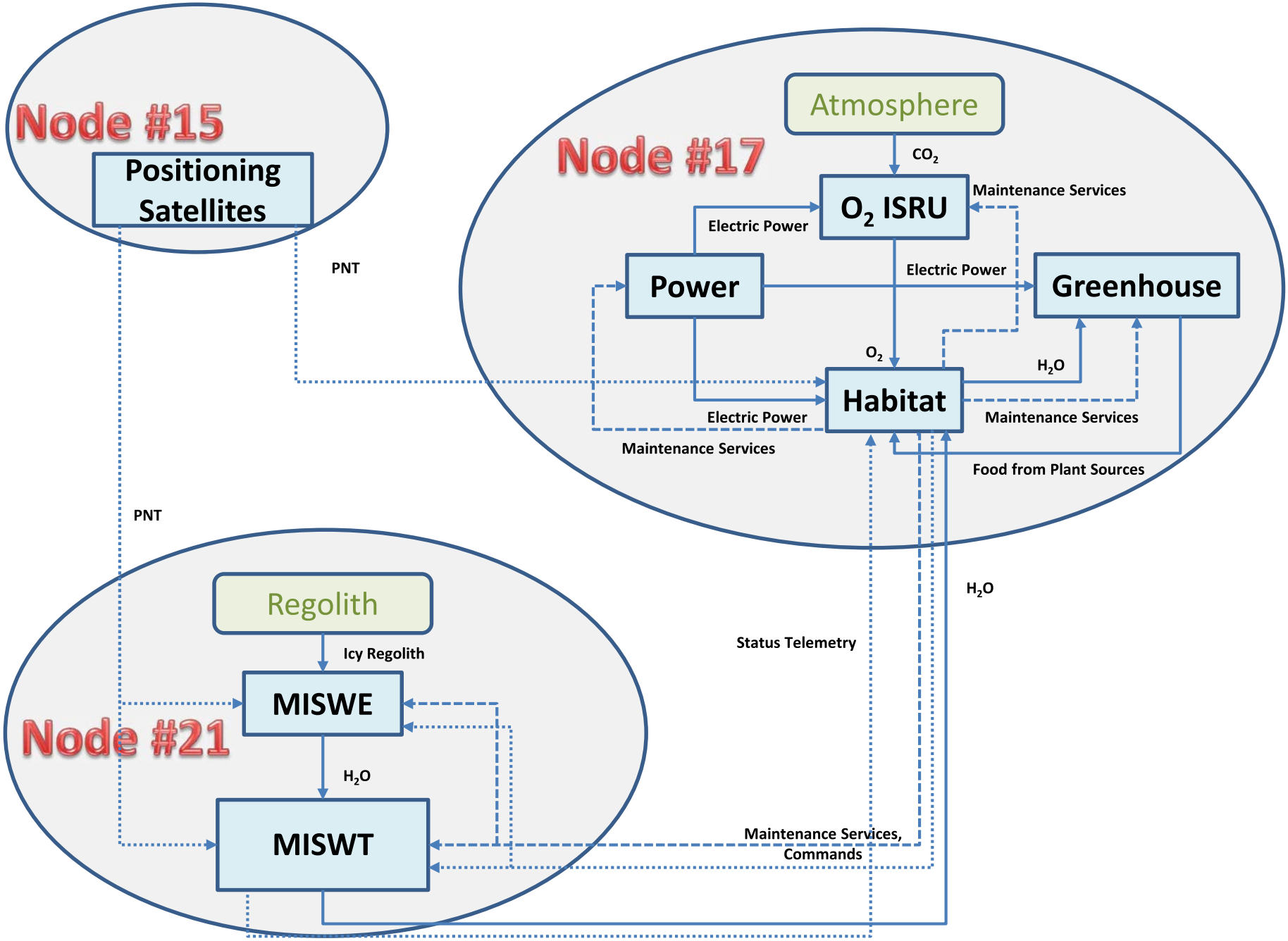
UNSW AUSTRALIA

System ID	System Name	System Short Name	Partner ID	System Description	System Type	System Type Name	System Function
1	Space Launch System (Block 1A)	SLS (Blk 1A)	1		1	Launch Vehicle	70 MT to LEO
2	Space Launch System (Block 1B)	SLS (Blk 1B)	1		1	Launch Vehicle	105 MT to LEO
3	Orion Lunar Variant (Block 1)	Orion (Blk 1)	1		2	In-Space Transportation	Earth
4	Orion Mars Variant (Block 2)	Orion (Blk 2)	1		2	In-Space Transportation	Transports crews from Earth to Mars orbit and returns them to Ear
5	Space Launch System (Blk 2)	SLS (Blk 2)	1		1	Launch Vehicle	130 MT to LEO
6	DRA5 NTR Departure Stage - Cargo	NTR	1		2	In-Space Transportation	
7	DRA5 LH2 Tank - Cargo	LH2 Tank	1		2	In-Space Transportation	
8	DRA5 Mars CargoLander	DAV	1	Common LOX/CH4 descent stage mated to an ascent stage without LOX	21	Mars Surface Logistics	
9	DRA5 Mars HabLander	SHAB	1	Common LOX/CH4 descent stage mated to a long-term crew surface habitat	15	Mars Surface Habitation	
10	DRA5 LH2 Drop Tank w/Long Saddle Truss	LH2 Drop Tank	1		2	In-Space Transportation	
11	DRA5 Mars Transfer Vehicle	MTV	1	Consists of 3 segments: TransHab, short saddle truss w/DM, consumables module	2	In-Space Transportation	
12	Mars Communications Relay Satellite	MARSAT	1		4	Deep Space Communications	
13	DRA5 Pressurized Rover		1		16	Mars Surface Mobility	
14	DRA5 Unpressurized Rover		1		16	Mars Surface Mobility	
15	DRA5 Robotic Rover		1		21	Mars Surface Logistics	
16	DRA5 Utility Power Cart		1		20	Mars Surface Power	
17	DRA5 Dynamic Isotope Power System Cart	DIPS Cart	1		20	Mars Surface Power	
18	DRA5 ISRU Plant-Stationary		1		18	Mars Surface ISRU-Type 2	
19	DRA5 Traverse Cache Vessel		1		18	Mars Surface ISRU-Type 2	
20	DRA5 FSPS	FSPS (30kW)	1		20	Mars Surface Power	
21	DRA5 Towable Drilling Equipment		1		18	Mars Surface ISRU-Type 2	
22	Mars Systems Simulation and Integration Laboratory	MSSIL	1		5	Mission Operations	
23	Aeroshell		1		2	In-Space Transportation	
24	DRA5 NTR Departure Stage - Crew	NTR - Crew	1		2	In-Space Transportation	
25	DRA5 Inline LH2 Tank - Crew	LH2 Tank - Crew	1		2	In-Space Transportation	
26	DRA5 NTR Engine	NTR Engine	1		2	In-Space Transportation	
27	DRA5 Mars EVA Suit		1		22	Other Mars Surface System	
28	TMI Module	TMI Module	1		2	In-Space Transportation	
29	MOI Module	MOI Module	1		2	In-Space Transportation	
30	TEI Module	TEI Module	1		2	In-Space Transportation	
31	Mars Surface Habitat - Variant 1	MHAB-1	0		15	Mars Surface Habitation	
32	Mars Surface Habitat - Variant 2	MHAB-2	0		15	Mars Surface Habitation	
33	Mars Surface Habitat - Variant 3	MHAB-3	0		15	Mars Surface Habitation	
34	Inflatable Mars Habitat Unit	IMHU	0		15	Mars Surface Habitation	
35	Falcon 9 Heavy	F9-H	8		1	Launch Vehicle	53 MT to LEO
36	Mars In Situ Water Extractor	MISWE	1	Honeybee Robotics mining system; 6-wheeled rover powered by 2 ASRGs	17	Mars Surface ISRU-Type 1	Icy soil acquisition/delivery, volatiles extraction/capture, water stor
37	100kWe SEP Tug	SEP100	1	SEP unit with 8 Hall thrusters w/16mt Xenon	2	In-Space Transportation	Transports uncrewed modules to Mars
38	DSN 34m Antenna Complex	DSN34	0		4	Deep Space Communications	
39	DSN 26m Antenna Complex	DSN26	0		4	Deep Space Communications	
40	Deep Space Habitat	DSH	1	Supports 4 crew for 500 days; 30mt vehicle w/SAs, batteries; ACS provided by Orion or prop m	2	In-Space Transportation	Transports crew only from HEO to HMO and return
41	Mars Surface Greenhouse Facility	MSGF	2	Supports 0.01 hectares (100 m-sq) of greenhouse environment	15	Mars Surface Habitation	Grows vegetables for colony
42	Mars In Situ Water Transporter	MISWT	1	Includes self-contained power system for thermal regulation and mobility	16	Mars Surface Mobility	Stores and transports large quantities of water to settlement sites

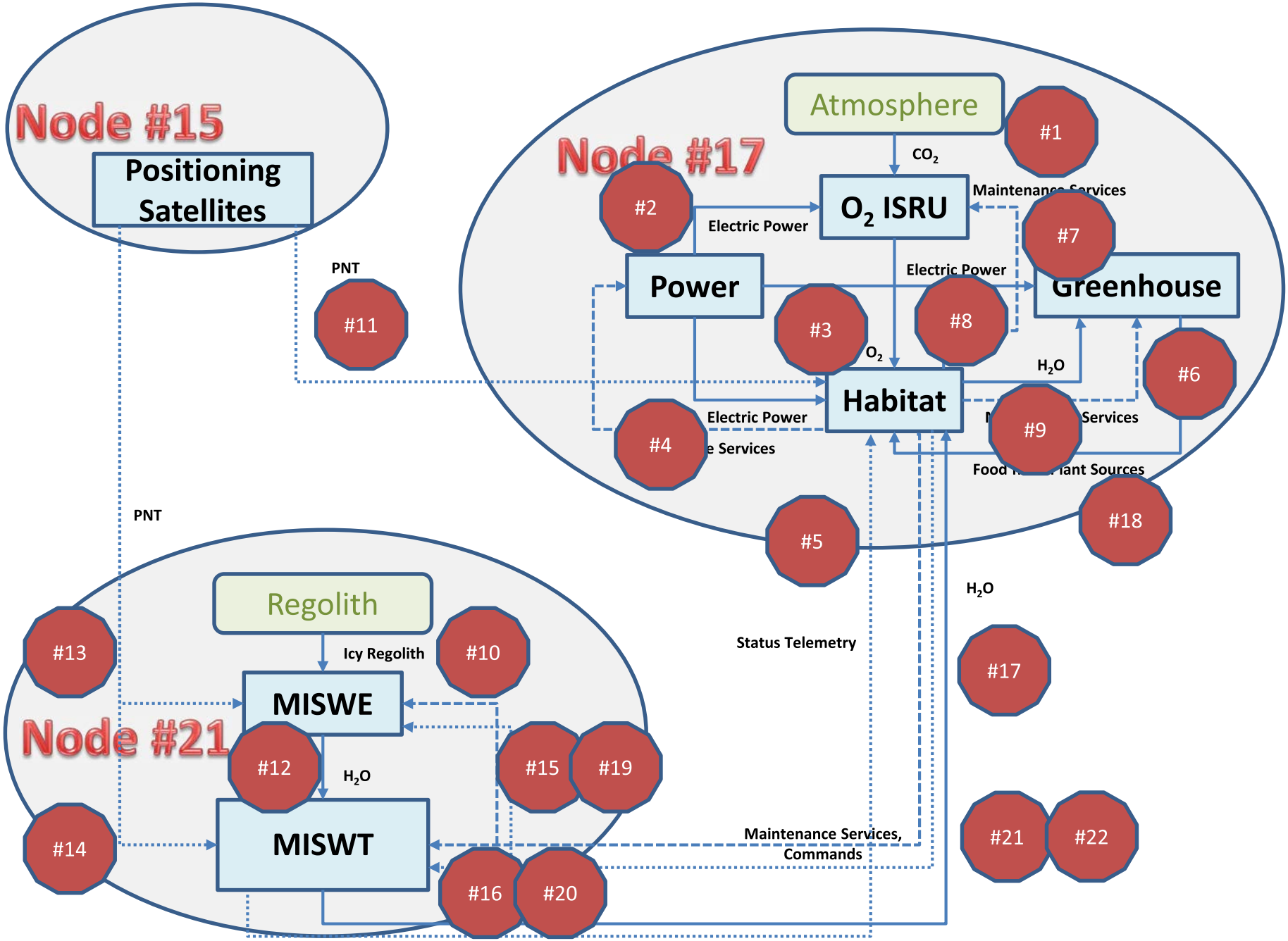




Nodes x Systems



SV-6 System Resource Flows



SV-6 System Resource Flows

Mars Colony Architecture Model (MCAM)

System Resource Flows Table (SV-6)

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Flow ID	Flow Name	Resource ID	Resource Name	Sink System ID	Sink System Name	Source System ID	Source System Name	Flow Periodicity	Flow Means
1	Mars Atmosphere to O2 Generator	5	Carbon Dioxide	18	DRA5 ISRU Plant-Stationary			Continuous	
2	Power to O2 Generator	6	Electric Power, DC	18	DRA5 ISRU Plant-Stationary	20	DRA5 FSPS	Continuous	Power Cable
3	O2 Generator to Habitat	3	Oxygen	31	Mars Surface Habitat - Variant 1	18	DRA5 ISRU Plant-Stationary	Continuous	Pipe
4	Power to Habitat	6	Electric Power, DC	31	Mars Surface Habitat - Variant 1	20	DRA5 FSPS	Continuous	Power Cable
5	Habitat to Power	1	Labor	20	DRA5 FSPS	31	Mars Surface Habitat - Variant 1	Irregular	EVA
6	Habitat to Greenhouse	1	Labor	41	Mars Surface Greenhouse Facilit	31	Mars Surface Habitat - Variant 1	Irregular	IVA
7	Habitat to O2 Generator	1	Labor	18	DRA5 ISRU Plant-Stationary	31	Mars Surface Habitat - Variant 1	Irregular	IVA
8	Power to Greenhouse	6	Electric Power, DC	41	Mars Surface Greenhouse Facilit	20	DRA5 FSPS	Continuous	Power Cable
9	H2O to Greenhouse	2	Water	41	Mars Surface Greenhouse Facilit	31	Mars Surface Habitat - Variant 1	Periodic	
10	Mars Regolith to H2O Extractor	7	Mars Icy Regolith	36	Mars In Situ Water Extractor			Periodic	Deep Fluted Auger
11	PNT to Habitat	0	Information	31	Mars Surface Habitat - Variant 1	12	Mars Communications Relay Satellite	Continuous	
12	H2O Extractor to H2O Transporter	2	Water	42	Mars In Situ Water Transporter	36	Mars In Situ Water Extractor	Periodic	Hose
13	PNT to H2O Extractor	0	Information	36	Mars In Situ Water Extractor	12	Mars Communications Relay Satellite	Continuous	
14	PNT to H2O Transporter	0	Information	42	Mars In Situ Water Transporter	12	Mars Communications Relay Satellite	Continuous	
15	Habitat to H2O Extractor	1	Labor	36	Mars In Situ Water Extractor	31	Mars Surface Habitat - Variant 1	Irregular	EVA
16	Habitat to H2O Transporter	1	Labor	42	Mars In Situ Water Transporter	31	Mars Surface Habitat - Variant 1	Irregular	EVA
17	H2O Transporter to Habitat	2	Water	31	Mars Surface Habitat - Variant 1	42	Mars In Situ Water Transporter	Periodic	Hose
18	Food to Habitat	9	Food from Plant Sources	31	Mars Surface Habitat - Variant 1	41	Mars Surface Greenhouse Facility	Periodic	IVA
19	H2O Transporter Telemetry to Habitat	0	Information	31	Mars Surface Habitat - Variant 1	42	Mars In Situ Water Transporter	Periodic	
20	H2O Extractor Telemetry to Habitat	0	Information	31	Mars Surface Habitat - Variant 1	36	Mars In Situ Water Extractor	Periodic	
21	Commands to H2O Transporter	0	Information	42	Mars In Situ Water Transporter	31	Mars Surface Habitat - Variant 1	Periodic	
22	Commands to H2O Extractor	0	Information	36	Mars In Situ Water Extractor	31	Mars Surface Habitat - Variant 1	Periodic	

Mars Colony Architecture Model (MCAM)

System Resource Flows Table (SV-6) Continued

Flow Performer Class ID	Flow Performer Class Name	Performer Type ID	Performer Type Name	Flow Units Type ID	Flow Units Type	Flow Rate	Data Source/Comments
1	System			38	kg/hour	0.8	Need real data
1	System	20	Mars Surface Power	31	watts	3	Need real data
1	System						
1	System	20	Mars Surface Power				
2	Person	20	Installation, Maintenance, and Repair Occupation	18	workhours/year		
2	Person	20	Installation, Maintenance, and Repair Occupation	18	workhours/year		
2	Person	20	Installation, Maintenance, and Repair Occupation	18	workhours/year		
1	System	20	Mars Surface Power	31	watts		
1	System						
1	System			38	kg/hour	18	Need real data
1	System	4	Deep Space Communications	40	kb/sec		
1	System						
1	System			40	kb/sec	0.0002	Need real data
1	System			40	kb/sec		
2	Person	20	Installation, Maintenance, and Repair Occupation	18	workhours/year		
2	Person	20	Installation, Maintenance, and Repair Occupation	18	workhours/year		
1	System						
2	Person	18	Farming, Fishing, and Forestry Occupations	18	workhours/year		
1	System	19	Mars Surface Comm/Nav	40	kb/sec		
1	System	19	Mars Surface Comm/Nav	40	kb/sec		
1	System	19	Mars Surface Comm/Nav	40	kb/sec		
1	System	19	Mars Surface Comm/Nav	40	kb/sec		

Mars Colony Architecture Model (MCAM)

Needlines x Resources Table (OV-3)

Jet Propulsion Laboratory
California Institute of Technology

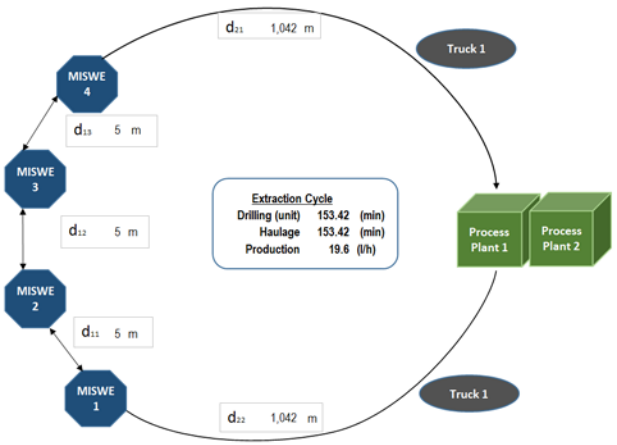
UNSW AUSTRALIA

Needline ID	Flow ID	Resource Name	Sink Node Name	Source Node Name	Include in Operational Resource Flows (T/F)
3	17	Water	Mars Settlement Site A	Mars Water Mining Site	TRUE
3	19	Information	Mars Settlement Site A	Mars Water Mining Site	TRUE
3	20	Information	Mars Settlement Site A	Mars Water Mining Site	TRUE
4	15	Labor	Mars Water Mining Site	Mars Settlement Site A	TRUE
4	16	Labor	Mars Water Mining Site	Mars Settlement Site A	TRUE
4	21	Information	Mars Water Mining Site	Mars Settlement Site A	TRUE
4	22	Information	Mars Water Mining Site	Mars Settlement Site A	TRUE
5	11	Information	Mars Settlement Site A	Mars Comm Relay Orbit	TRUE
6	13	Information	Mars Water Mining Site	Mars Comm Relay Orbit	TRUE
6	14	Information	Mars Water Mining Site	Mars Comm Relay Orbit	TRUE

OV-3 Table

Extraction Process Model

- Mining phases, systems to be used in each phase
- ISRU (all resources) mining process description, systems to be used, production function type and parameters, Q = F(K,L)



Human Water Requirement		2.90	l/day
		1.09	(l/h)
Production Target			
Initial Crew	8		
H2O	8.7	(l/h)	
Required Crew[1]	6		
	6.5	(l/h)	
Extraction & Process Requirement			
	Performance		
Equipment	N°	Unit	Fleet
MISWE	2	11	22 (l/h)
Truck	1	20	20 (l/h)
P.Plant	2	13	27 (l/h)

5

Note:
[1] One Person by 2 MISWE, one for haulage and one for process plant in 12 (H) shift

Technical Data

MISWE			
Drilling	Rate	1	(m/h)
		0.011	(m³/h)
	Diameter	0.120	(m)
	Volume	0.011	(m³)
Speed	Up	1.8	(m/min)
	Flat	2.4	(m/min)
	Down	3.0	(m/min)
Cycle	Up drill	30	(sec)
	load	30	(sec)
	Drill tie	20	(sec)
Transporter			
Capacity		0.05	(m³)
Density		1.5	
Speed	Empty	15.5	(m/min)
	Full	12.4	(m/min)
Cycle	Loading	30	(sec)
	Unloading	20	(sec)
Process Plant			
Times MISWE Capacity		50	
Process Capacity		0.013	(m³/h)
		13.333	(l/h)
Water Grade		12.000	(%)
Recovery		82.000	(%)

50

Water Requirment

Consumption rate (person)		2.90	l/day
		0.12	(l/h)
Number of person		9.00	
Consumtion Target		1.09	(l/h)

Production Cycle

MISWE Fleet				
Drilling	Deep	2.5000	(m)	
	Drill tie	0.3333	(min)	
	Drilling	150.0000	(min)	
	Up Drilling	0.5000	(min)	
	Loading	0.5000	(min)	
	Total	151.3333	(min)	
Move	Distance	5.0000	(m)	
	Time	2.0833	(min)	
Unitary	Total Cycle	153.4167	min	
	Performance	0.0111	(m³/h)	
		11.0579	(l/h)	
Fleet	**Distance -Between (d1i)**	5.0000	m	
	Number	1.7684	unit	
	Performance	19.5546	(l/h)	R1
Transporter Fleet				
Distance	Between MISWE	0.0100	km	
	To Process Plant (d21)	1.0421	km	
	To Drilling Site (d22)	1.0421	km	
Time	Loading	0.5000	min	
per MISWE	Haulage	0.4032	min	
	Total	0.9032	min	
Time	Loading	1.0000	min	
	Haulage (empty)	67.2342	min	
	Haulage (full)	84.8492	min	
	unloading	0.3333	min	
Unit	Total Cycle	153.4167	min	
	Performance	0.0196	m^3/h	
		19.5546	l/h	
Fleet	**Number**	1.0000	unit	
	Performance	19.5546	l/h	R3
Process Plant				
Capacity		0.0133	(m³/h)	
		13.33	l/h	
Production	Water (Mass)	1.07	l/h	
	Water (Recovery)	0.87	l/h	
		20.99	l/day	
	Performance	15.24	m^3/l	
Fleet	**Number**	1.24	unit	
	Throughput	16.58	l/h	R2
	Production	1.09	l/h	

Infrastructure and ILS Model

- Time-phased deliveries and production capacity for ISRU systems
- Demand for power systems, habitat systems, etc. as colony grows
- Mars colony internal demands for *in situ* resources
- Demand for spares to support colony and ISRU systems
- Additive manufacturing capabilities

In general, what will the Mars Colony and Interplanetary Supply Chain (forward and reverse) look like over time?

Economic Integration Model

- Scenarios
  - What markets are likely to materialize?
  - What production efficiencies and related technologies are likely to be available?

- Profitability
  - Revenues calculations
  - Costs calculations
  - Net Present Value, ROI, Real Option Value calculations
  - Will subsidies be needed, and for how long?

Summary

- A Mars Colony architecture is largely driven by:
  - Orbital mechanics
  - Human physiology
  - System technologies
  - Mars environments
  - Economic and social constraints
- MCAM's purpose is to support an exploratory investigation of various architectures, CONOPS, and representative scenarios.
  - Houses architectural information in a structured way that enables standard views to be constructed
  - When integrated with the downstream models, enables more complex views to be developed, in particular, those representing commercial profitability and payoffs from ISRU technology investments

BACK-UP

Mars Colony Architecture Model (MCAM)

Comparison of Terminologies

DoDAF 2.02	UPDM	MoDAF 1.3	MCAM
Node	Node	Node	Node
System	System or CapabilityConfiguration	CapabilityConfiguration	System
Needline (informal in v2.02)	Needline	Needline	Needline
Activity	Function	Function	Function
Measure	Measurement	MeasurableProperty	Measure Value
MeasureType	MeasureType	N/A	Measure
MeasureTypeUnitsofMeasure	SysML DimensionType (SysML 1.3 uses ValueType)	N/A	Unit Type
N/A	ActualProjectMilestone or DeployedMilestone or IncrementMilestone or NoLongerUsedMilestone	ProjectMilestone or DeployedMilestone or CapabilityIncrement or StatusAtMilestone	Milestone
Organization	ActualOrganization	ActualOrganisation	Partner
locationNamedByAddress	LocationKind or GeopoliticalExtent	N/A	Node Location
Performer	Participant or PhysicalResource or LogicalArchitecture or Performer	Node or PhysicalAsset or LogicalArchitecture	Performer Class
whole part of a PersonRoleType	PersonType	N/A	Person Type (by BLS Standard Occupation Classification)
Representation	Alias	Alias	Short Name
Resource	ExchangeElement	ResourceType	Resource

Mars Colony Architecture Model (MCAM)

Person Type Table (as part of AV-2)

PersonType ID	PersonType SOC	PersonType Description
0	unknown	unknown, unallocated, or not applicable
1	11-0000	Management Occupations
2	13-0000	Business and Financial Operations Occupations
3	15-0000	Computer and Mathematical Occupations
4	17-0000	Architecture and Engineering Occupations
5	19-0000	Life, Physical, and Social Science Occupations
6	21-0000	Community and Social Service Occupations
7	23-0000	Legal Occupations
8	25-0000	Education, Training, and Library Occupations
9	27-0000	Arts, Design, Entertainment, Sports, and Media Occupations
10	29-0000	Healthcare Practitioners and Technical Occupations
11	31-0000	Healthcare Support Occupations
12	33-0000	Protective Service Occupations
13	35-0000	Food Preparation and Serving Related Occupations
14	37-0000	Building and Grounds Cleaning and Maintenance Occupations
15	39-0000	Personal Care and Service Occupations
16	41-0000	Sales and Related Occupations
17	43-0000	Office and Administrative Support Occupations
18	45-0000	Farming, Fishing, and Forestry Occupations
19	47-0000	Construction and Extraction Occupations
20	49-0000	Installation, Maintenance, and Repair Occupations
21	51-0000	Production Occupations
22	53-0000	Transportation and Material Moving Occupations
23	55-0000	Military Specific Occupations

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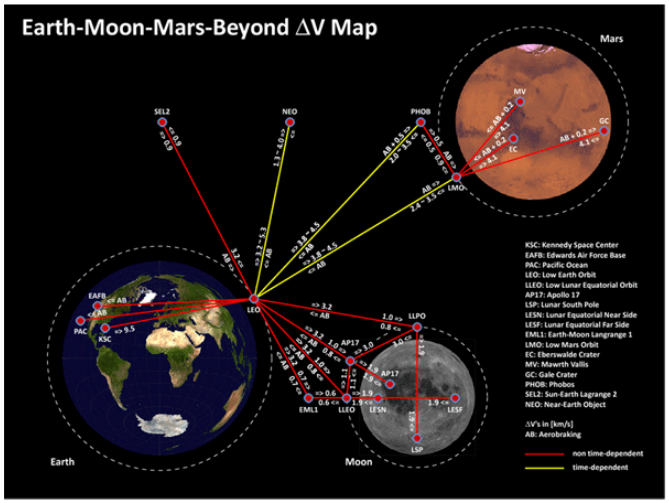

An Earth-Moon-Mars Logistical Network in SpaceNet

Announcements

SpaceNet Public Release

Oct. 1 2009 — SpaceNet 2.5 is officially released to the public. Check out the downloads page for more information.

The SpaceNet team would like to thank everyone who contributed to the past cycle of development.

Additional Resources