AN INTEGRATED ECONOMICS MODEL FOR ISRU IN SUPPORT OF A MARS COLONY

Jet Propulsion Laboratory (JPL)/California Institute of Technology

UNSW Australia
School of Mining Engineering
School of Electrical Engineering and Telecommunications/
Australian Centre for Space Engineering Research (ACSER)
School of Business

Massachusetts Institute of Technology
Department of Aeronautics/Astronautics

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An International and Multidisciplinary Team of Investigators

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  - Others (Mars Program Chief Engineer, Foundry A Team, ISRU SMEs . . .)

- **UNSW Australia (In-kind contributions)**
  - Prof. Serkan Saydam and Carlos Tapia-Cortez, School of Mining Engineering
  - Prof. Andrew Dempster, School of Electrical Engineering and Telecommunications / Director, Australian Centre for Space Engineering Research (ACSER)
  - Dr. Jeff Coulton, Australian School of Business

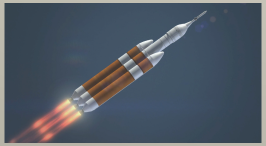
- **MIT (In-kind contributions)**
  - Prof. Olivier deWeck, Department of Aeronautics / Astronautics
  - Dr. Sydney Do, Department of Aeronautics / Astronautics

Background

- **UNSW and JPL responded (in 2015) to a NASA Research Announcement on the potential commercial profitability of "mining" water on Mars in support of a growing Mars Colony**

Scope of This Research

2014



Orion ETF-1

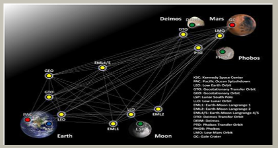
2030's-2040's

First Human Landing On Mars

2040's-2050's

Establishment Of A Mars Colony

2050's - ?



Economic Viability

1 2 3

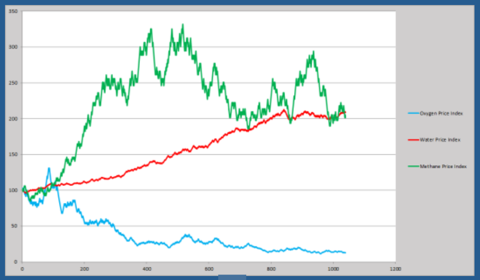
End-to-End Model Data Flow

UE mass, power, DDT&E and unit cost, design life, H_2O initial price, price drift and volatility, tax rate, etc.

Extraction Process Model

Net H_2O demand (litres/week)

Economics Model



20-Year Forecasts for Revenues , Costs, and After-Tax Profits

E[NPV], Std Dev[NPV], IRR, and Prob{NPV>0}

Mars Colony Architecture Model

Technical parameters, e.g., drill rate

Number of UE, Total H_2O delivered

HabNet

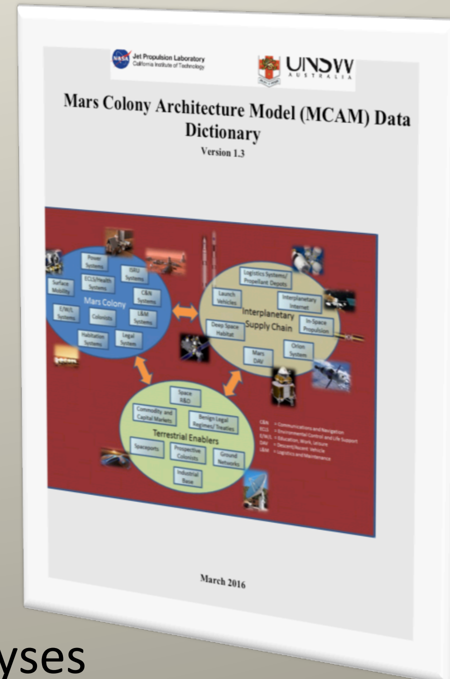
Number of colonists, activities, and physiological requirements, by person type and gender

UE = Unit Equipment; NPV = Net Present Value; IRR = Internal Rate of Return

Mars Colony Architecture Model (MCAM)

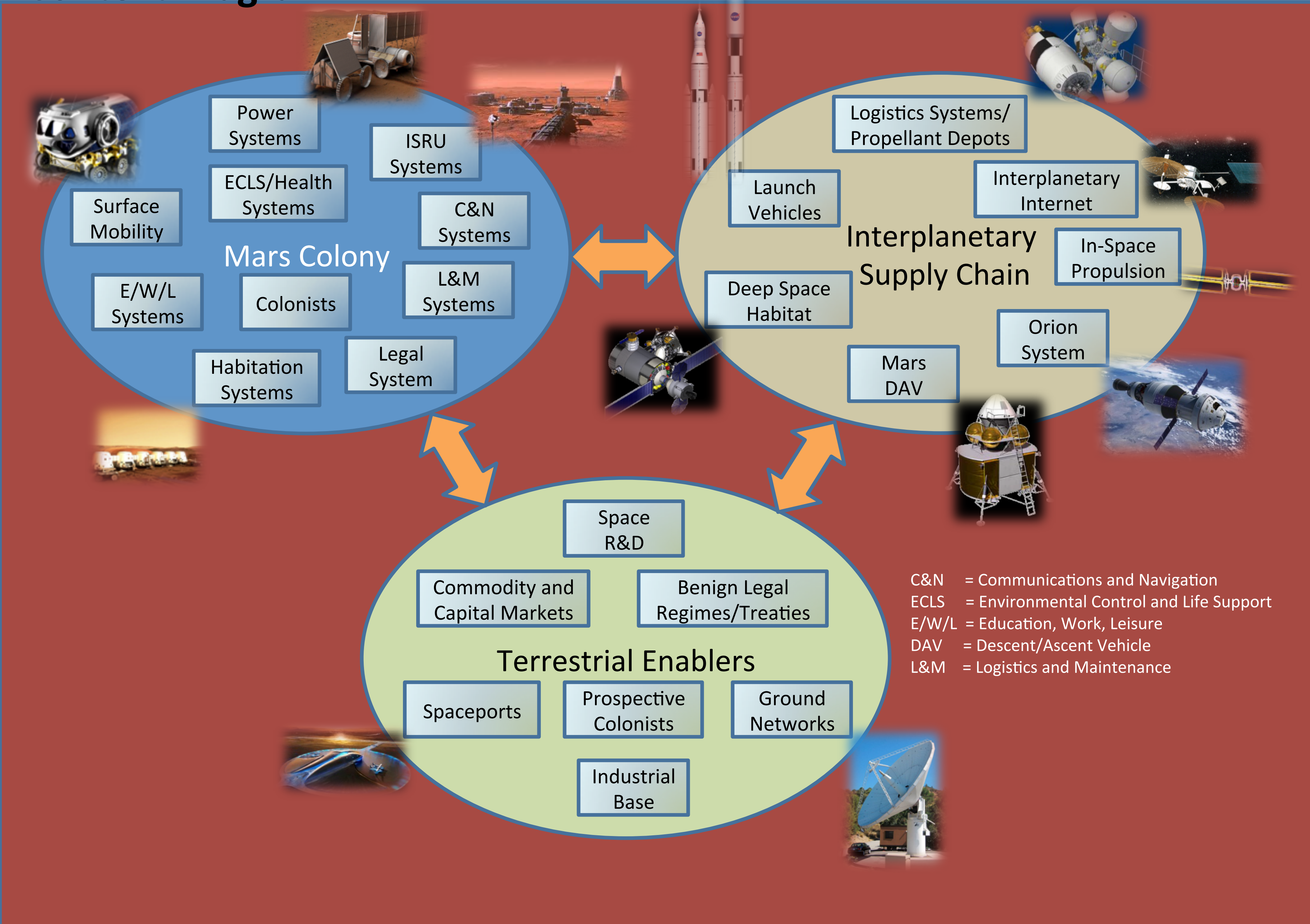
- Data model based on DoDAF 2.02 with "for-purpose" extensions
- MCAM Key Constructs
  - Operational Nodes (Surface Locations, Orbits, Lagrange Points)
  - Systems (Transport, Mining, Habitation, etc.)
  - Operational Activities/Functions
  - Resources (People, Material, Information, etc.)
  - Milestones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

Types and Subtypes Permeate



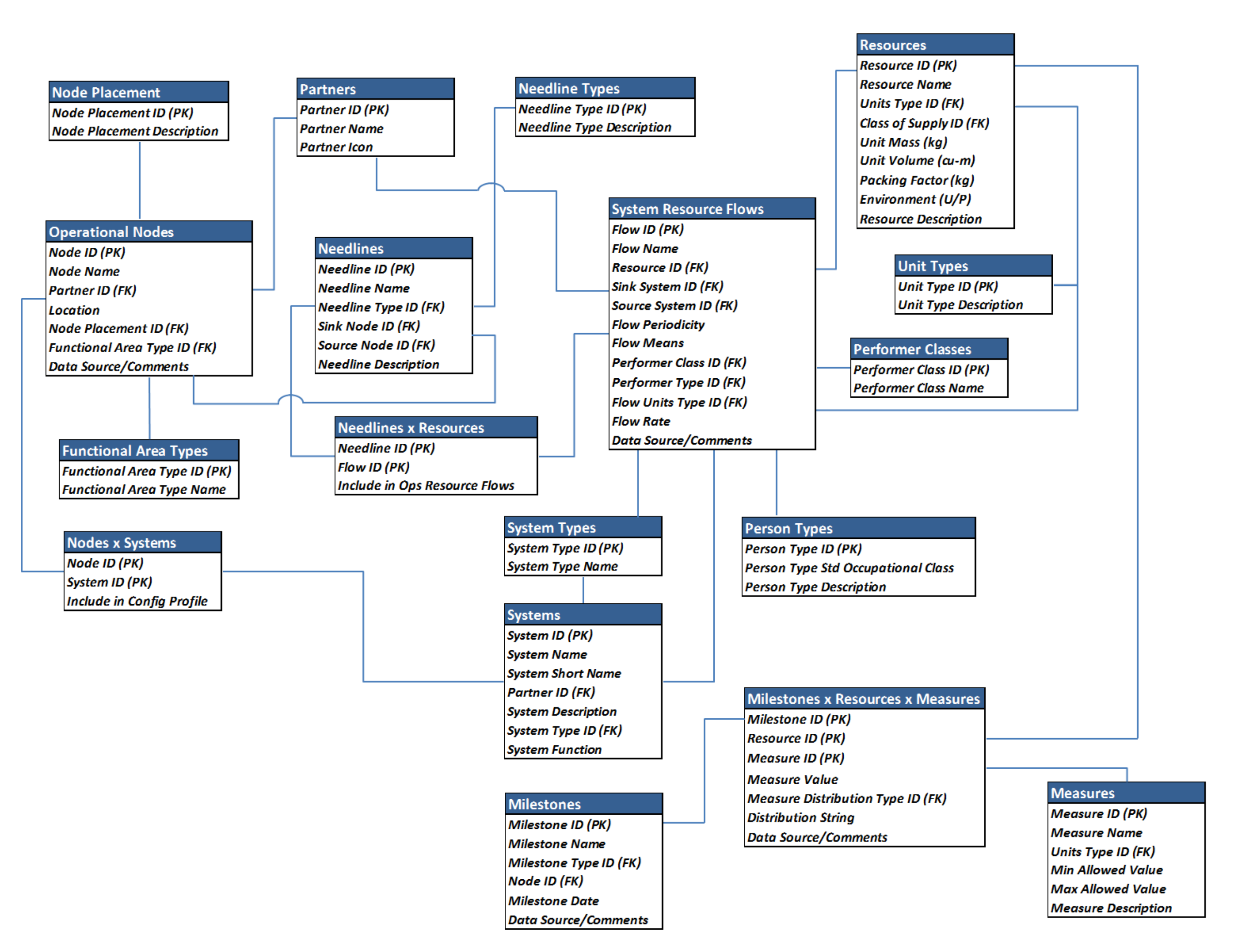
- "For-purpose" extensions permit quantitative analyses
- Key quantitative relationships are needed for ISRU (i.e., extraction output (kg) of mining operations based on technology, number of mining systems deployed, number of persons by personnel type, etc.)

Context Diagram



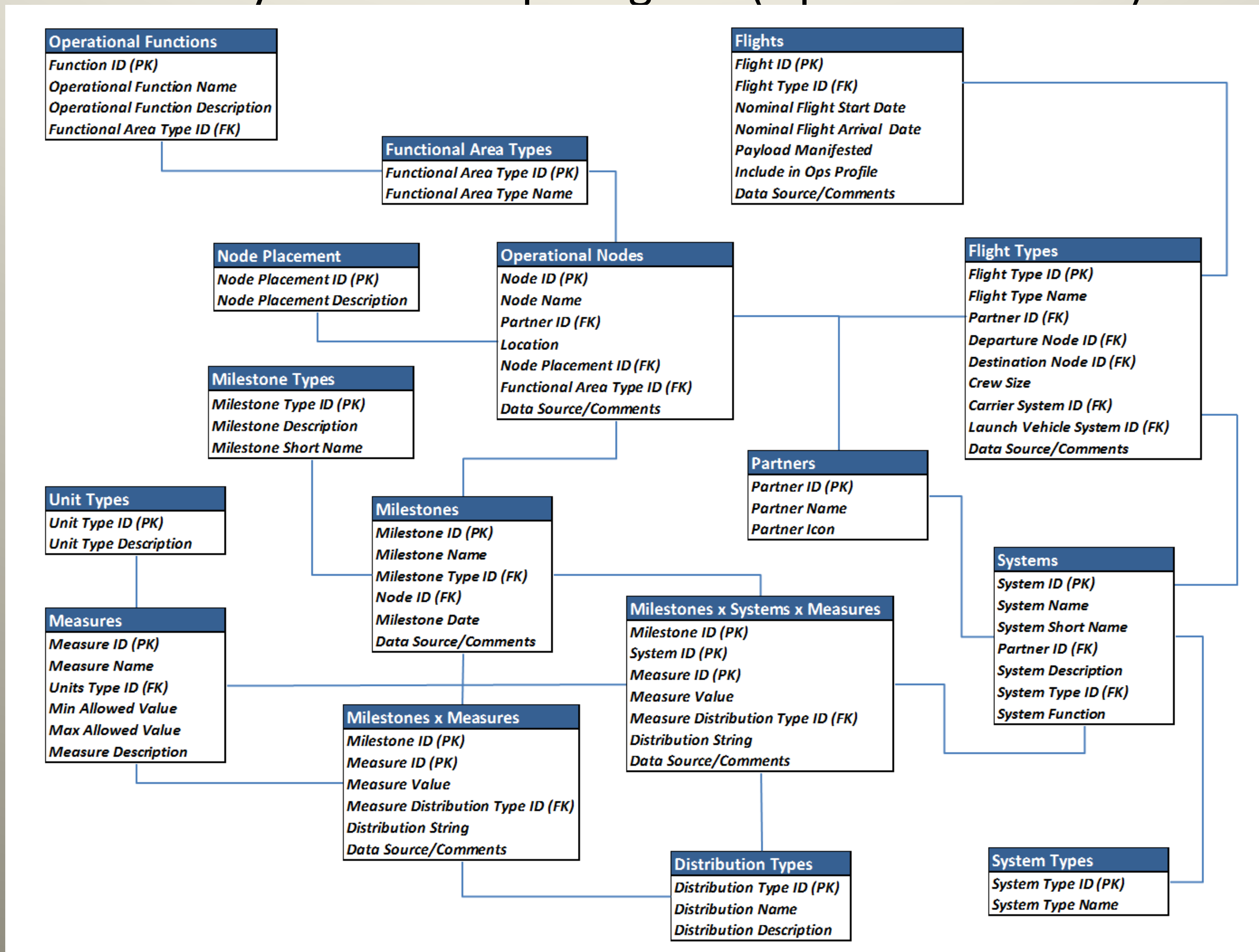
Mars Colony Architecture Model (MCAM)

Entity-Relationship Diagram (System Resource Focus)



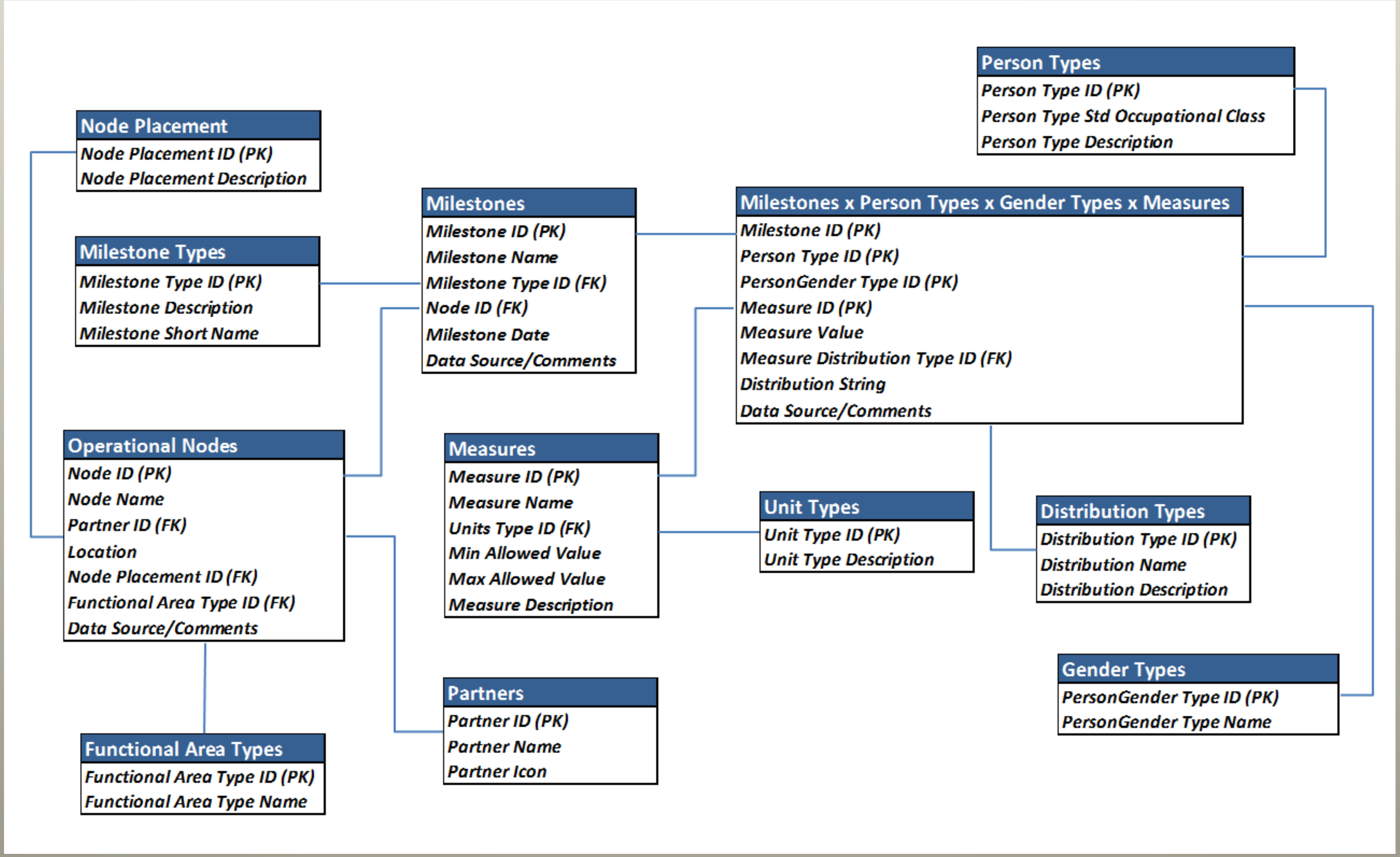
Mars Colony Architecture Model (MCAM)

Entity-Relationship Diagram (Operations Focus)



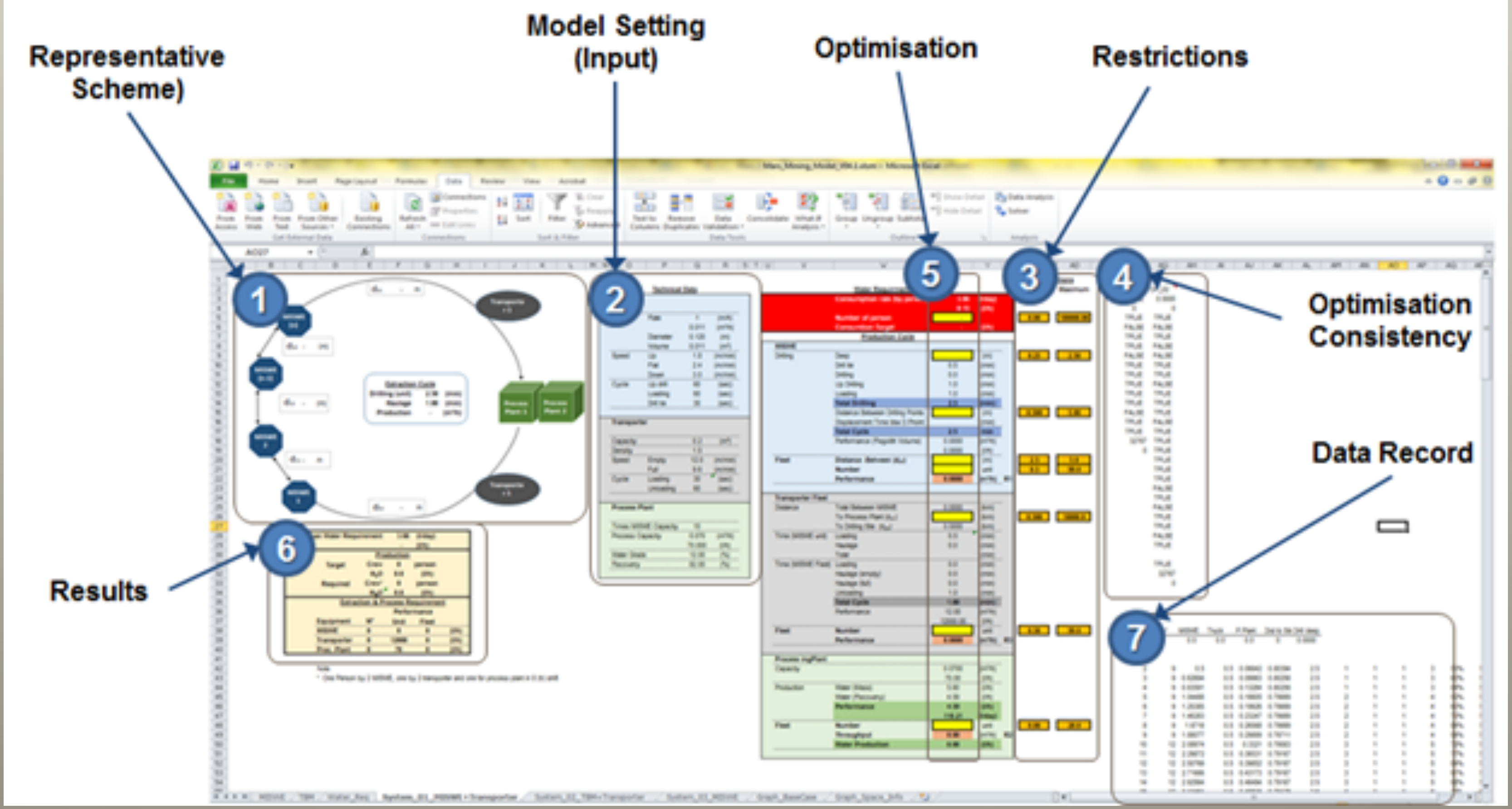
Mars Colony Architecture Model (MCAM)

Entity-Relationship Diagram (Human Activities Focus)



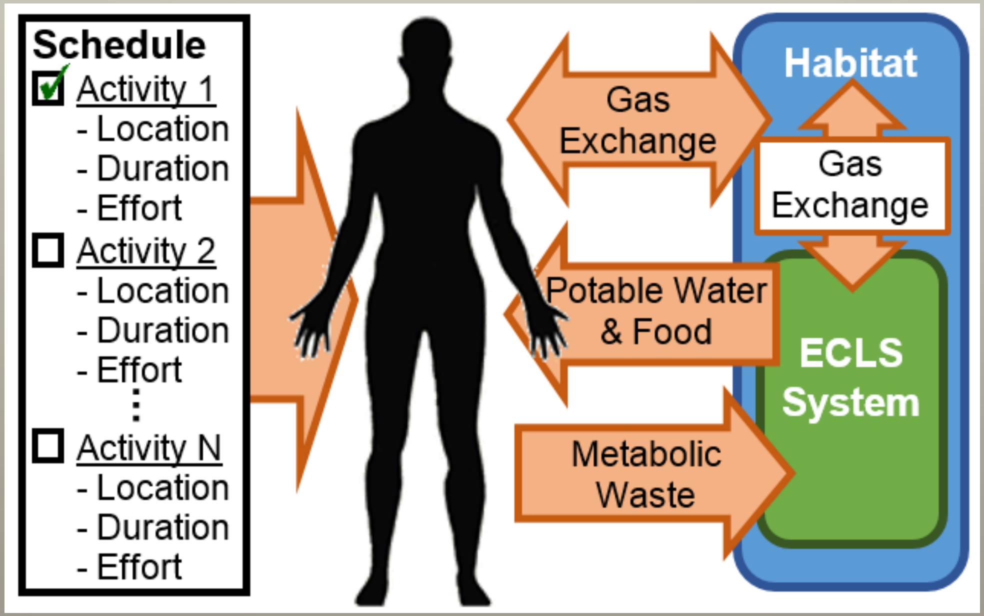
Extraction Process Model

- ISRU (water) mining process description, systems to be used, environmental and system technical parameters
- Optimization of the number of systems of each type needed to meet demand

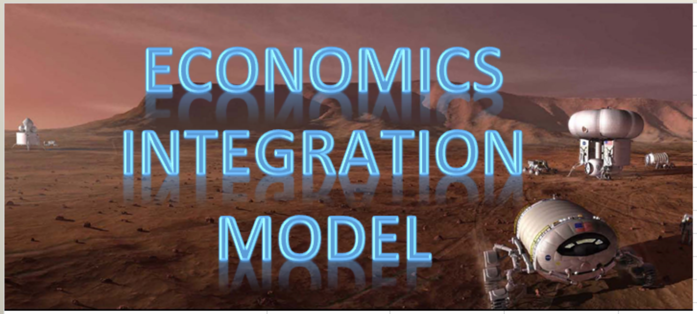


HabNet

- Mid-fidelity time-based ECLS system simulator based on BioSim
- Computes the external demand for ISRU water based on ECLS system closure, number, type, activities, and gender of Mars Colony inhabitants



Economics Integration Model

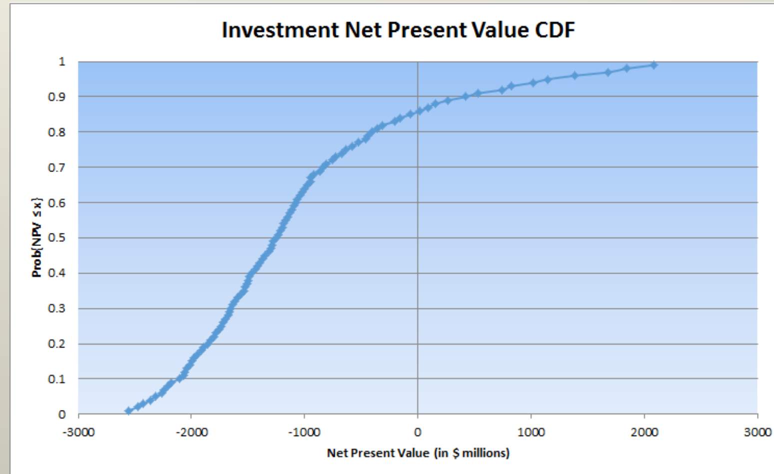


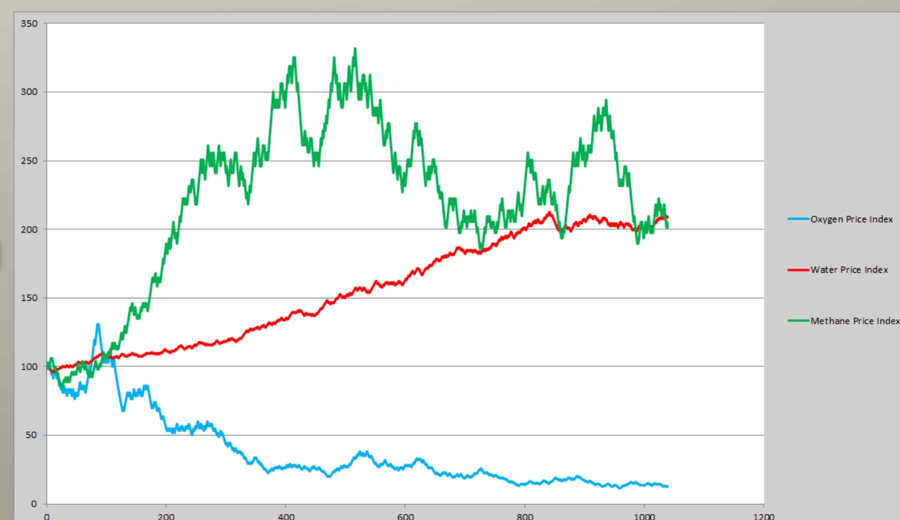
	MISWEs	Transporters	Plants	Total Elements
Quantity	1	1	1	3
Unit Equipment Price ($M)	$ 200.00	$ 90.00	$ 655.00	
Mass (kg)	$ 1,000.00	$ 600.00	$ 1,200.00	
Design Life (yrs)	10	10	10	
Delivered Water (kg/week)				42

Global Parameters	
DiscountRate	20.0%
NumModelYears	20
YearModelStart	1/1/2055
Drift (%/week)	0.05%
Volatility (weekly)	0.50%
Initial Water Price ($/kg)	$ 4,137.00
TaxRate	30.00%

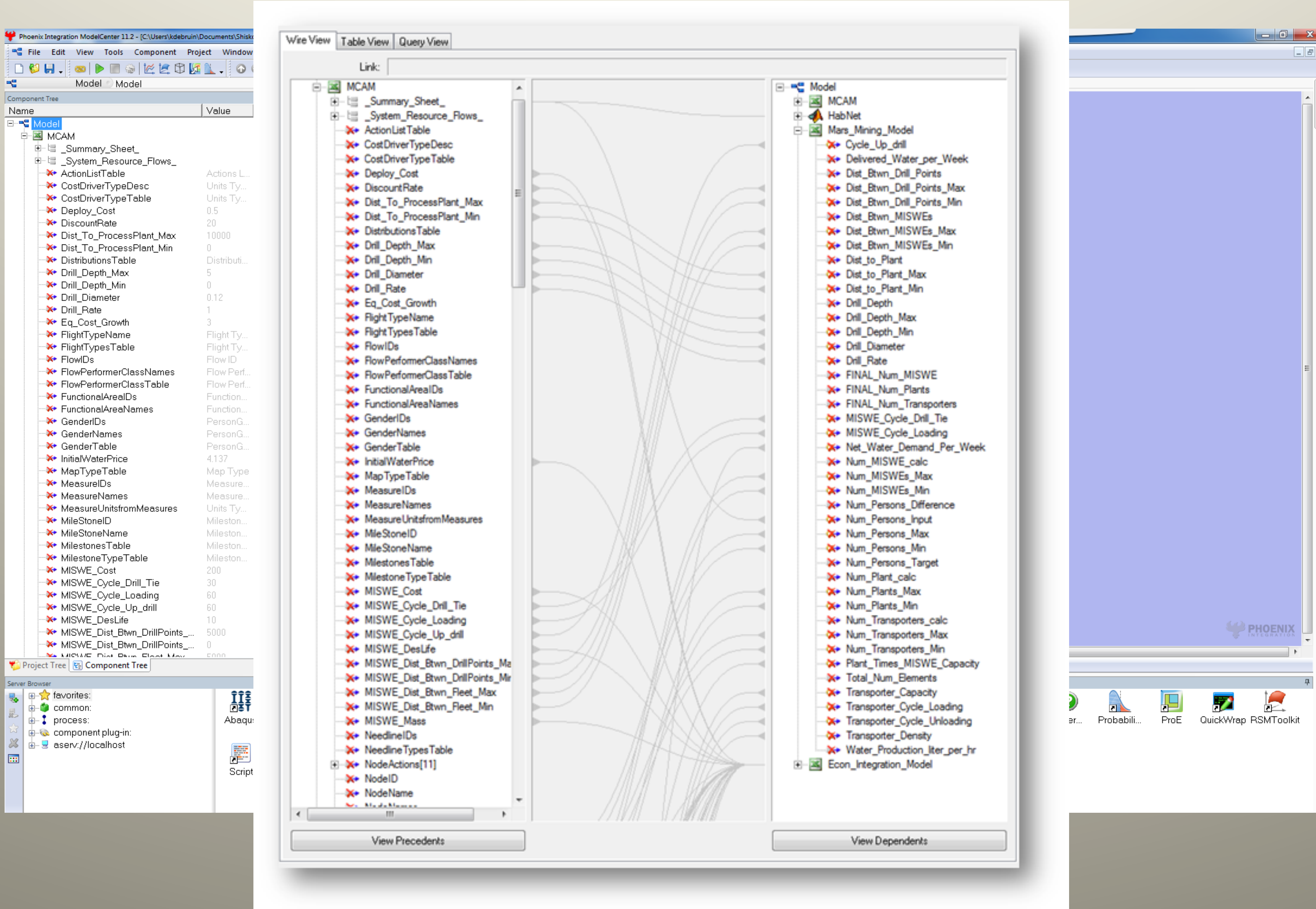
Cost Drivers	
Launch and Landing Cost ($M/kg)	$ 0.50
SalaryGrowth	3.00%
Equipment Cost Growth	3.00%

Avg Yearly Water Price Index	
1	103.36
2	108.94
3	113.48
4	112.26
5	112.39
6	114.44
7	112.58
8	114.22
9	118.41
10	120.84
11	120.81
12	123.31
13	128.76
14	134.47
15	133.96
16	131.63
17	136.74
18	141.26
19	141.09
20	131.62



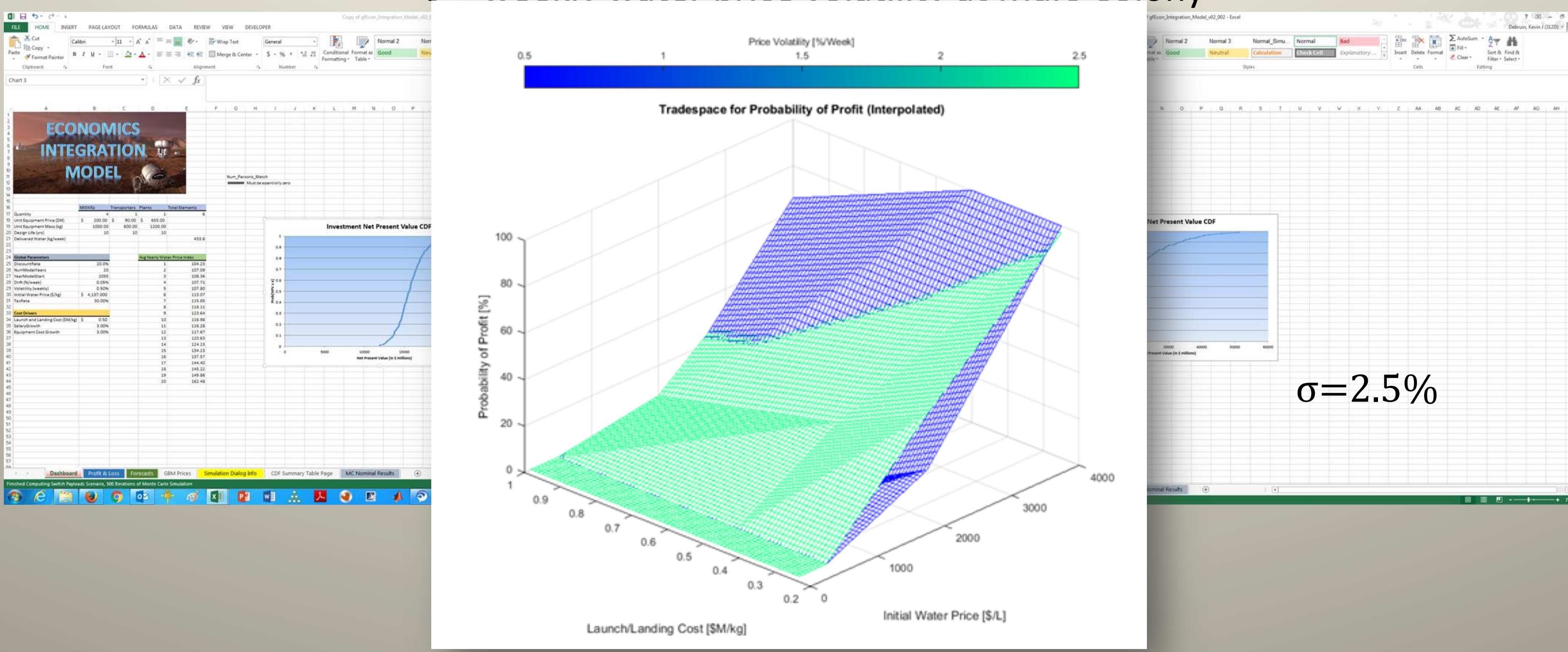


ModelCenter© Provides the Integration "Glue"



Profitability S-Curve Changes In Response To Parameter Shifts ($\nabla f(x)$)

σ = weekly water price volatility at Mars Colony



σ=2.5%

Even with the current simple set-up, a user can control >50 scenario parameters and technical attributes through MCAM.

Major Findings To Date

- A Mars Colony architecture is largely driven by:
  - Orbital mechanics
  - Human physiology
  - System technologies
  - Mars environments
  - Economic and social constraints
- Commercial viability of mining water on Mars is far from guaranteed, but could be met by several combinations of technical and economic attributes.
- Local logistics (water location and availability) on Mars affects the Colony's optimal surface architecture (includes location), which in turn, affects the required interplanetary supply chain infrastructure.
- Identifying what design choices and technology investments have the highest payoff will require further refinements in each of these models.