A NASA SUPPLY CHAIN BEYOND LOW EARTH ORBIT

EXPLORE MOON to MARS

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Agenda

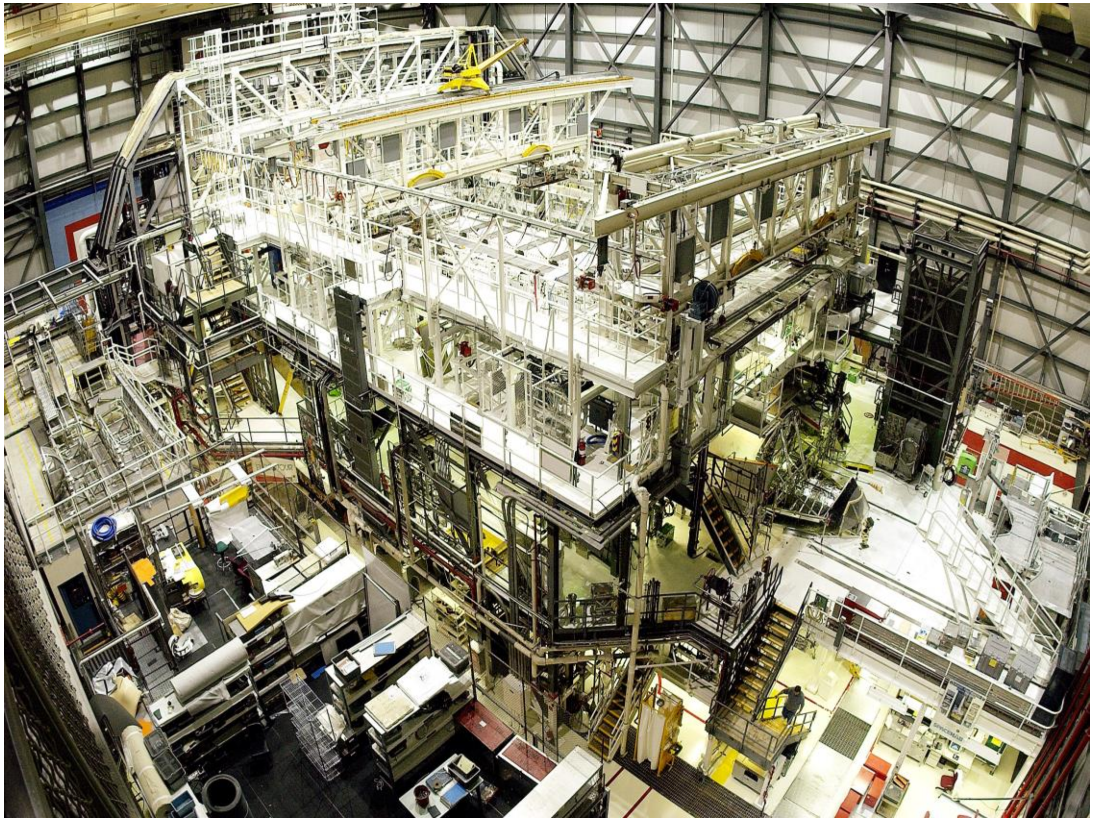
NASA's Space Logistics R&T project for Exploration

- Space Shuttle Program Logistics Lessons Learned
- Modeling and Simulation to assess In-Space Manufacturing, 3D printing technology adaption and sourcing risk
  - Network modeling for sequencing product delivery logistics nodal positioning

Summary

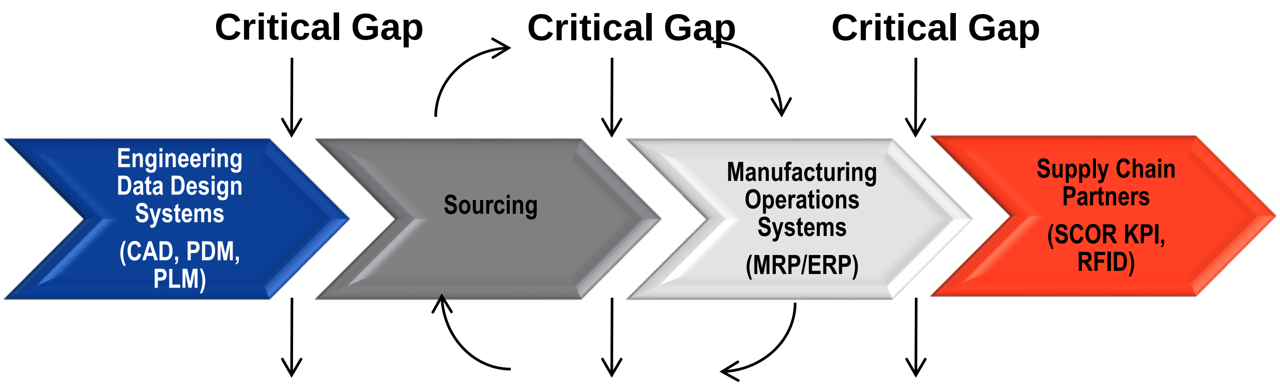
Space Shuttle Program Orbiter Processing Concept

Actual Orbiter Processing Operations



SSP Operational Gaps

Gaps with Design, Sourcing & Supply Chain

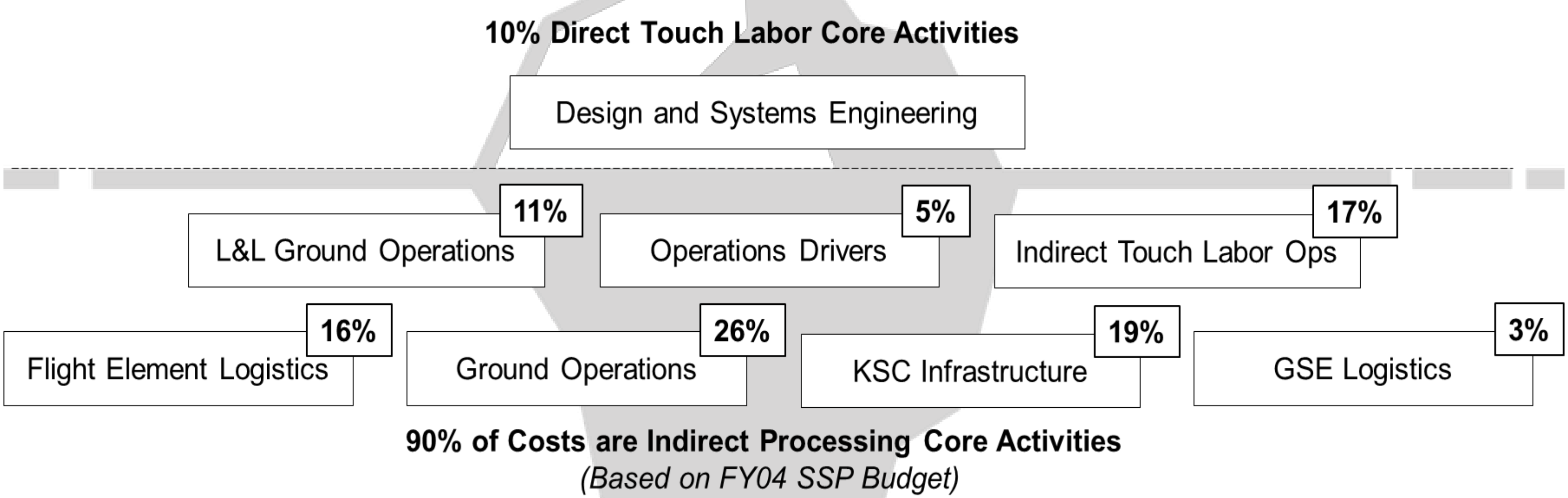


<u>Issues:</u>
- Data “locked” in engineering
- Ineffective Communication
- Increased Timeliness
- Lack of Shared Knowledge
- Increased Margin on Initial Quotes
- Lack of IP Protection
- Lack of classification (SMRC)
- Supplier involvement

<u>Issues:</u>
- Assembly Quoting Challenges
- Manufacturing Readiness
- Industrial Base Viability
- Demand Aggregation
- Inadequate view of total cost
- Difficult global part transition
- Counterfeit Parts
- Product Quality

<u>Issues</u>:
- Incomplete Specification Data
- Increased indirect non-recurring cost
- Increase in change order activity
- Large inventory costs
- Frequent Obsolescence occurrences
- Lack of export controls
- Poor supply chain readiness

Space Shuttle Program
Ground Operations Cost Breakdown



Source: http://strategic.mit.edu/docs/3_84-AIAA-2006-7234.pdf

National Aeronautics and Space Administration

NASA/Department of Commerce Survey

- 30% of suppliers are NASA dependent
- 46% had no interest to support Commercial Human Space Flight
- 14% had no interest to support future NASA programs
- 19% of suppliers high risk of insolvency
- Manufacturing capacity utilization <50%
- NASA product Market Cap decreased
- 53% of suppliers support DoD
- 12 other Agencies also impacted

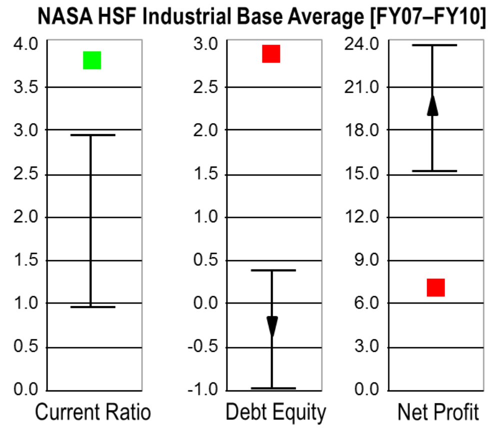
https://www.bis.doc.gov/index.php/forms-documents/other-areas/641-national-aeronautics-and-space-administration-nasa-industrial-base-post-space-shuttle/file

Supply Chain Post-Shuttle Lessons Learned

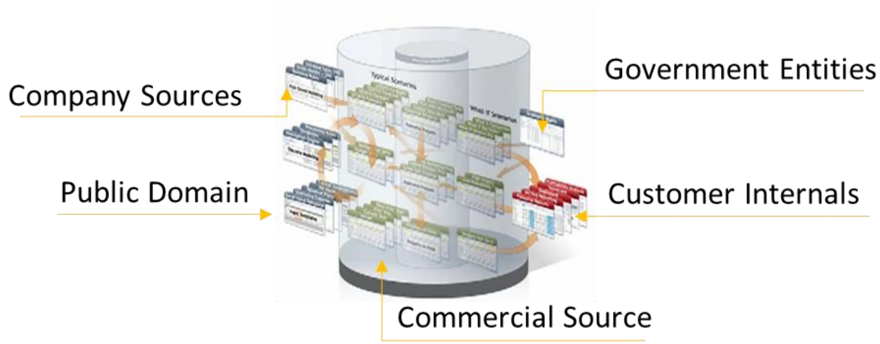
"For want of a nail a kingdom was lost" *c. 1230 Freidank Bescheidenheit*

The space industry's profit margins lagged behind A&D, and other high technology manufacturing sectors

- Profitability was typically lower the further down the supply chain a company was situated from the first tier
- Because of low visibility into suppliers below the tier-1 level, it is difficult to assess resiliency and product quality of specific tiers or subsectors within the NASA Supply Chain



Step 1. Data Sourcing – Content is King!



Data Sources

- D&B Hoovers
- SBA
- SAM (CCR)
- US-Spending
- VETBIZ
- USGS
- USFS
- NOAA
- GIDEP
- GOV-REP
- US Census
- Geospatial

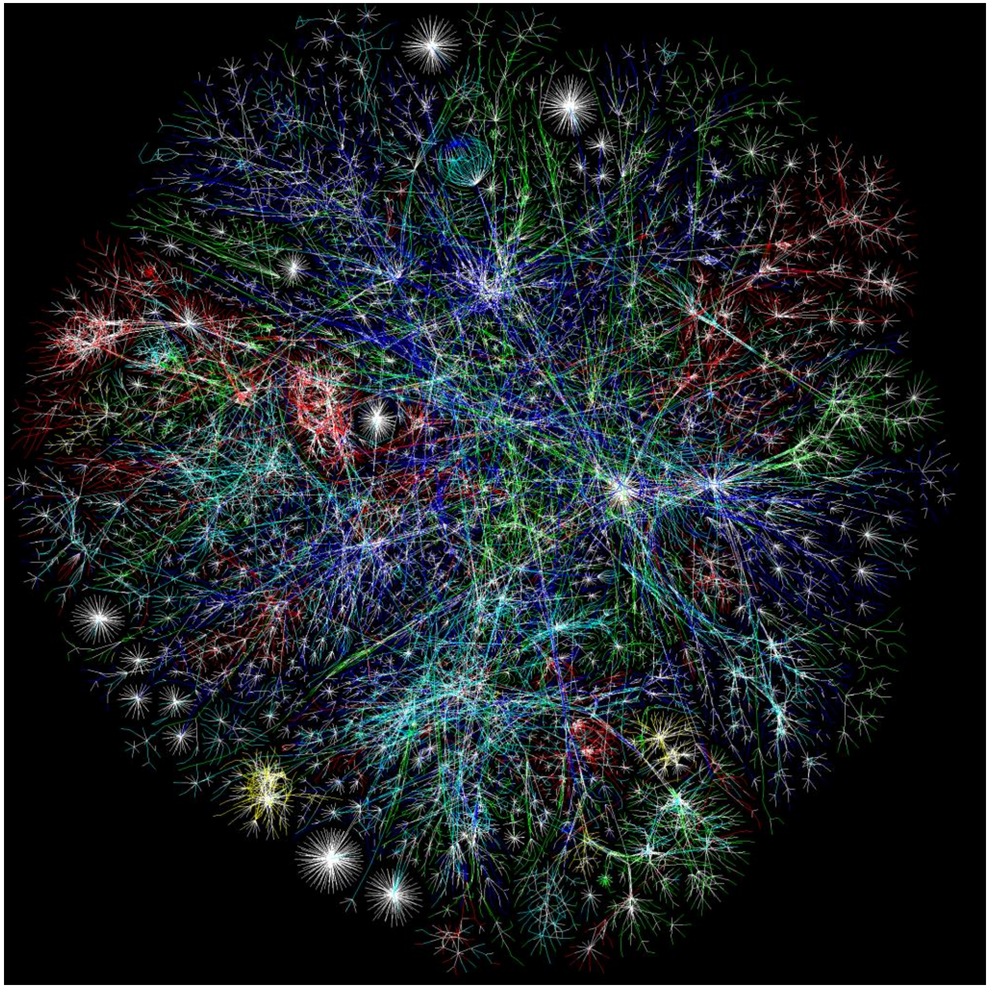
Data Richness

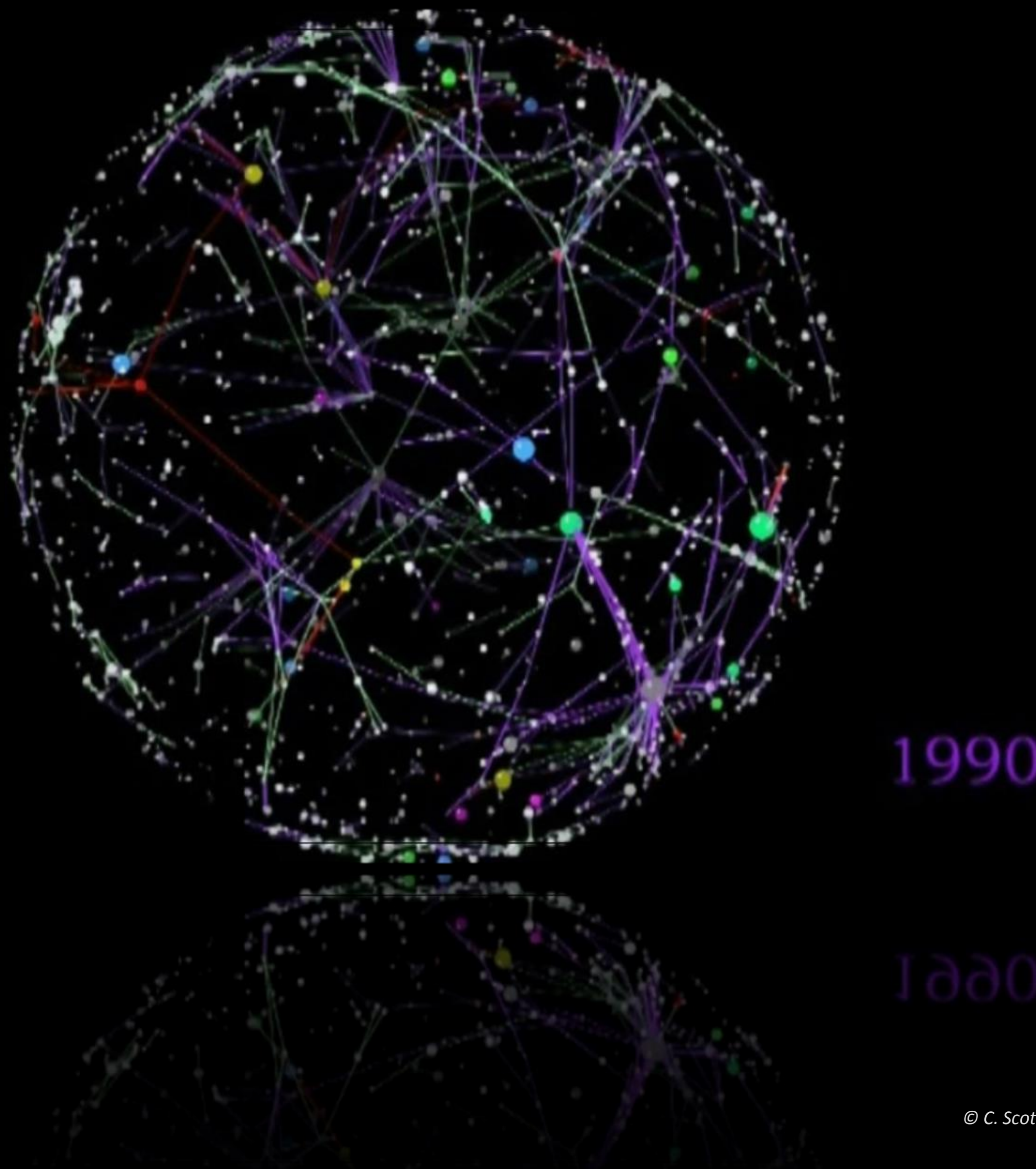
- 450+ data points on 85 million+ companies
- 2 billion+ government contract records over 5 years
- Over 450,000 US government registered companies
- Distinct company classifications
- Company financial data
- Number of employees by location
- Geospatial risk
- Geopolitical location
- Government representation

Data Correlation

- DUNS
- Company Name
- Location
- CAGE
- Relationship
- Geocode
- Political
- Risk
- User Defined
- And much more…

Visibility of the Complex and “Multi-functional” Supply Chain was achieved

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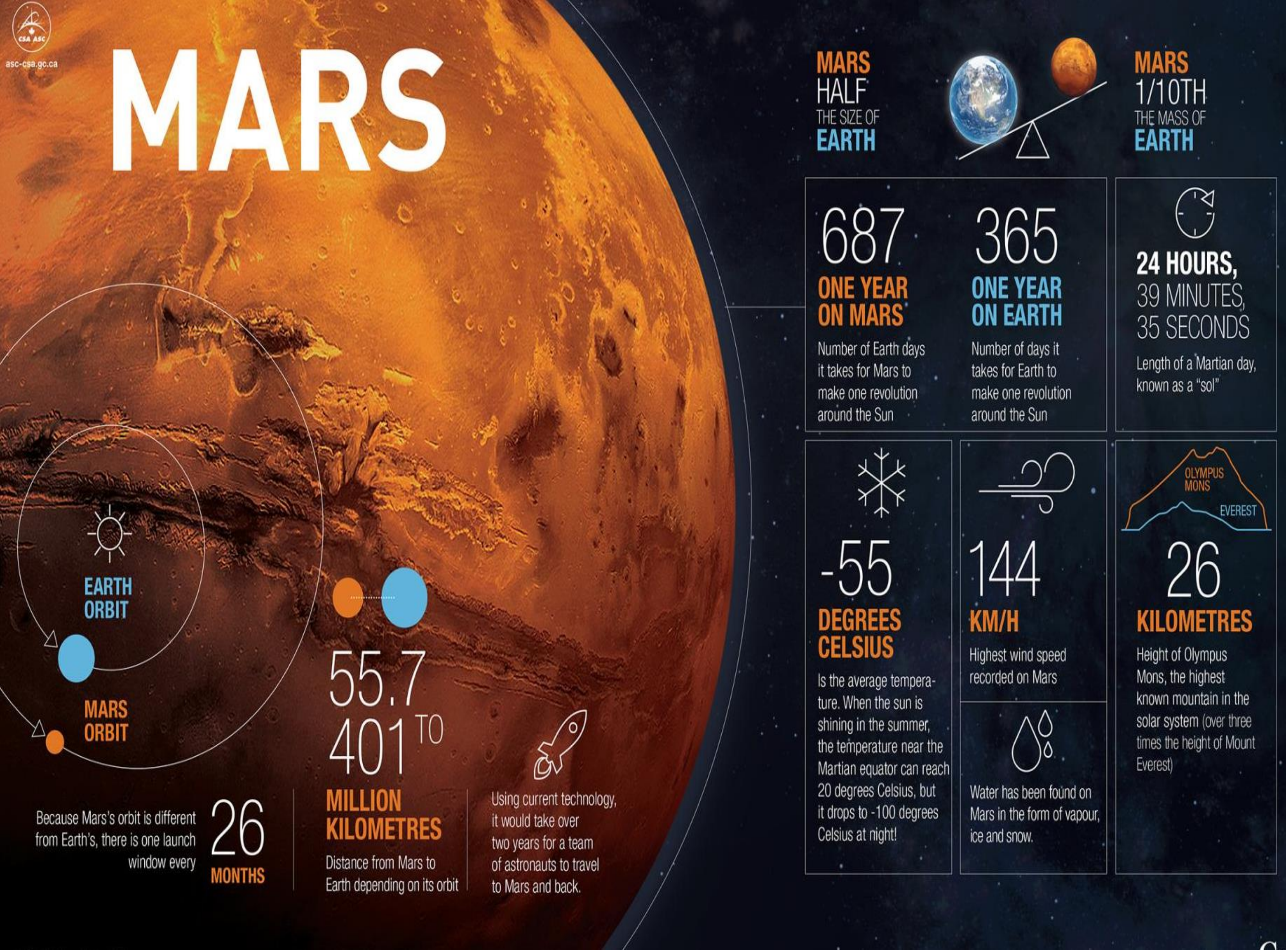
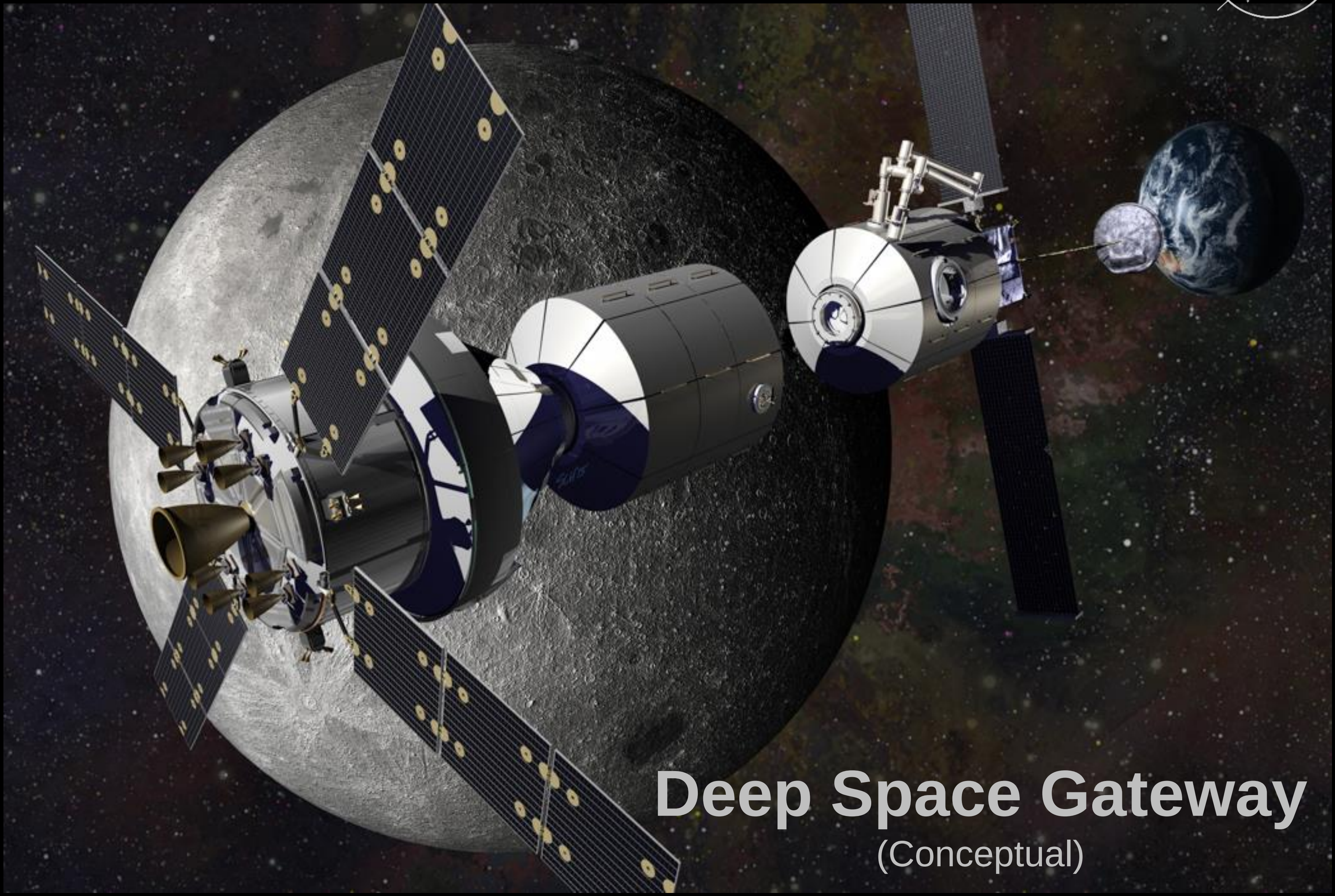

CSA ASC
asc-csa.gc.ca
MARS
MARS HALF THE SIZE OF EARTH
MARS 1/10TH THE MASS OF EARTH
687
ONE YEAR ON MARS
Number of Earth days it takes for Mars to make one revolution around the Sun
365
ONE YEAR ON EARTH
Number of days it takes for Earth to make one revolution around the Sun
24 HOURS, 39 MINUTES, 35 SECONDS
Length of a Martian day, known as a "sol"
-55
DEGREES CELSIUS
Is the average tempera-ture. When the sun is shining in the summer, the temperature near the Martian equator can reach 20 degrees Celsius, but it drops to -100 degrees Celsius at night!
144
KM/H
Highest wind speed recorded on Mars
Water has been found on Mars in the form of vapour, ice and snow.
OLYMPUS MONS
EVEREST
26
KILOMETRES
Height of Olympus Mons, the highest known mountain in the solar system (over three times the height of Mount Everest)
EARTH ORBIT
MARS ORBIT
Because Mars's orbit is different from Earth's, there is one launch window every
26
MONTHS
55.7 TO 401
MILLION KILOMETRES
Distance from Mars to Earth depending on its orbit
Using current technology, it would take over two years for a team of astronauts to travel to Mars and back.

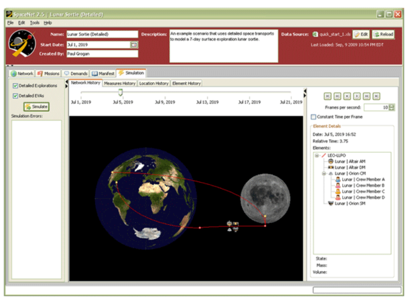
National Aeronautics and Space Administration

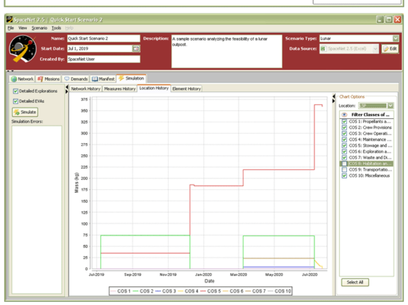


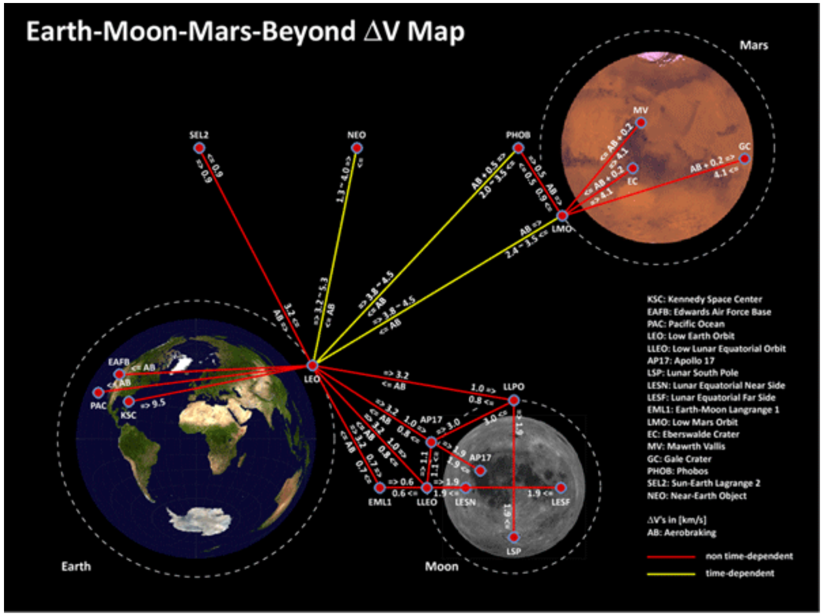
Campaign-Level Network Flow Modeling

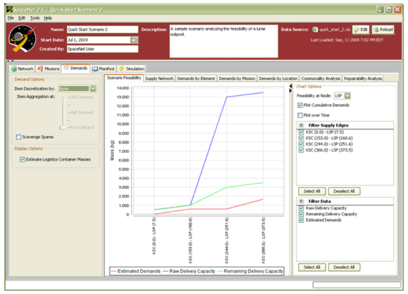
NASA/MIT developed Supply Chain Model “SpaceNet”

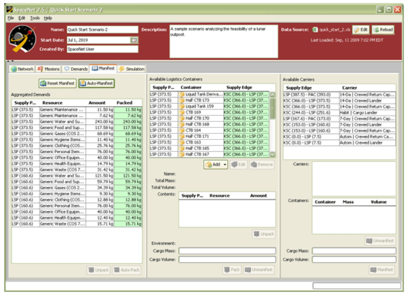
- Network modeling for sequencing multi-commodity network flows
- High-fidelity analysis of logistics nodal positioning and flight manifest
- Models the balance of constraints such as mass transformation e.g. propellant, water etc.
- To consider In-Space Manufacturing (ISM) infrastructure & Feedstock











What is In-Space Manufacturing (ISM)?

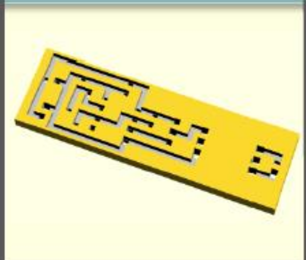
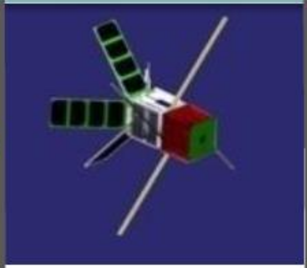
ISM is on-demand manufacturing using In-situ Resource Utilization (ISRU)

- Regolith-Based 3D Printing or with binder additives such as a Polymer feedstock
- Required for affordable, sustainable space operations beyond Low-Earth Orbit
- Years away from complementing supply chain but success is being realized;

A B

Bench-top scale freestanding structures created by Swamp Works 3D Regolith Construction process: A) BP-1 Hollow Cone Structure; (source:...

More than just 3D Printing….
In-space Manufacturing Technology Development Areas

RECYCLER	PRINTED ELECTRONICS	PRINTABLE SATELLITES	MULTI MATERIAL 3D PRINTING	EXTERNAL STRUCTURES & REPAIRS	ADDITIVE CONSTRUCTION
					 Contour Crafting Simulation Plan for Lunar Settlement Infrastructure Build-Up B. Khoshnevis, USC 
Recycling/Reclaiming 3D Printed Parts and/or packing materials into feedstock materials. This capability is crucial to sustainability in-space.	Leverage ground-based developments to enable in-space manufacturing of functional electronic components, sensors, and circuits. Image: *Courtesy of Dr. Jessica Koehne (NASA/ARC)*	The combination of 3D Print coupled with Printable Electronics enables on-orbit capability to produce "on demand" satellites.	Additively manufacturing metallic parts in space is a desirable capability for large structures, high strength requirement components (greater than nonmetallics or composites can offer), and repairs. NASA is evaluating various technologies for such applications. Image: *Manufacturing Establishment website*	Astronauts will perform repairs on tools, components, and structures in space using structured light scanning to create digital model of damage and AM technologies such as 3D Print and metallic manufacturing technologies (e.g. E-beam welding, ultrasonic welding, EBF3) to perform the repair. Image: *NASA*	Illustration of a lunar habitat, constructed using the Moon's soil and a 3D printer. Credit: Foster+Partners

Summary

The End Game of iSCM

- Quality of Data
- Data Architecture and Ontology
- Security and High Performance Computing
  - Micro-simulation tools that model complex interdependencies between industrial base and critical infrastructure sectors
- Vertical Chain Integration

Methodology to obtain the Value Proposition

- SCM Resilience modeling
  - 3D Printing Technology maturity and adoption
- SCM “War Game” distribution visualization
- Model risk: natural disasters, transportation, economic, sole sources