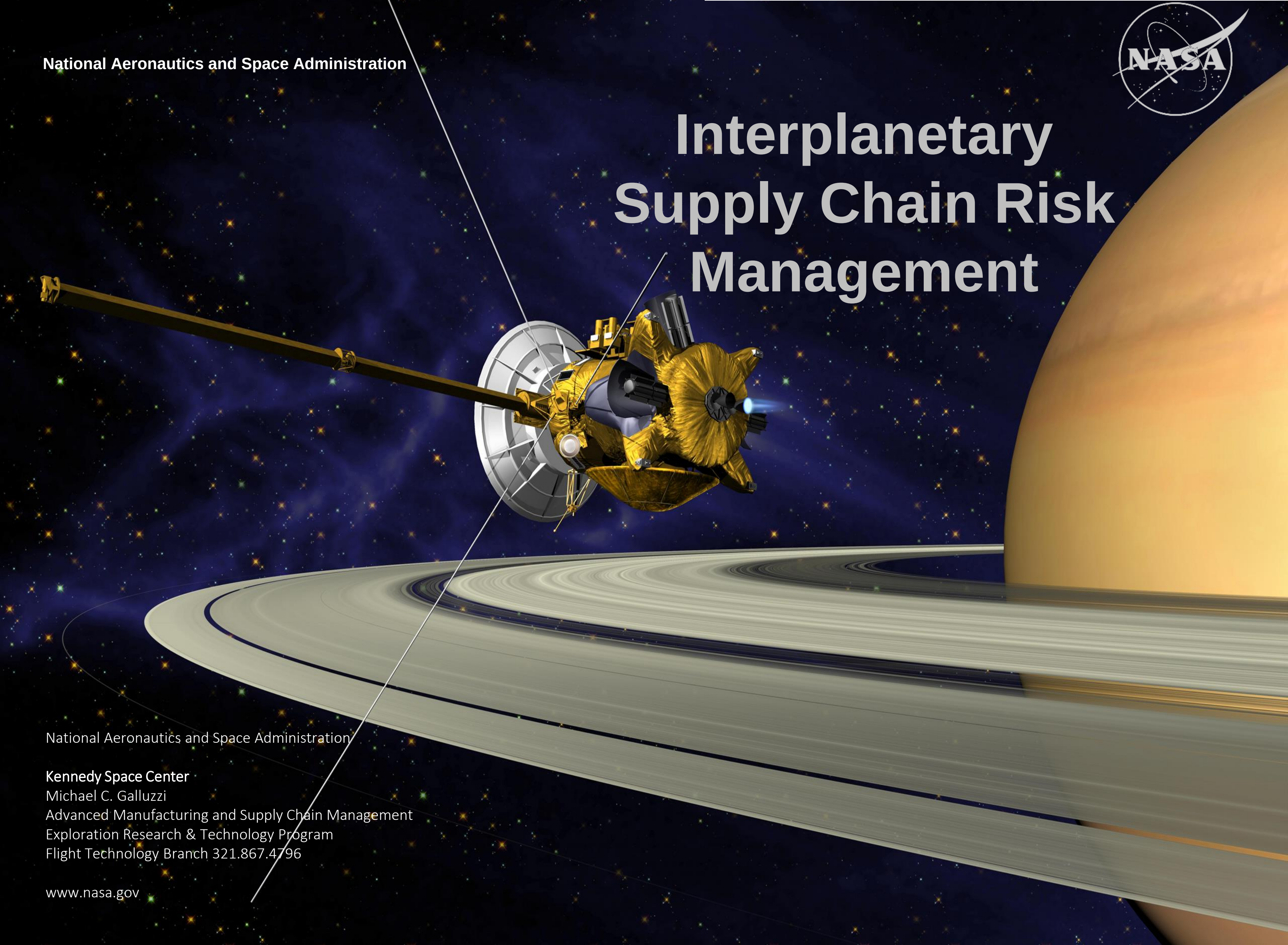
National Aeronautics and Space Administration



Interplanetary Supply Chain Risk Management

National Aeronautics and Space Administration

Kennedy Space Center
Michael C. Galluzzi
Advanced Manufacturing and Supply Chain Management
Exploration Research & Technology Program
Flight Technology Branch 321.867.4796

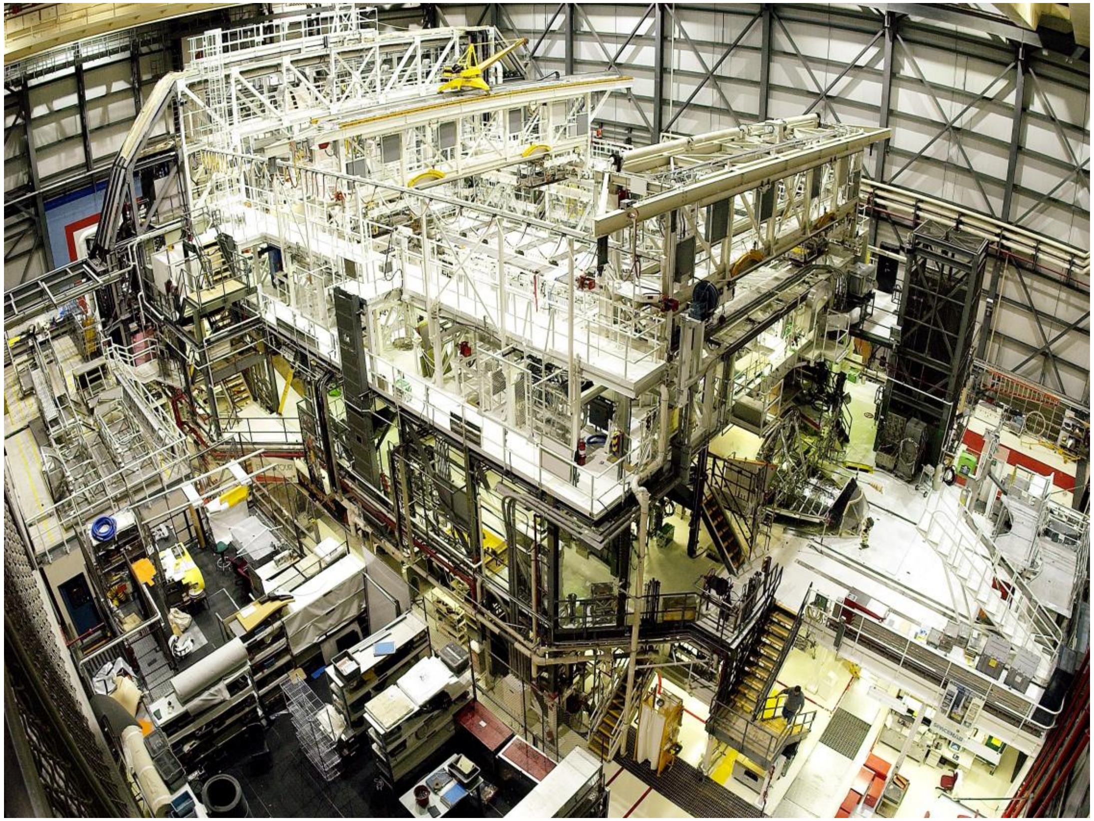
www.nasa.gov

Agenda

- **NASA's interplanetary Supply Chain (iSCM) for Exploration**
  - Emphasis on Kennedy Space Center ground processing operations
  - Economic modeling to assess ISM 3D printing adaption and supply chain risk
  - Network modeling for sequencing interplanetary supply chain and logistics nodal positioning
  - In Space Manufacturing (ISM) Initiative
  - iSCM Value Proposition
- **Summary**

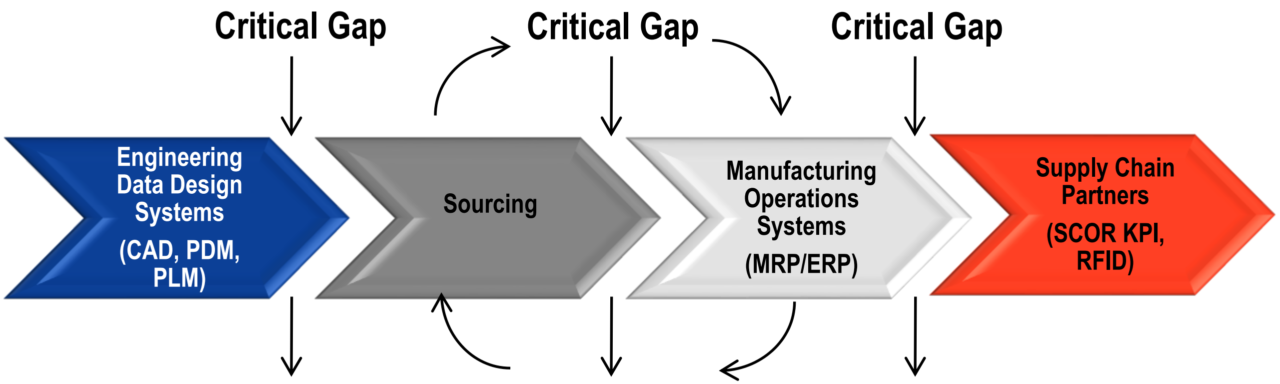
Space Shuttle Program (SSP) Orbiter Processing Concept Design Circa.1972

Actual Orbiter Processing Operations



SSP Operational Gaps

Gaps with Design, Sourcing & Supply Chain

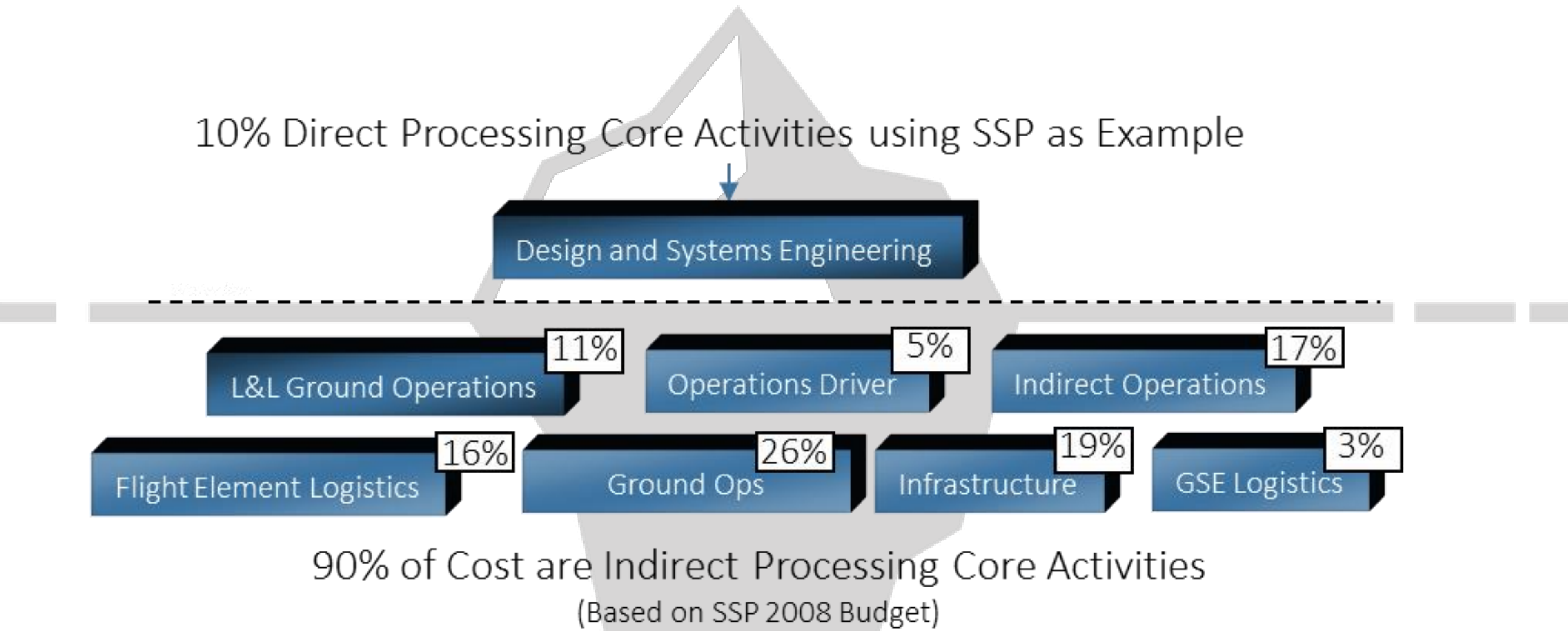


Issues:
- Key data "locked" in engineering
- Ineffective Communication
- Increased Timeliness
- Lack of Shared Knowledge
- Increased Margin on Initial Quotes
- Lack of IP Protection
- Lack of classification for export
- Supplier involvement

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

Issues:
- 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

SSP Ground Operations Cost Breakdown



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


FOR
SALE

NASA/Department of Commerce Survey

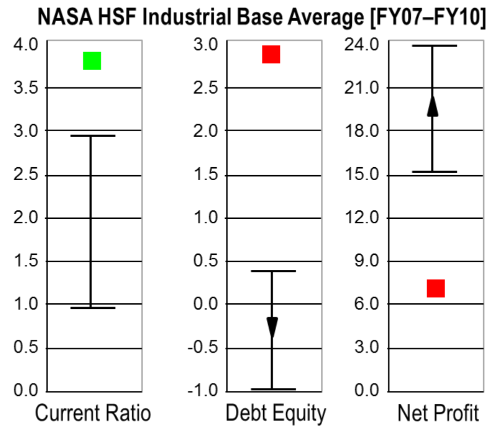
- 30% of suppliers NASA dependent
- 46% had no interest to support Commercial Human Space Flight
- 14% had no interest to support future NASA programs
- 19% of suppliers high risk of insolvency
- Manufacturing capacity utilization <50%
- NASA product Market Cap decreased
- 53% of suppliers support DoD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

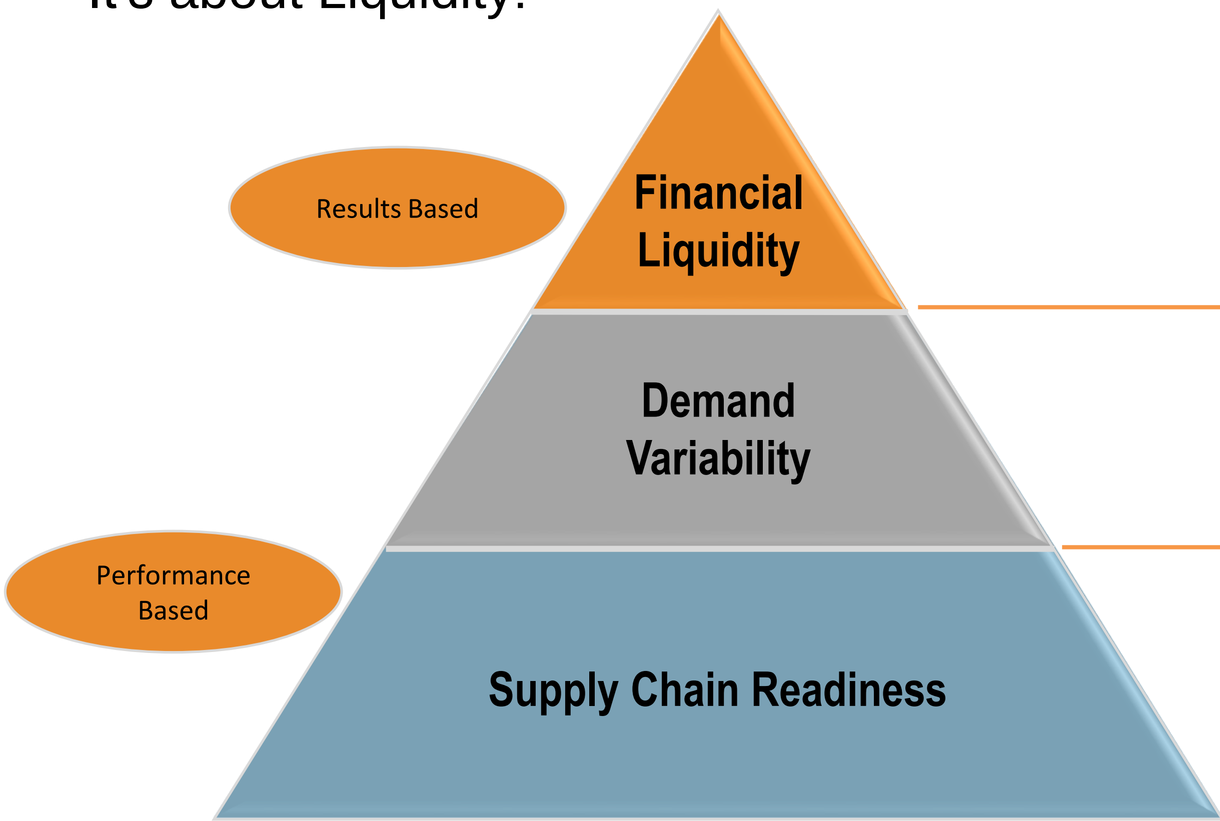
"For want of a nail a kingdom was lost" *c. 1230 Freidank Bescheidenheit*

- **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



NASA Supply Chain Economic Resiliency Model

Product Demand Forecasting of Macroeconomic Influences
- It's about Liquidity!



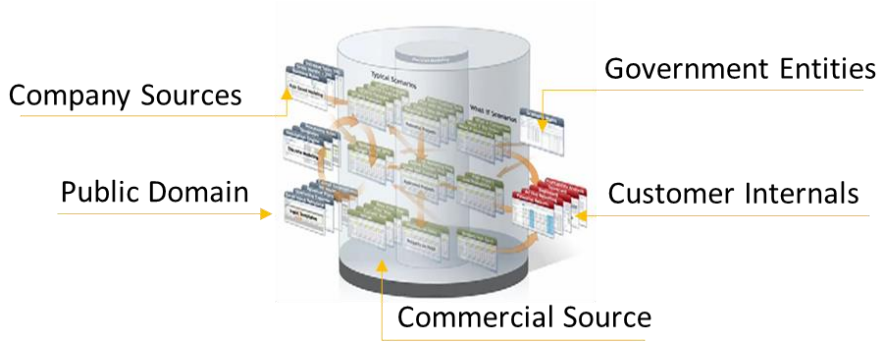
- Current Ratio
- Debt Ratio
- Net Profit Margin
- Altman Z Score
- Customer Diversity

- Dependency on Specific Customer
- Purchase Order Time Gap
- System Utilization
- Criticality/Sole Source
- Inventory Turnover

- Vertical Chain Visibility "Tier Mapping"
- Supplier Commonality/Interoperability
- Manufacturing Readiness Levels
- Technology Readiness Level
- SCOR® Key Performance Indicators
- Quality Considerations
- On-Time Delivery
- Number of Competitors
- Manufacturing Capacity
- Functional Capability

primesupplier
ECONOMIC RESILIENCE INDEX MODEL

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

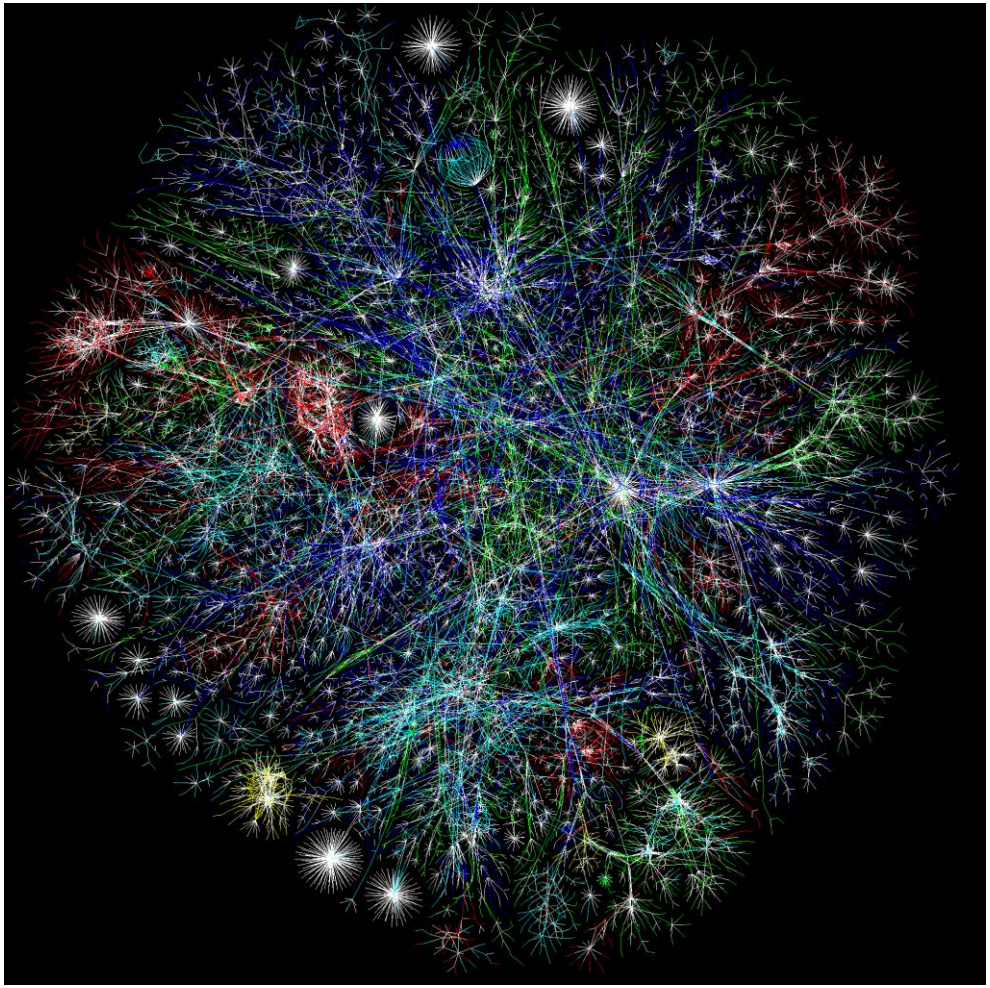
Data Correlation

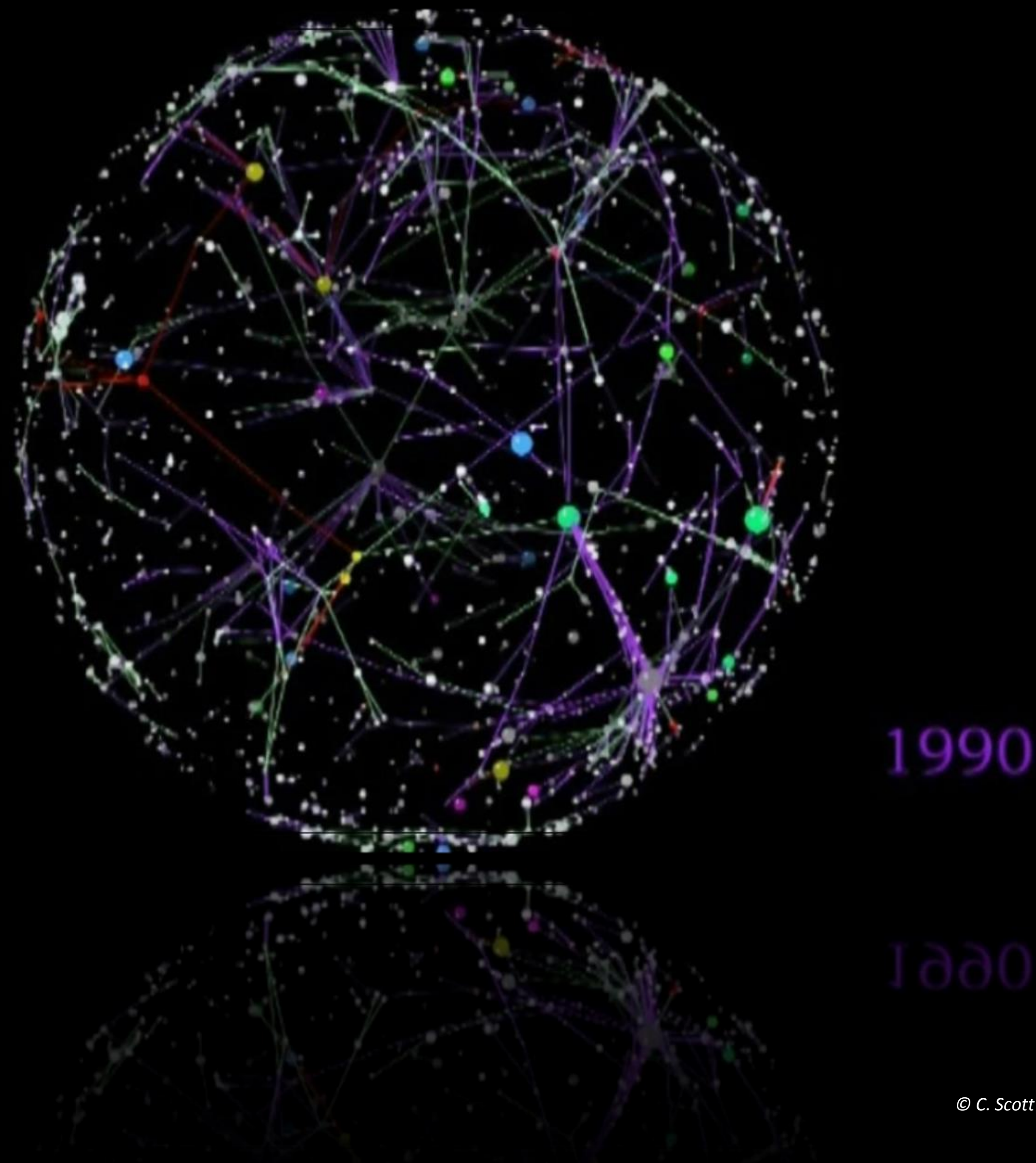
- DUNS
- Company Name
- Location
- CAGE
- Relationship
- Geocode
- Political
- Risk
- User Defined
- And much more…

Supply Chain Economic Resiliency Model

Insert screen shots here

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

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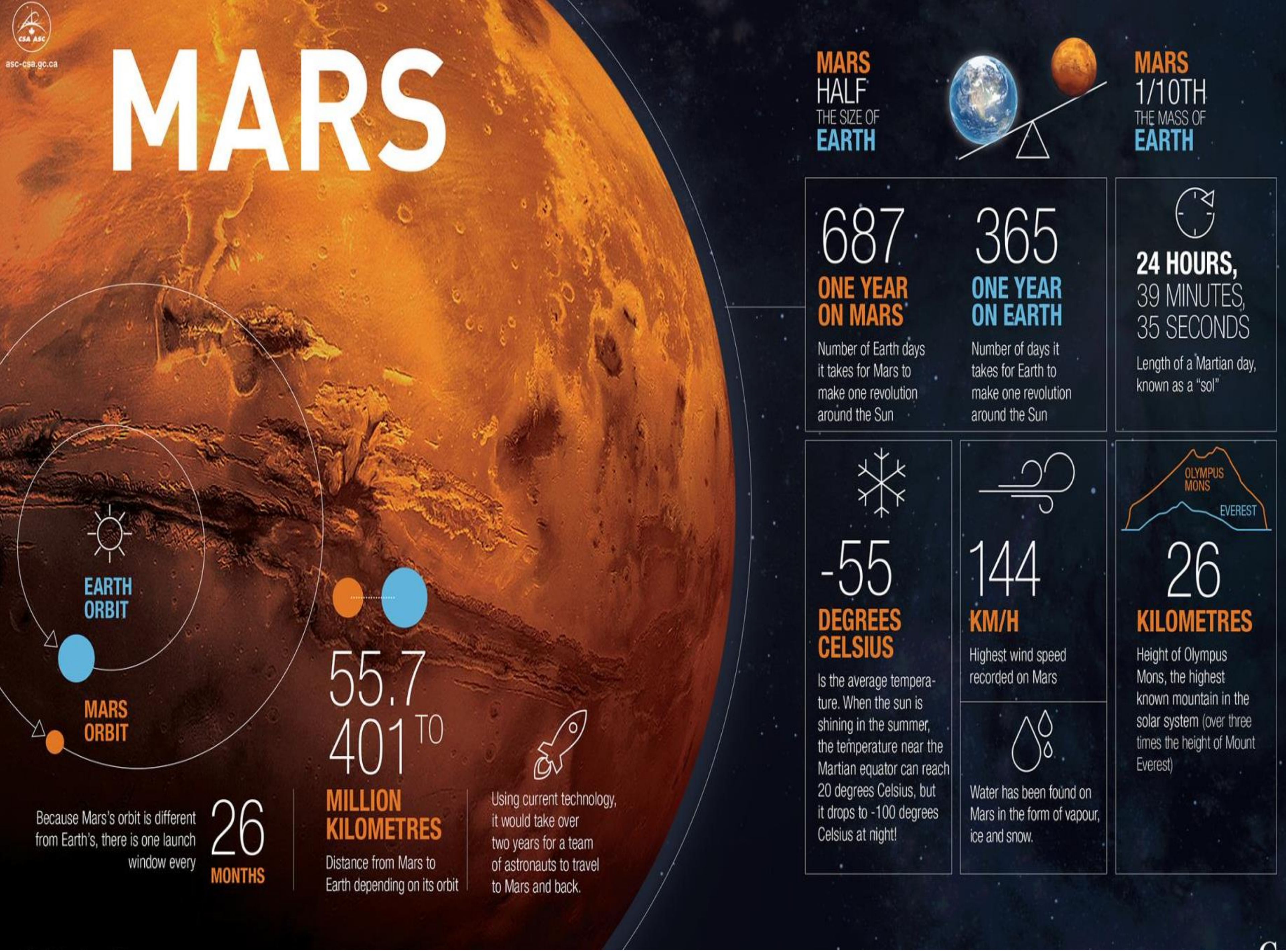
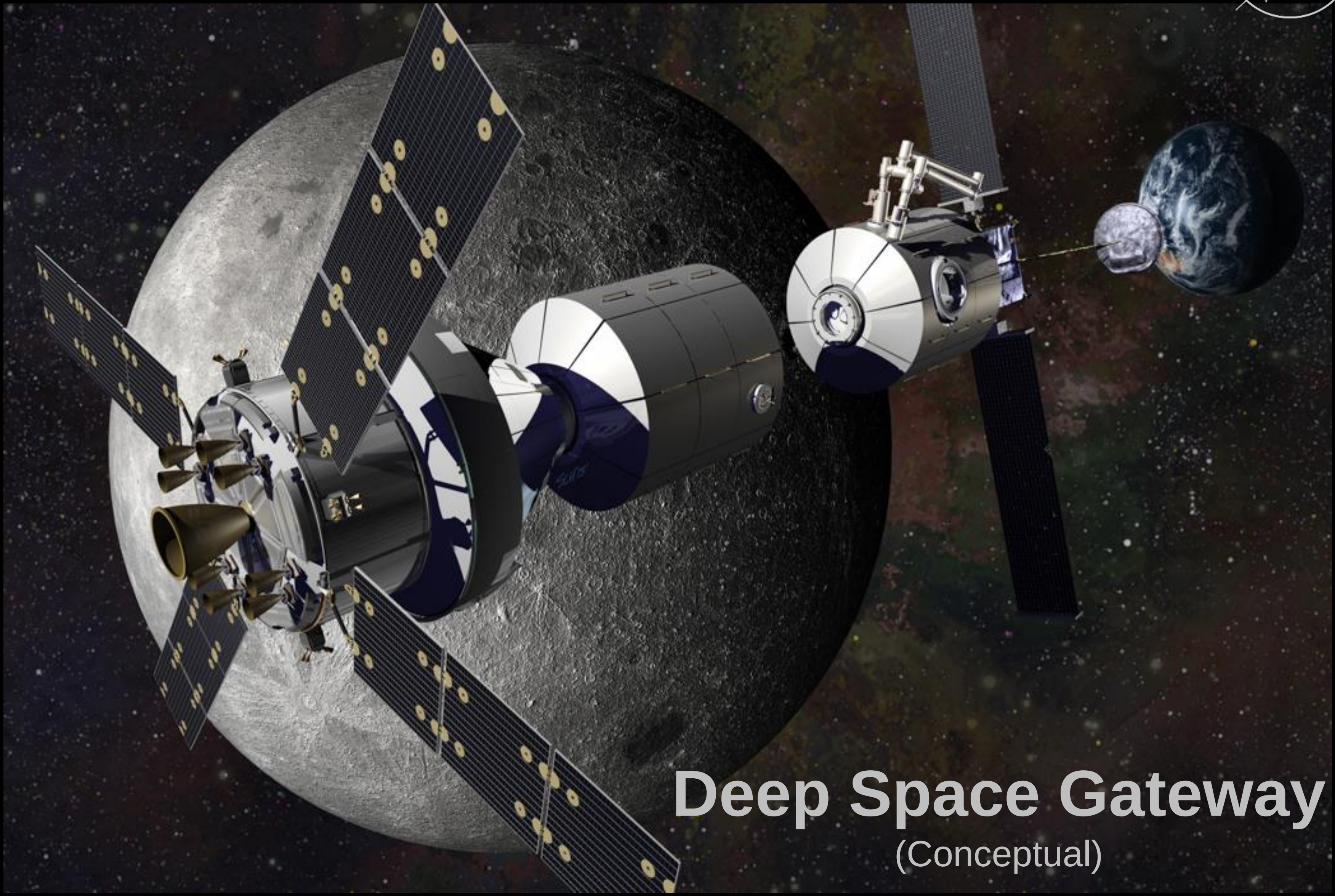
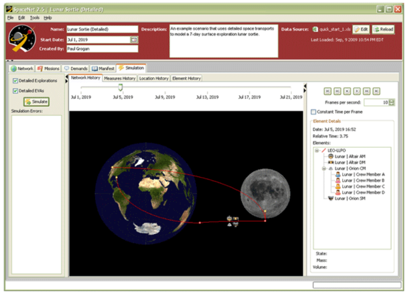

CSA ASC
asc-csa.gc.ca
MARS
MARS HALF THE SIZE OF EARTH
MARS 1/10TH THE MASS OF EARTH
687
ONE YEAR ON MARS
Number of Earth days it takes for Mars to make one revolution around the Sun
365
ONE YEAR ON EARTH
Number of days it takes for Earth to make one revolution around the Sun
24 HOURS, 39 MINUTES, 35 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.

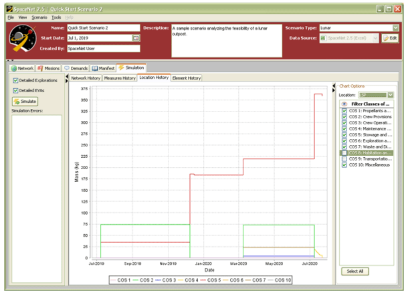

Deep Space Gateway
(Conceptual)

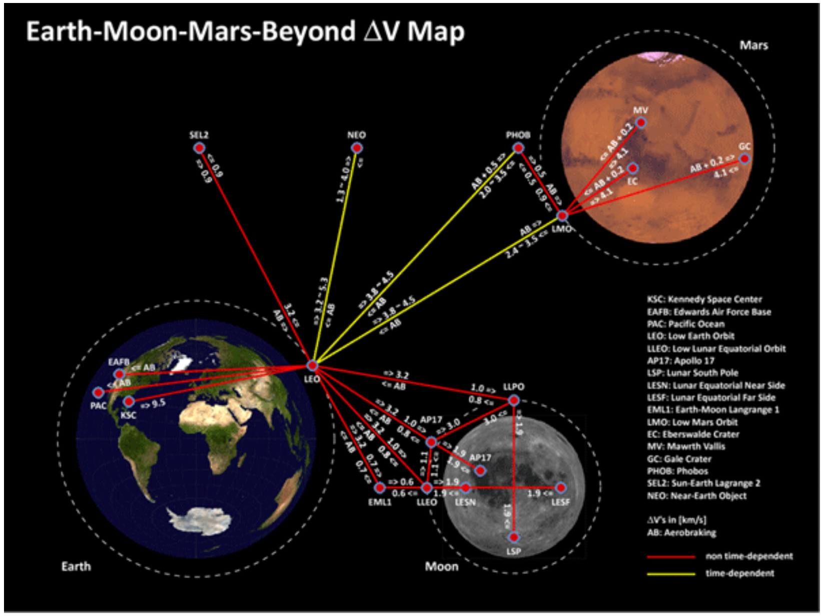
Campaign-Level Network Flow Modeling

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
- To consider In-Space Manufacturing (ISM) infrastructure & Feedstock







$$\mathcal{J} = \sum_{(i,j,e)\in\mathcal{A}} \mathbf{c}_{ije}^{+\,T} \mathbf{x}_{ije}^{+}$$

$$\sum_{j:(i,j,e)\in\mathcal{A}} \mathbf{x}_{ije}^{+} - \sum_{j:(j,i,e)\in\mathcal{A}} \mathbf{x}_{jie}^{-} \le \mathbf{b}_i \;\; \forall\, i\in\mathcal{N}$$

$$\mathbf{x}_{ije}^{-} = B_{ije}\mathbf{x}_{ije}^{+} \;\; \forall\, (i, j, e)\in\mathcal{A}$$

$$C_{ije}^{+}\mathbf{x}_{ije}^{+} \le \mathbf{p}_{ije}^{+} \;\; \forall\, (i, j, e)\in\mathcal{A}$$

$$\mathbf{x}_{ije}^{+} \ge 0_{k\times 1} \;\; \forall\, (i, j, e)\in\mathcal{A}$$

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:...

Value Proposition from iSCM and ISM

Value Source	SSP FY2004 BASELINE Cost[1]	Improvement % Range[2]	Cost Improvement Assumed	
Reduction in material handling Labor Cost due to Less Inventory	175 M (Hardware)	10% (Reduction in parts)	17.5 M	Less parts need reduced material/part Inventory handling costs
Finished Goods Inventory Reduction	229.3 M	15-33%	55.0 M	Change in manufacturing model; In-space demand supply visibility
Reduced Cost of Obsolescence	74.2 M [3]	30-50%	29.6 M	On-demand in-space manufacturing reducing or eliminating Earth-based sources of supply.
Totals	**$478.1 M**	**20 - 25%**	**$102.1 M**	**Reduced Logistics Footprint**

Note 1: Baseline has been set based on NASA SSP Flight Element Logistics inputs and Federal Procurement Database (FPDS). Details available in NASA LLEGO Model
Note 2: Benefit ranges have been estimated based on SAP customer and industry benchmarks
Note 3: SSP 2004 Transition & Retirement SLEP POP SCM Risk Budget. Critical Vendor Viability, DMSMS, Aging Hardware

Estimated Annual cost savings

$100M - $135M

Summary

The End Game of iSCM

- Integrate with reliable and quality data sources
- Develop common data ontology
- Provide secure cloud-base & mobile device application for real-time data streaming capable of supporting:
  - Micro-simulation tools that model complex interdependencies between economic and critical infrastructure sectors
- Require lower-tier suppliers provide data and integrate with platform

Methodology to obtain the Value Proposition

- Constantly run economic resilience simulations
- Analysis of product sources and product quality (liquidity:quality)
- Model risk: natural disasters, transportation, economic, sole sources
- Assess advanced manufacturing technology readiness e.g. 3D Printing
- Ensure rapid response and mitigation to supply chain disruption