Integrated Modeling Capabilities JPL-LaRC Briefing

Kim Simpson

Kevin Bonanne

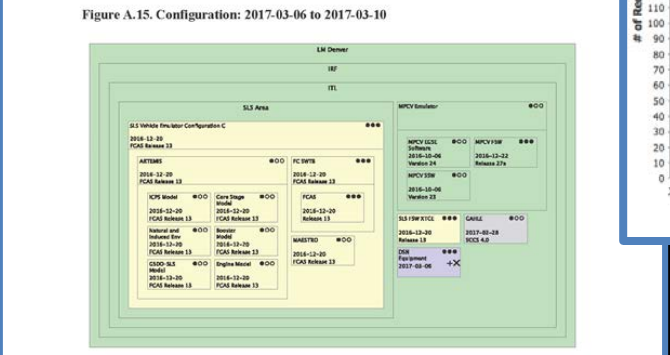
Jim Grimes

Marc Sarrel

Sheldon Shen

Jet Propulsion Laboratory, California Institute of Technology.

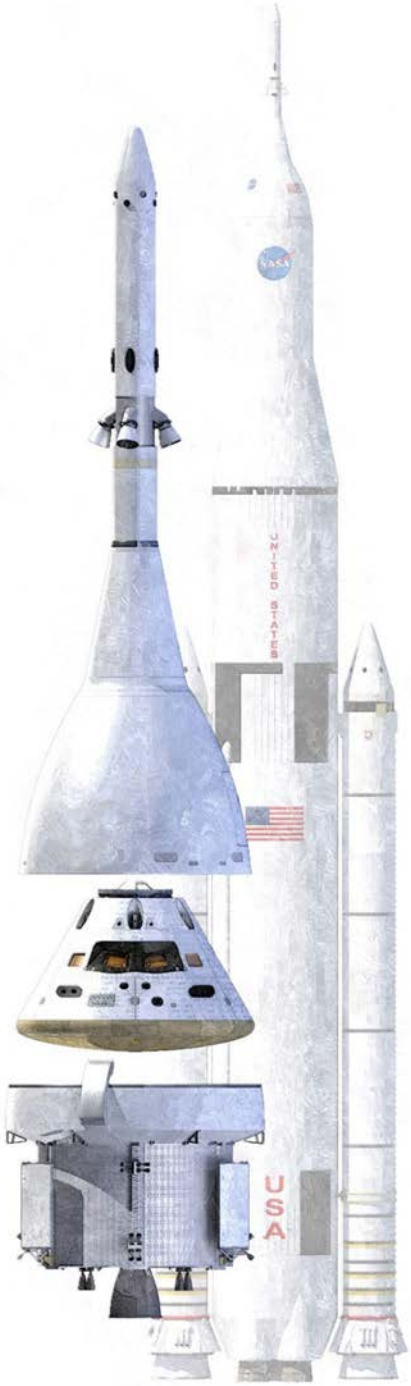
October 12th, 2016



A.4. Test Activity: Orion-NEN&SN Pre-Compat and Hardline-Only Test to MCC

Table A.4. Orion-NEN&SN Pre-Compat and Hardline-Only Test to MCC Description

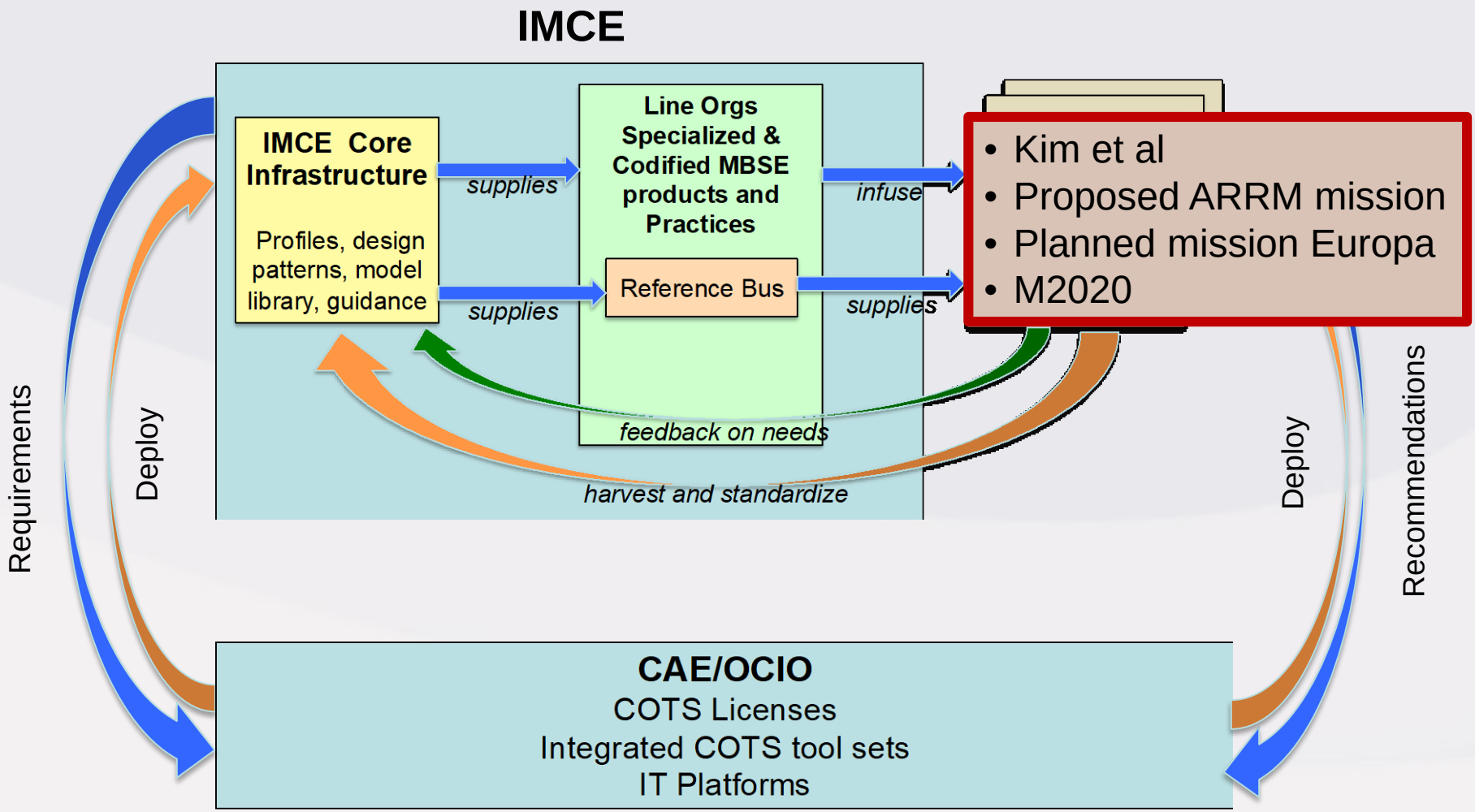
Start	End	ISP	Source
2017-04-10	2017-04-14	SpaceComm_04	LM-ORN-0430 Test Windows rev5 - chart 5
Tested In			
LM Denver . IRF . ITL			
Might Verify			



Endorsement Disclaimer: Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement by the United States Government or the Jet Propulsion Laboratory, California Institute of Technology.

© 2016 California Institute of Technology. Government sponsorship acknowledged.

JPL's MBSE
IMCE/CAE/Project Relationships



Purpose

- Developed a nimble, re-usable <u>architecture</u>, <u>systems engineering</u> and <u>analysis</u> capability

  …5 year investment while performing complex System of Systems (SoS) engineering of human space flight missions

- Proven systems engineering capability solving real problems

  …systems architecture, engineering and analysis

- Extensible to variety of programs/projects

  …SE methodologies applicable to any mission, human or robotic

Systems Engineering TDT
Organizational Construct

SE TDT
Lead: Jon Holladay, MSFC / GSFC
Deputy TDT: Vicki Regenie[1], AFRC
Deputy CLT: Todd MacLeod, MSFC
SELDP: Roger Forsgren[5], HQ/APPEL

SE Center Reps for CLT
Center Reps for Capability Leadership Team
Evaluate and Prioritize NASA SE Strategy

NASA SE Advancement
Dan Yuchnovicz[1], LaRC / Britt Walters[6], JSC
Maintain SE TDT Tactical Implementation
Forum for discussion of SE advancement opportunities

SE Capability Focus Efforts FY16
- **MBSE Pathfinder**; Karen Weiland[2, 6], GRC
- **NASA SE Consortium;** Dr. Mike Watson[5], MSFC
- **Complex Systems/IAWG**; Dr. Anna-Maria McGowan[5], LARC
- **SE Handbook**; Steven Hirshorn[5], HQ / Jana Killebrew[2], ARC

Primarily NESC assessment focused, but also provide expertise in evaluation and implementation of NASA SE Advancement planning

Cross-cutting discipline representative

- GN&C TDT — N. Dennehy[3]
- Software TDT — M. Aguilar[3]
- Human Factors TDT — C. Dischinger[3]
- S&MA (NASA Safety Center) — Mike Blythe[4] / Don Hull[1]

Subject Matter Experts

Validation & Verification Team
Tim Brady[1], JSC / Kim Simpson, JPL

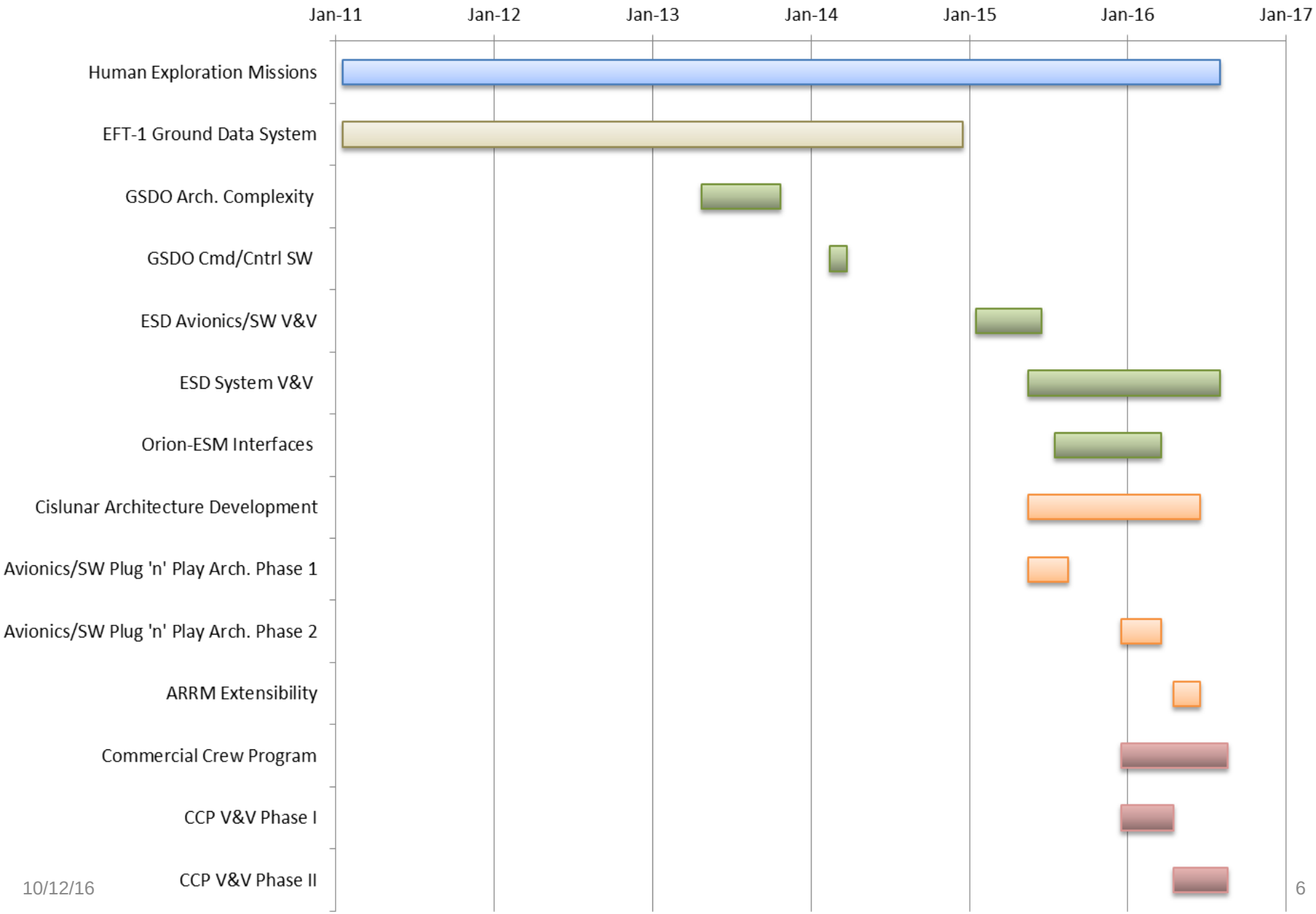
Systems Analysis Team
Tim Barth[1], KSC

Engineering Statistics Team
Ken Johnson[1], MSFC

Data Mining & Trending Team
Bob Beil[1], KSC

- Orion to European Service Module (ESM) I/F Assessment
- Exploration Systems Division (ESD) V&V Assessment
- Commercial Crew Program (CCP) V&V Assessment

Schedule of Activities - Past and Present



Exploration Flight Test 1 (EFT-1), Ground Data System

Marc Sarrel

SCOPE/KEY ACCOMPLISHMENTS

- **Integrated and cross-checked the separate EFT-1 ground system designs**
  - GS designed in stovepipes
- **Certification of Flight Readiness for Ground System**
- **Ground System Build Definition and Planning**
- **Ground System V&V tracking**

- **Six flight phases**
- **Six test venues**
- **Six major geographical locations**
- **Two recovery ship tests**
- **Fourteen GS configurations**
- **Two hundred and thirty requirements**
- **Thirty types of data**

CAPABILITIES ENHANCED/ADAPTED

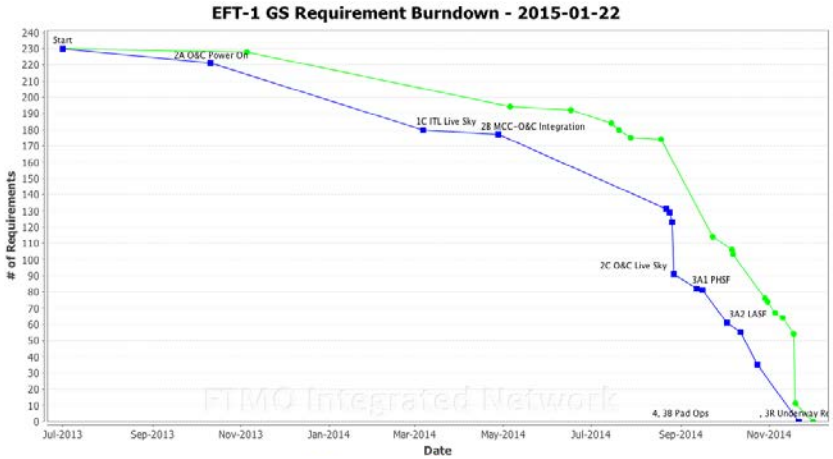
- **First adoption and large-scale use of Tom Sawyer to automatically produce diagrams**
- **Automatic calculation of data paths over ground network**
- **Locations, components, connections and organizations**

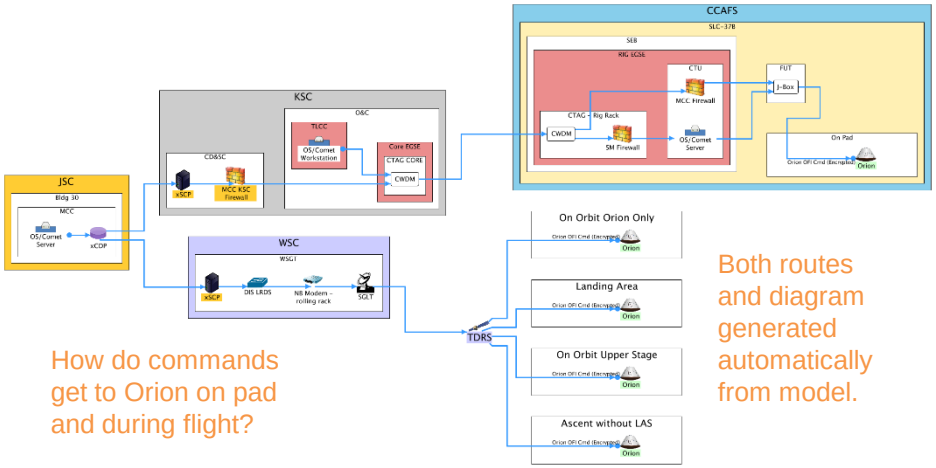
DELIVERABLES

- **Four delivered versions of Ground System Architecture Description Document (Jun 2013, Apr 2014, Sep 2014, Jan 2015)**
- **Weekly production of V&V Report with burndown**
- **Sign-off for GS CoFR**

SCHEDULE

- **February 2011 – Start of task**
- **November 2014 – Signed off GS portion of CoFR**
- **December 2014 – Successful flight of EFT-1**
- **January 2015 – Close-out**





How do commands get to Orion on pad and during flight?

Both routes and diagram generated automatically from model.

Exploration System Development Integrated Avionics and Software Verification and Validation Plan NESC Assessment (EAVV)

Marc Sarrel

SCOPE/KEY ACCOMPLISHMENTS

- **Assess risk of having set of distributed software and avionics test beds, rather than single integrated facility with highest fidelity simulators**
  - Assumption: Fidelity of simulators improves over time with subsequent deliveries
- **Identify configurations of test facilities that will support each test activity per delivery and test schedules**
- **Test activities linked to requirements they verify**
- **Nineteen verification activities**
- **Two hundred twenty-two deliveries**
- **Forty-seven resulting configurations**
- **Two hundred twenty requirements**

CAPABILITIES ENHANCED/ADAPTED

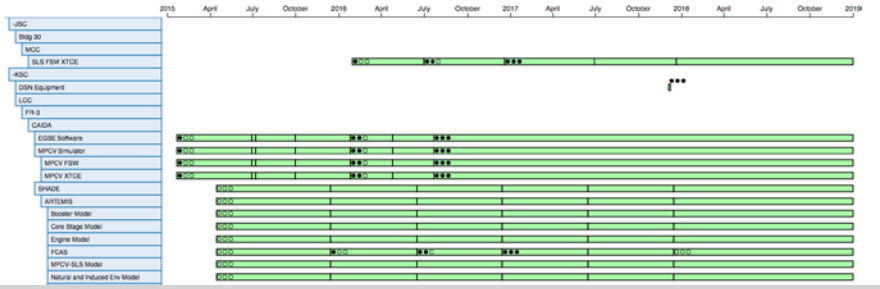
- **Addition of timeline capability to represent delivery and test schedules**
  - delivery dates, version id, fidelity level
- **Highlight changes to configuration with each delivery**
- **Re-used capabilities from EFT-1 for capturing location, components and organizations**

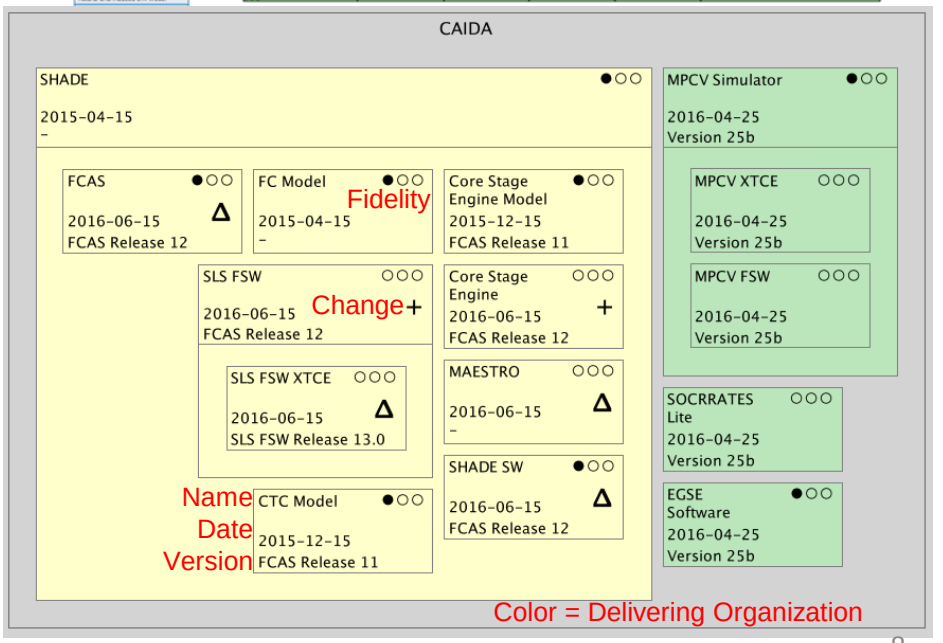
DELIVERABLES

- **Avionics & Software test configurations, including assessment of fidelity (full, partial, limited)**

SCHEDULE

- **Task start: Feb 2015**
- **Task end: Jul 2015**





Orion-ESM Interfaces (Esmeralda)

Kevin Bonanne

SCOPE/KEY ACCOMPLISHMENTS

- Analyzed Orion-European Service Module Interfaces using MBSE
- Evaluated technical gaps and inconsistencies difficult to uncover via the document-based review process
- Included analysis of interface verification methods

CAPABILITIES ENHANCED/ADAPTED

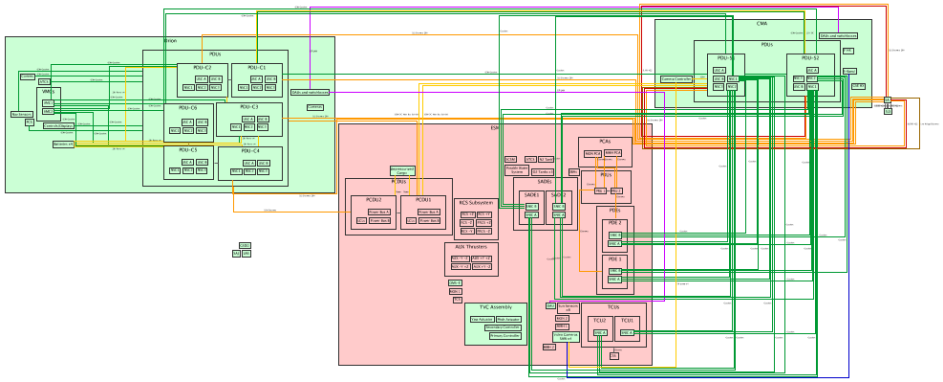
- Leveraged patterns from EFT-1 for components, interfaces, and organizations
- Added capability to have various network types along with filtering and color coding in views
- Developed automatic requirement and V&V filtered views

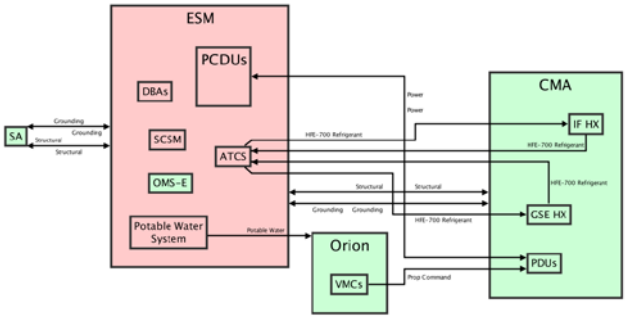
DELIVERABLES

- Unknowns, gaps, and inconsistencies in interfaces
- Direct interaction with stakeholders to resolve issues
- Views of interfaces organized by requirement document and verification method and scope

SCHEDULE

- Aug 2015 – Task approval
- Sept 2015 – Face-to-face at JSC
- Dec 2015 – Final briefing to key program stakeholders
- April 2016 – Task completed





Proving Ground Plug-n-Play Architecture (Penelope)

Kevin Bonanne/Jim Grimes

SCOPE/KEY ACCOMPLISHMENTS

- Analyze Proving Ground Habitation System (PGHS) components/functions and identify where standards may be applied to create a plug-and-play architecture
- Established methodology for tracking and reporting build-up of components and functions on orbit
- Prototyped a Mass Rollup (MEL) capability, based on our model patterns and ANSI/AIAA S-120A

CAPABILITIES ENHANCED/ADAPTED

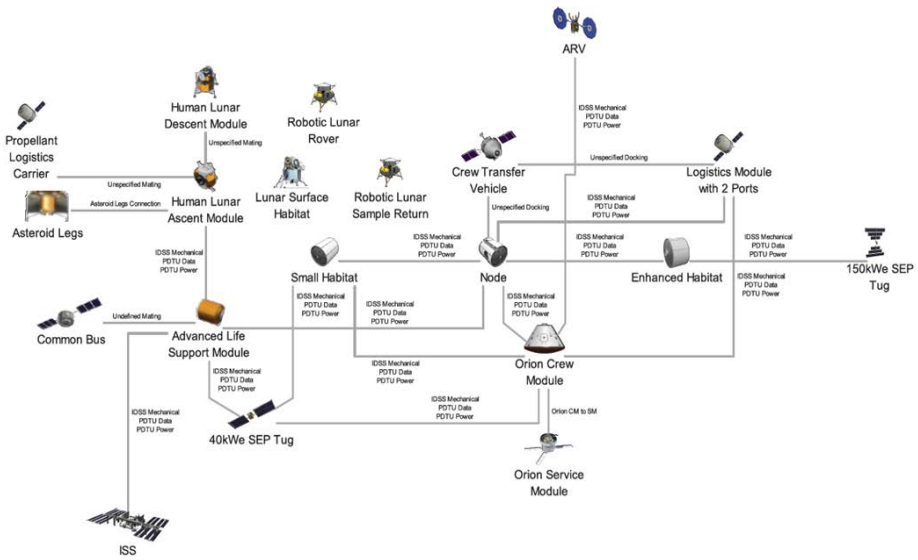
- Leveraged patterns from EFT-1 for components and interfaces
- Expanded upon timeline pattern from EAVV
- Developed system views to show modular buildup over time
- Created pattern for trade study analysis

DELIVERABLES

- Architectural views and standardized reports
- Structure, Metrics and Figures of Merits for plug-and-play avionics trades

SCHEDULE

- June 2015 – Initiation of task
- Mar 2016 – Trade study plan presented to Skip Hatfield
- Apr 2016 – Avionics plug 'n' play trade analysis
- May 2016 – Initiated ARRM Extensibility study



MBSE with Programmatic Cost (Planning for Humans2Mars)

Jim Grimes

SCOPE/KEY ACCOMPLISHMENTS

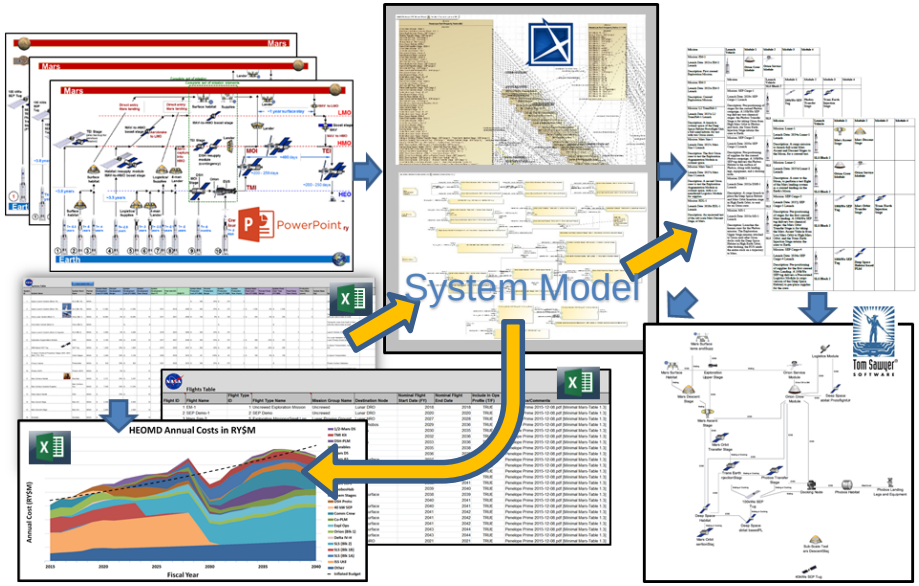
- **Developed quick-turnaround tool for affordability assessment of multiple multi-decade scenarios**
- **Created a consistent, repeatable, and transparent method for generating affordability assessments**
  - Lunar Proving Ground (Scenarios 2C and 4)
  - Minimal Mars (Phobos in 2033 – Mars in 2039)
  - SLS-Based Proving Ground + Mars (Phobos in 2035 – Mars in 2041)
  - SLS-Based Proving Ground + Mars (Phobos in 2033 – Mars in 2039)
  - SLS-Based Proving Ground + Mars (Phobos in 2028 – Mars in 2039)

CAPABILITIES ENHANCED/ADAPTED

- **Leveraged:**
  - Aerospace's affordability assessment spreadsheet for "A Minimal Architecture for Human Journeys to Mars."
- **Re-designed/Developed:**
  - Flexible and transparent user interface for scenario costing.
  - Added Systems, Flights, and Flight Types data tables
  - Integrated with H/RMSO MBSE architecture suite of tools
- **In Development:**
  - Integrating cost data into System Model
  - Adding cost overview to document generation
  - Adding turn-key sand-chart generation from System Model

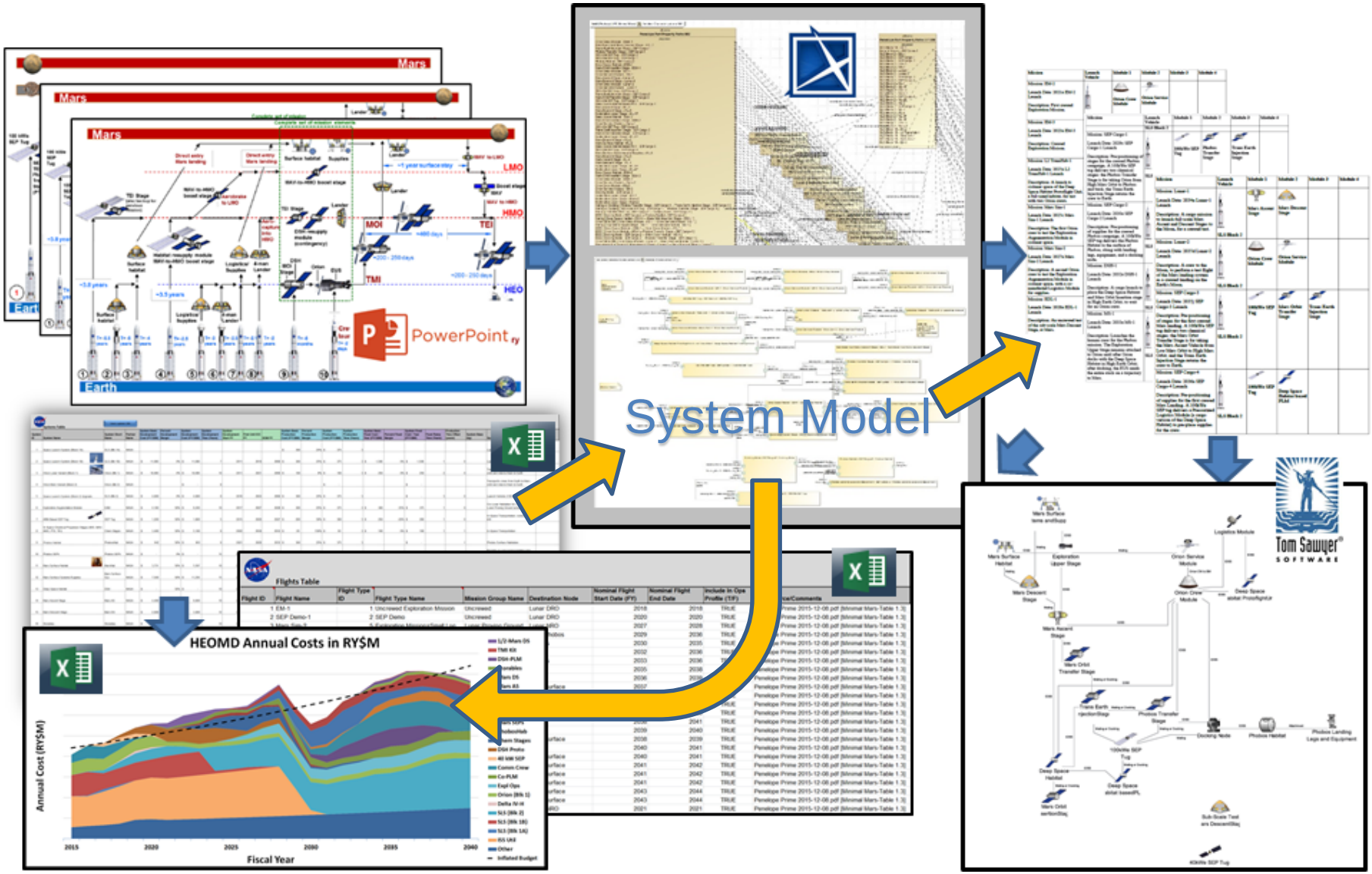
DELIVERABLES

- **Document View (upper right)**
- **Stick Figure View (lower right)**
- **Sand Chart View (lower left)**
- **Dance Card View (not shown)**



MBSE with Programmatic Cost (Planning for Humans2Mars)

Jim Grimes



Commercial Crew Verification & Validation

Sheldon Shen

SCOPE/KEY ACCOMPLISHMENTS

- Perform analyses of V&V adequacy and develop reports that coincide with Boeing's and SpaceX's Design Certification Reviews

CAPABILITIES ENHANCED/ADAPTED

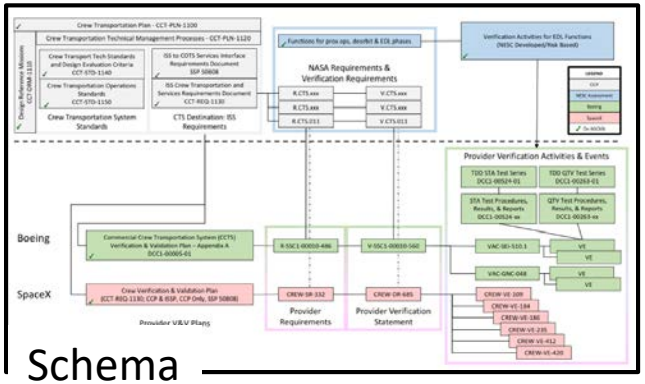
- Leveraged:
  - Tom Sawyer Perspectives
  - Profiles and scripts
- Developed:
  - Automated tools for converting V&V plans to MBSE models.
  - MBSE models for systematically evaluating V&V plans.
  - V&V visualization capabilities

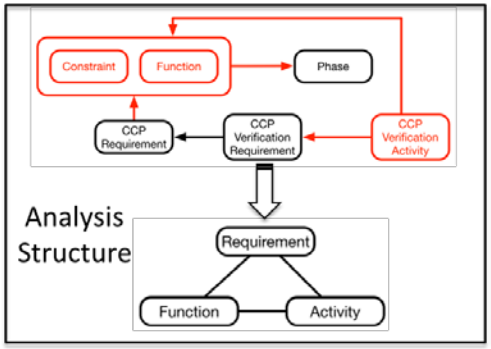
DELIVERABLES

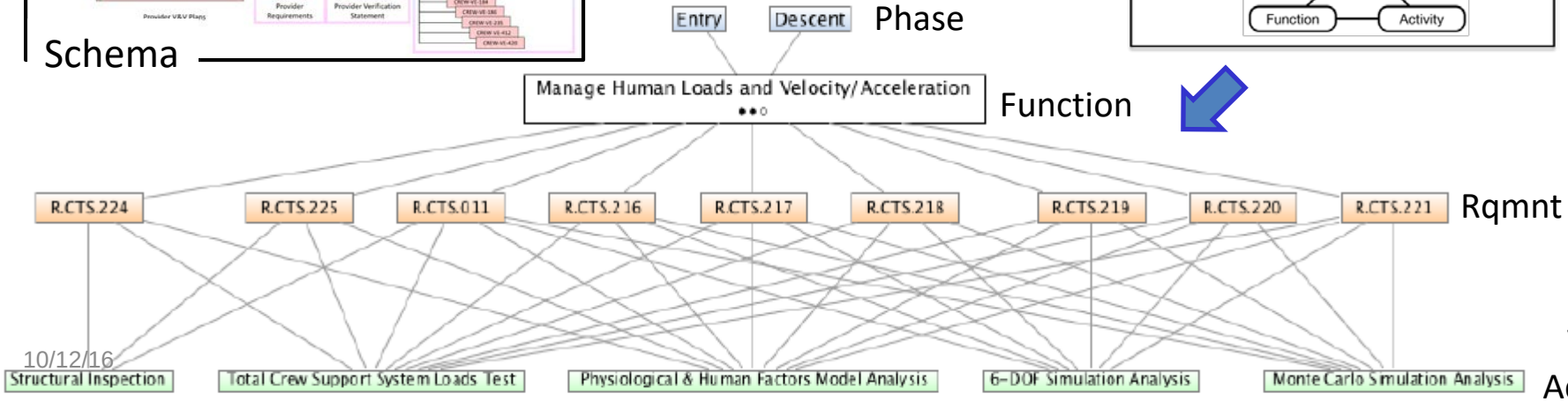
- Mapping of the integration and flow of the V&V implementation between the CCP and the two partners
- Significant gaps in the V&V campaign that may impact the CCP's ability to provide a fully validated and integrated configuration ready for launch

DELIVERABLES/SCHEDULE

- CCP V&V Phase I - January 2016 - May 2016
- CCP V&V Phase II - May 2016 - September 2016



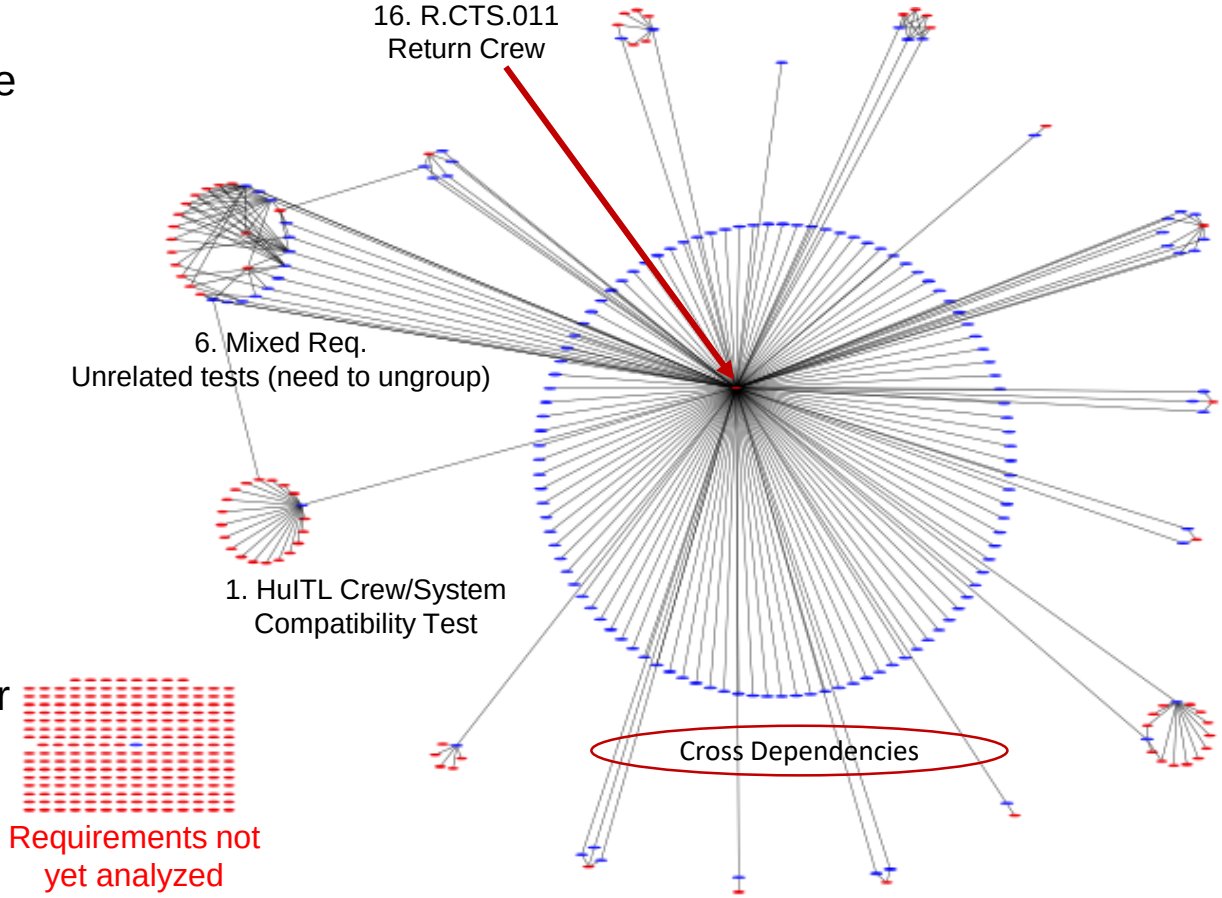




Commercial Crew V&V Partition Analysis

Marc Sarrel

- Requirements and related verification activities may be partitioned into groups
  - Based on subject matter expert (SME) evaluations of requirements and verification activities
  - Ex. generated 17 groups
- Performing verification activities by group provides opportunity to close most or all of the requirements in that group
  - Still some cross-group dependencies

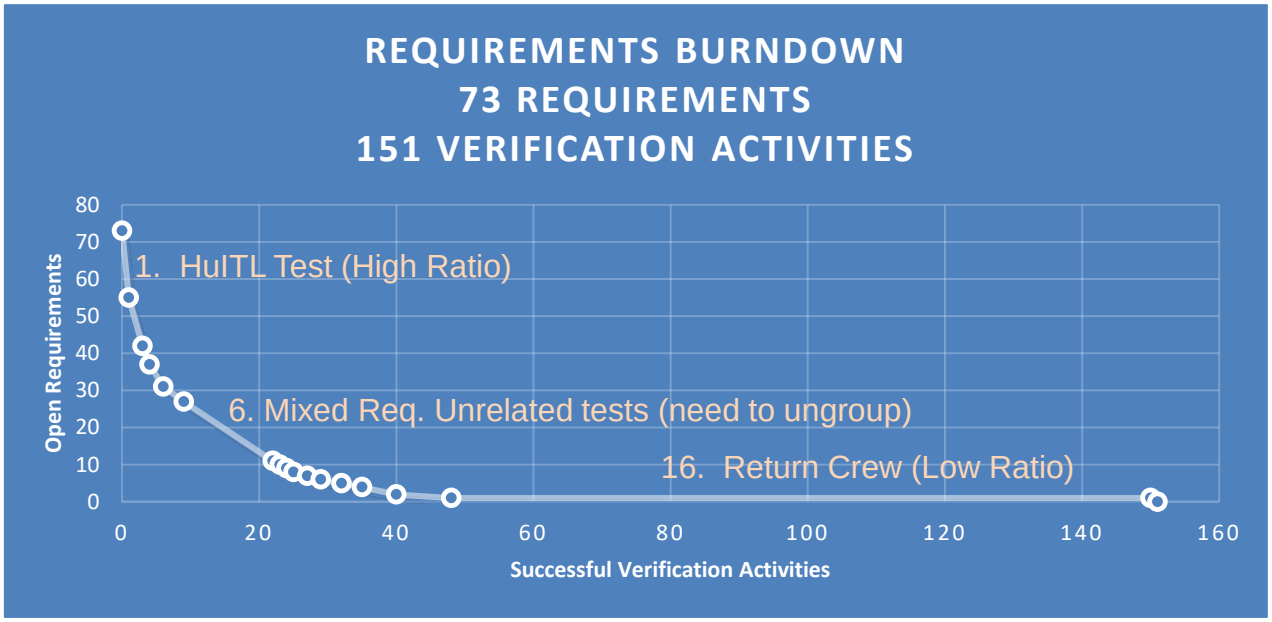


Analysis enables more effective human reasoning of complex V&V interrelationships

Commercial Crew V&V Partition Analysis

Marc Sarrel

Group	Reqs	VAs	Req per VA
1	19	1	19.000
2	13	2	6.500
3	5	1	5.000
4	6	2	3.000
5	4	3	1.333
6	16	13	1.231
7	1	1	1.000
8	1	1	1.000
9	1	1	1.000
10	1	2	0.500
11	1	2	0.500
12	1	3	0.333
13	1	3	0.333
14	1	5	0.200
15	1	8	0.125
16	1	102	0.010
17	0	1	0.000
Totals	73	151	



- Order groups to do the highest-payoff verification activities first
- Reduce risk early
- ***In absence of any other constraints,*** gives good order to perform verification activities
- Each marker indicates all verification activities in that group were successful
  - First marker is starting point of 73 requirements
- Add other types of constraints to make more realistic – external constraint solver
  - E.g. Resource utilization, Duration, Required configuration, Component availability, Risk reduction, etc.
- Reduce risk early, utilize resources efficiently, re-plan quickly.

SEEMAV (Prototype)

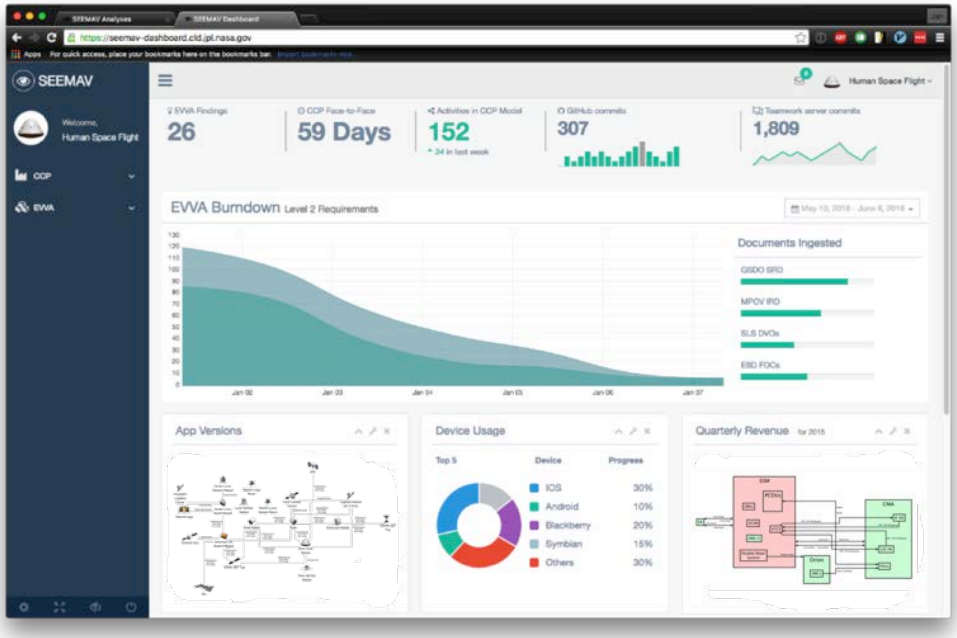
Jan Van Bruggen

Systems Engineering Ecosystem for Modeling, Analysis, and Visualization

SCOPE/KEY ACCOMPLISHMENTS
Designed and developed a cloud computing pipeline for MBSE
CAPABILITIES ENHANCED/ADAPTED

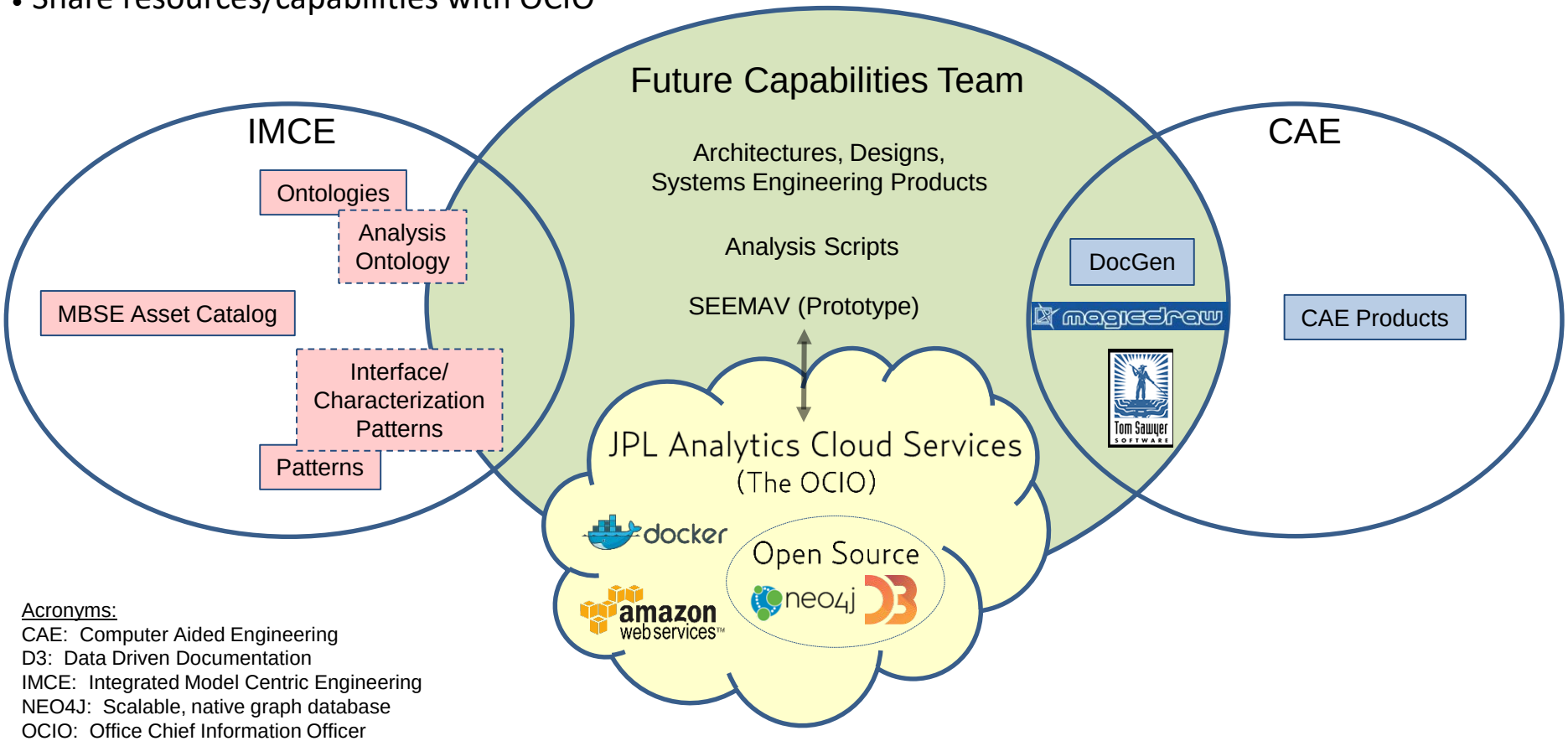
▪ **Leveraged:**
  ▪ JPL Analytics Cloud Services for computing & orchestrating
▪ **Enhancements:**
  ▪ Automate common tasks
  ▪ Eliminate human-in-the-loop bottlenecks
  ▪ Enable continuous delivery
  ▪ Monitor project status
  ▪ Re-use engineering analyses (code) between assessments
  ▪ Tool independence

DELIVERABLES
▪ **Proof-of-concept web apps** ▪ **Interactive visualizations for stakeholders** ▪ **Model input interfaces for "non-modelers"**
SCHEDULE
▪ **Apr 2016 – Design** ▪ **June 2016 – Proof-of-concept** ▪ **July 2016 – In use for NESC assessments** ▪ **Oct 2016 – 3X funding (forecasted) for JPL-wide expansion**



Relationships with JPL Institutional Providers

- Developing capabilities (expertise, model infrastructure, patterns and scripts) that serve customer's needs
- Use some products provided by IMCE and CAE, but don't contribute anything back. Should we?
- Share resources/capabilities with OCIO



Acronyms:
CAE: Computer Aided Engineering
D3: Data Driven Documentation
IMCE: Integrated Model Centric Engineering
NEO4J: Scalable, native graph database
OCIO: Office Chief Information Officer
SEEMAV: Systems Engineering Ecosystem for Modeling, Analysis, and Visualization

Summary Chart

- Continuing to apply methodologies to help HEOMD and NESC solve SE issues and concerns
- Looking for opportunities to infuse technologies