Effort to Accelerate MBSE Adoption and Usage at JSC

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Agenda

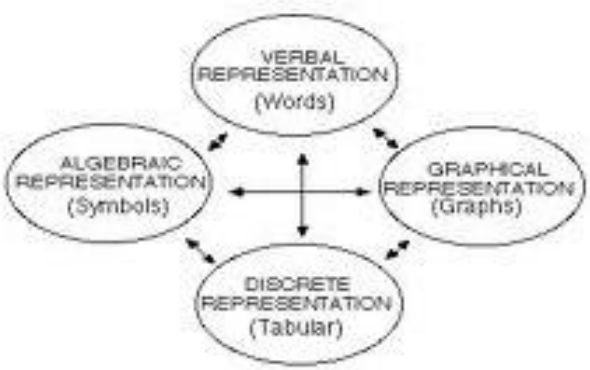
- **Motivation**
- **Challenges to MBSE Adoption**
- **Effort to Facilitate MBSE Adoption**
  - Approaches to Address Challenges
  - Modeling Methods
  - Reusable Model Elements
  - Toolset
  - Project Case Studies
- **Conclusion**

Motivation Catalyst

- Spacecraft design and operation stakeholders are creating models/artifacts of the same system with different processes, tools, and representations.

- These oft uncoordinated approaches create locally successful products but also create a communication barrier among the various stakeholders (the "Tower of Babel" Effect).

- The same information is captured multiple times, in multiple places, with multiple representations, creating a maintenance challenge.



MBSE at JSC

- JSC has applied MBSE using SysML to a number of advanced projects since 2009
- Objective of MBSE is to reduce product cycle time, improve product quality, and product maintainability
- MBSE provides a formal understanding of the features and structure of a product

Challenges to MBSE Adoption

1. Force of inertia impedes MBSE Adoption

- High risk environment (space projects) tends to gravitate toward conservative engineering
- Over valuation of current approaches to achieve success
- Perception that potential long term benefits are outweighed by short term risks
- Stories, real or perceived, of undelivered promises of MBSE are often presented to challenge the move

2. Additional Costs & Efforts Associated with MBSE Adoption

- Adopting MBSE requires additional costs
  - Buying enough tool licenses & trainings
- Additional effort to build the models
  - Learning a tool
  - Time consuming effort to build the model from scratch
  - Starting the model development can be daunting
  - Limited readily available library of reusable system models
  - Extra costs associated with early adoption for small and short duration projects

Challenges to MBSE Adoption

3. Difficulty in getting started with MBSE

- No roadmap to follow the best practices required for successful adoption
- Multiple issues need to be resolved even at the start of a project
  - What training is needed for whom?
  - What is the right mix of team skills needed?
  - What modeling methodology to use?
  - What tool to use?
  - Are there some guidelines or a process to follow?
- SysML language semantic is very rich and complex
  - Difficult to decide which modeling technique is appropriate for the project
  - After classroom training sessions, modelers still do not know how to begin
  - No defined process to guide modelers in the development of the SysML model representing the target system
- MBSE is first and foremost Systems Engineering
- NASA Systems Engineering Handbook does not provide much guidance regarding MBSE

Approaches to offset "force of inertia"

- **Alleviate the perception of increased risks using targeted presentations focused on**
  - Benefits of using MBSE
  - Availability of the models tools
  - Successful project experiences
  - Emphasize the value proposition
  - Provide evidence on how the project can benefit by adopting MBSE
- **Identify a project champion**
  - JSC SysML User's Group help champion the change
  - Systems Engineers are the primary target audience.
- **Provide tools and concrete added value examples that benefit SME daily activities**
  - SME does not have direct responsibility for system engineering
- **Demonstrate the capability to support communication between all the project stakeholders**

Approaches to address “Additional Costs and Efforts” for MBSE Adoption

- **Requires a combination of institutional and project support for training software tool licenses**

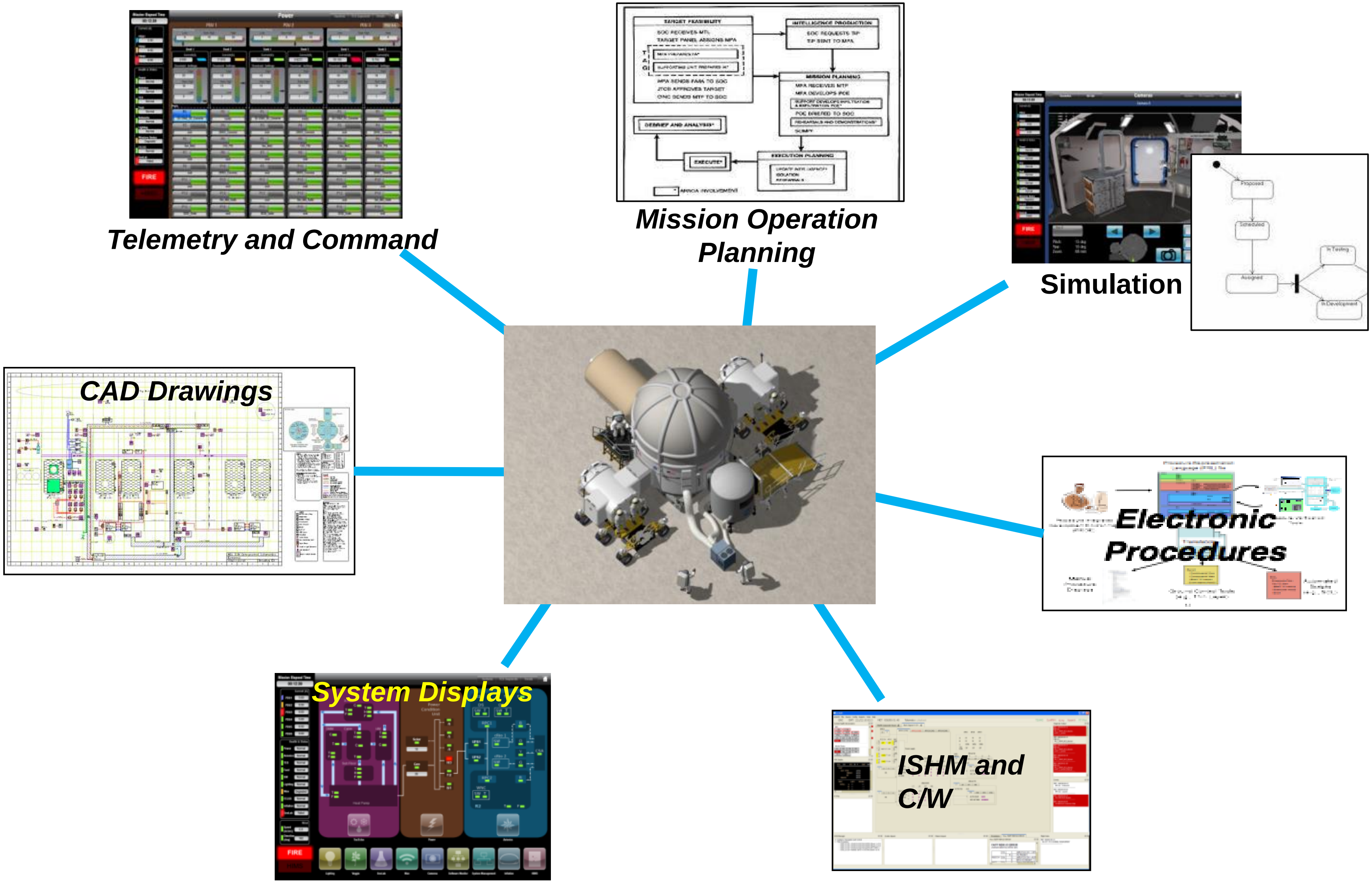
- **Provide for a team of expert modelers that can be matrixed into the project for successful MBSE adoption**
  - Experienced Modeler is partner with the System Engineers to support adoption of modeling practices and tools
  - Project Mentor is part of the project team and be involved in the system integration and design

Approaches to address “how to get started?”

- **“Model with a Purpose” is an important concept for successful adoption**
  - Helps clearly define the goal and objective of the project
  - Helps manage expectation with the stakeholders
  - Helps narrowing down modeling methods
  - Helps identify the most appropriate modeling diagrams

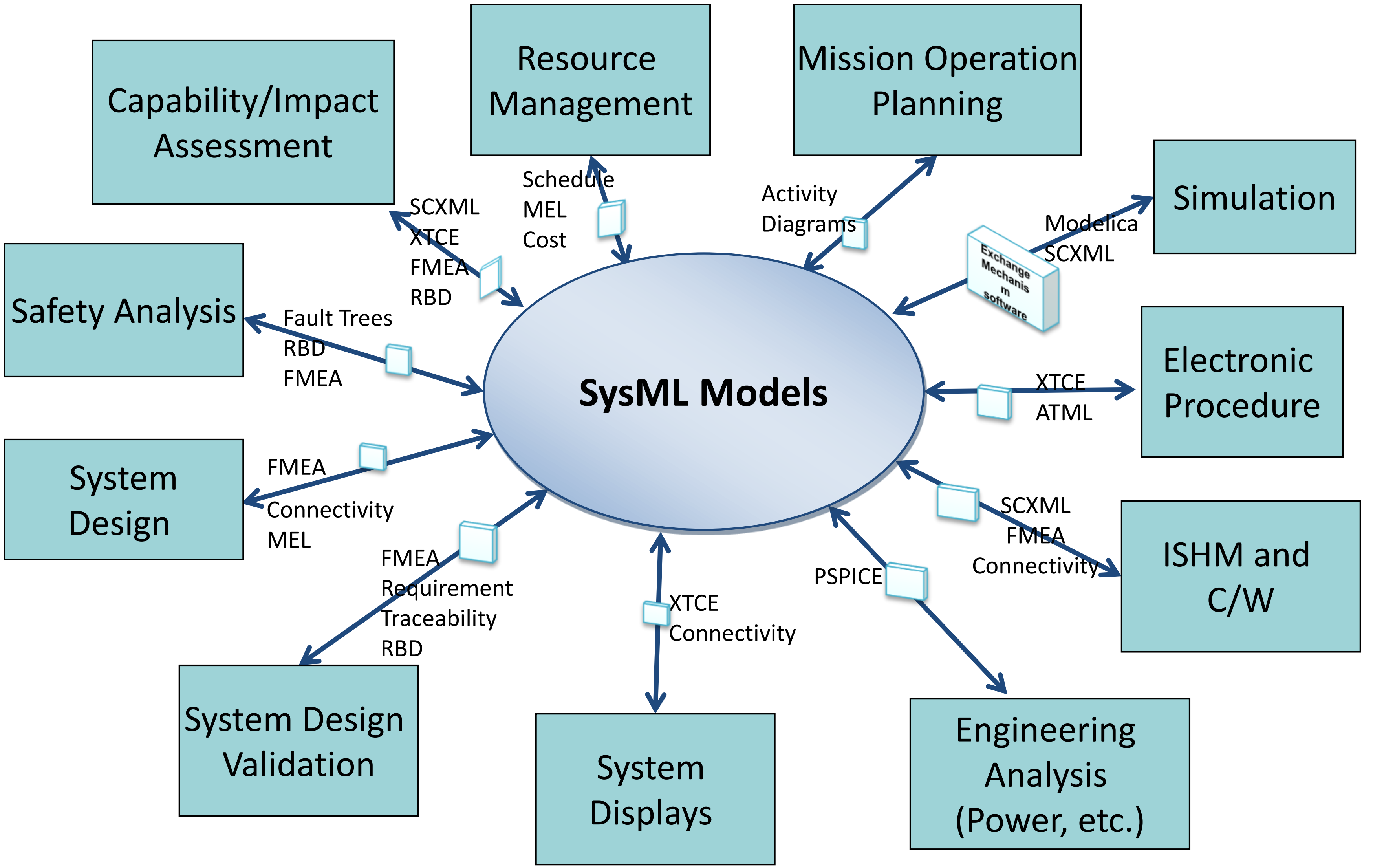
- **JSC System Modeling Team (JSMT) focused on**
  - Developing modeling methods
  - Developing tools to generate project artifacts
  - Providing modeling and tool guidelines
  - Providing exemplary reference models
  - Providing reusable model component

Artifacts by Multiple Stakeholders



Uses of System Models

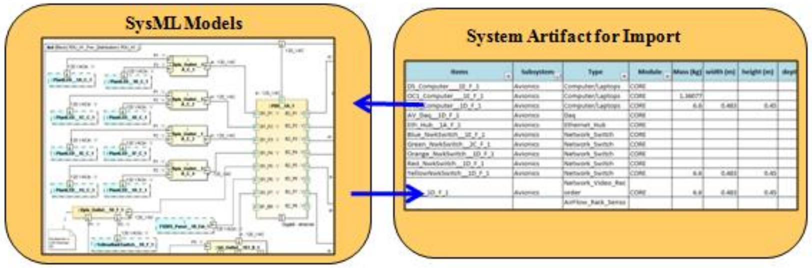
Model once and Use many times



Experience with SysML Modeling and Tool Set Development

- **Developed a modeling methodology**
- **Developed SysML Models for Multiple NASA Projects:**
  - *Deep Space Habitat (DSH)/ Habitat Demonstration Unit (HDU)*
  - *Exploration Augmentation Module (EAM)*
  - *Integrated Power and Avionics System (IPAS)*
  - *Cascade Distiller System (CDS) Life Support System (LSS)*
  - *Human Exploration Testbed Integration and Analysis (HESTIA)*
  - *Advanced Exploration System - Modular Power Systems (AMPS)*
  - *Orion*
- **Developed SysML Library Repository**
  - *Collection of SysML Models*
- **Provide a suite of data exchange tools**
  - *To extract System Engineering products from the models*
  - *To build models by extracting automatically or semi automatically information from existing sources*
  - *To support Fault Management engineering*

Model Based Engineering/ SysML Data Exchange Tool Development

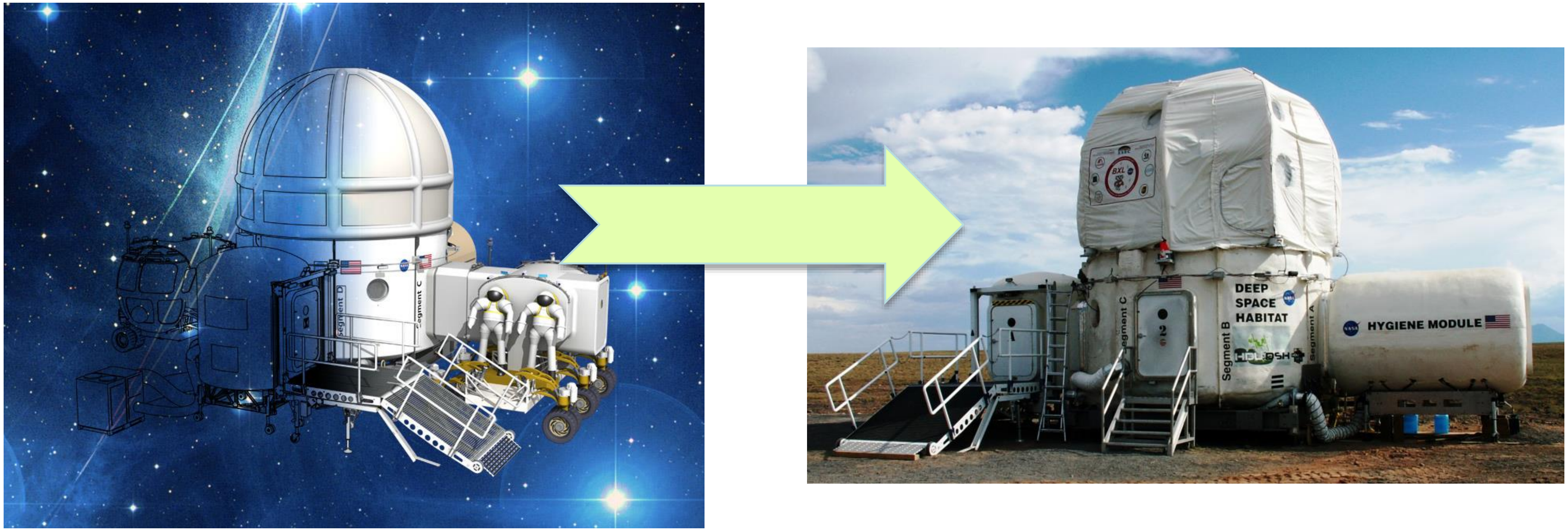


- Plug-Ins in use by NASA projects:
  1. **MEL plug-in:** Generates a Master Equipment List (MEL); mines data related to SysML block attributes and relationships
  2. **Connectivity plug-in:** Generates connectivity and conveyed information data
  3. **FSM plug-in**: Generates Finite State Machine data for use by simulator engines
  4. **XTCE plug-in:** Generates Command and Telemetry data (via XML file)
  5. **SysML Builder plug-in**: Generates SysML elements and diagrams from an Excel/CSV template (for SysML modelers and AutoCAD data extraction)
  6. **FMECA plug-in**: Generates a subset of FMECA data (failure modes and derives end effects)
  7. **FTA plug-in**: Generates Fault Tree Analysis for a selected event

- **Prototype Plug-Ins:**
  8. **PRA plug-in:** Traverses the behavior diagrams extracting the reliability values and compute the system reliability numbers.
  9. **UUT plug-in**: Generates ATML (Automated Test Mark-Up Language) for Unit Under Test (UUT)
  10. **Power Analysis plug-in**: Traverses connectivity to calculate total current
  11. **PSpice Netlist plug- in**: Generates P-SPICE netlist from SysML models
  12. **GUNNS/Trick plug-ins**: Generates data for the General-Use Nodal Network Solver (GUNNS) modeling software for use with NASA's Trick simulation environment
  13. **TEAMs plug-in**: Generates Failure Mode and connectivity data for import to TEAMs tool
  14. **Parametric Analyzer Plug-in:** Runs parametric analysis

Case Study 1 – HDU/DSH

- **Multi-center Technology Investment Project started in 2010.**
- **Objectives:**
  - Evaluate and validate Lunar Surface System (LSS) Habitat Concept efficiency and effectiveness
  - Build, integrate, test, and evaluate the vertical habitat configuration utilizing developmental hardware & software



HDU/DSH Modeling and Tool Overview

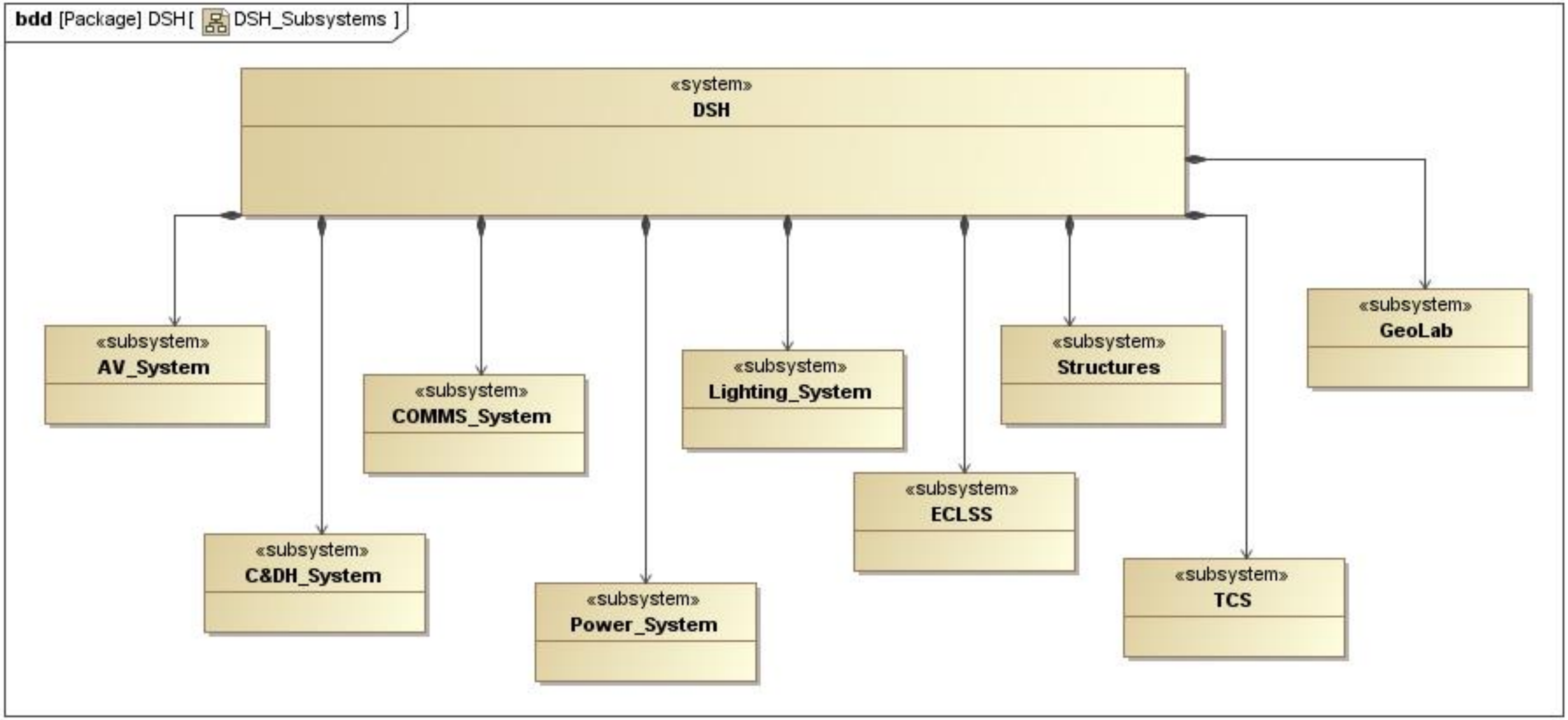
- The team's role in support of the HDU/DSH project was developing the software architecture
  - Maintaining command and telemetry dictionaries, creating crew displays, developing electronic procedures

- An initial modeling approach was developed specifically targeted to the products needed for the hardware/software integration
  - The initial target artifacts were system connectivity representation to populate crew displays and XTCE to capture Telemetry and Commands for various software applications

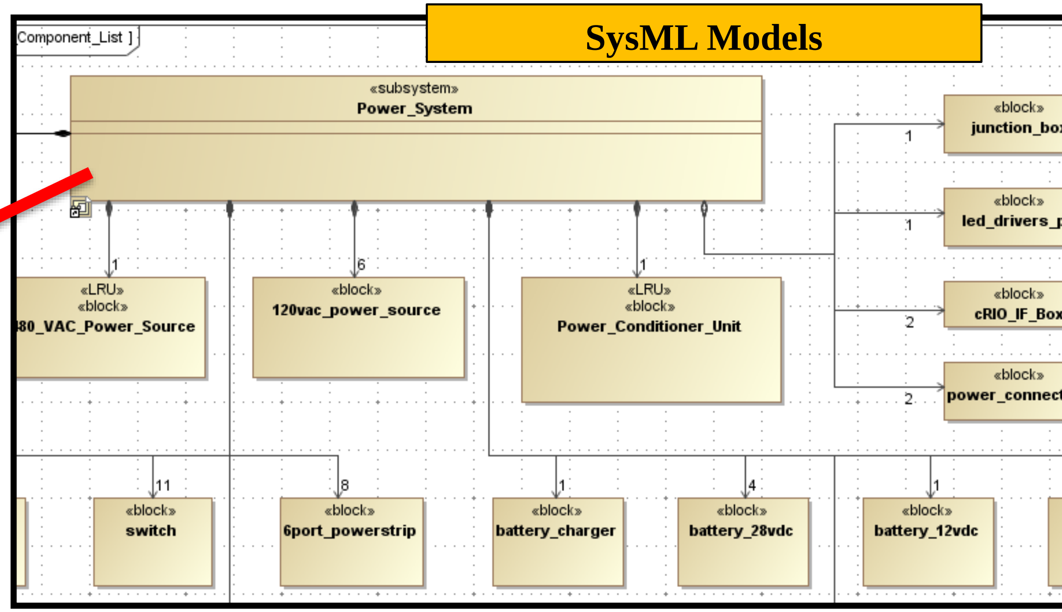
- Detailed SysML models of all the subsystems including a full set of structural and behavioral models were built throughout the design phase

- The model and SysML tools were used to support HDU/DSH surface operations and testing.

DSH System Model



Created tool to generate master equipment list (MEL)

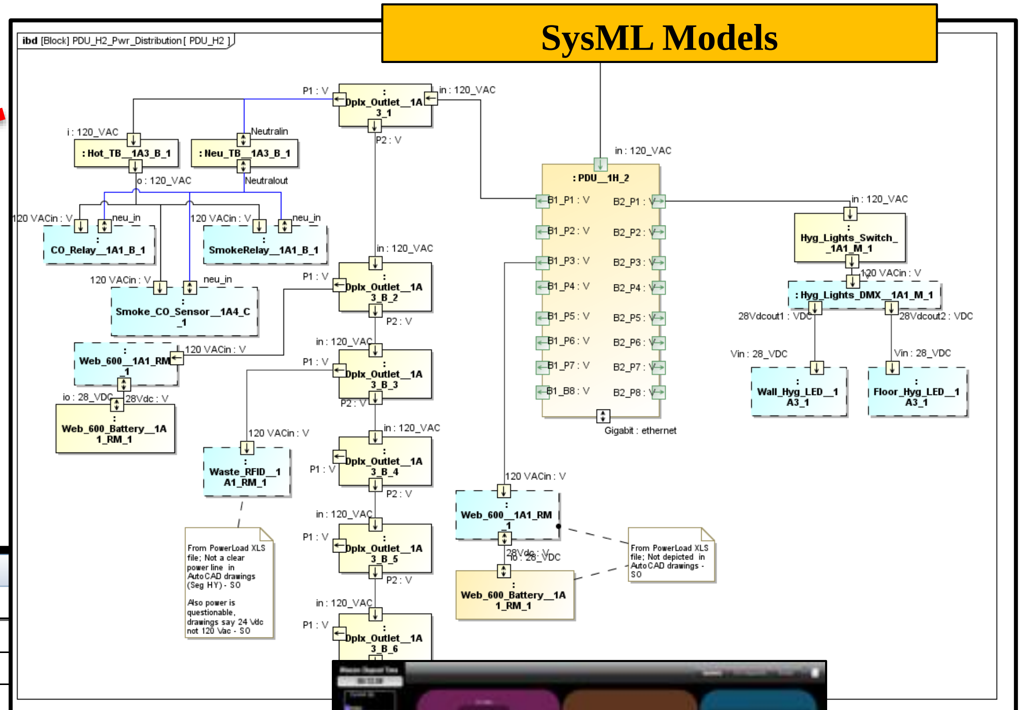


MEL

	A	B	C	D	G	H	I	J	K	L	M	N
1	Component Type (* = Removed Items or Test Articles)	Subsystem	Documentation	Qty	Mass (kg)	width (m)	height (m)	depth (m)	Avg Power (W)	Max Power (W)	Voltage Type	No
2	pdu	Power_System		6		0.114	0.4449986	0.089				
3	dplx_outlet	Power_System		47								
4	quad_outlet	Power_System		12								
5	battery_12vdc	Power_System		1		0.181	0.167	0.076				
6	battery_28vdc	Power_System		4								
7	battery_charger	Power_System		1					80		120VAC	
8	poe_injector	Power_System		1								
10	6port_powerstrip	Power_System		8	1.36				60			
12	rpc	Power_System	Avionics Power Distribution Unit aka RPC	2	4.5	0.445	0.089	0.114	1	1	120 VAC	
20	ups_accumetrics	Power_System	Uninterrupted Power Supply (Accumentrics)	2	19.73	0.09	0.043	0.041	140	140	120 VAC	
22	120vac_to_12vdc_converter	Power_System		2								
23	120vac_to_24vdc_converter	Power_System		3								
24	variable_converter	Power_System		1	8.6	0.254	0.2032	0.1016				

Created tool to extract connectivity

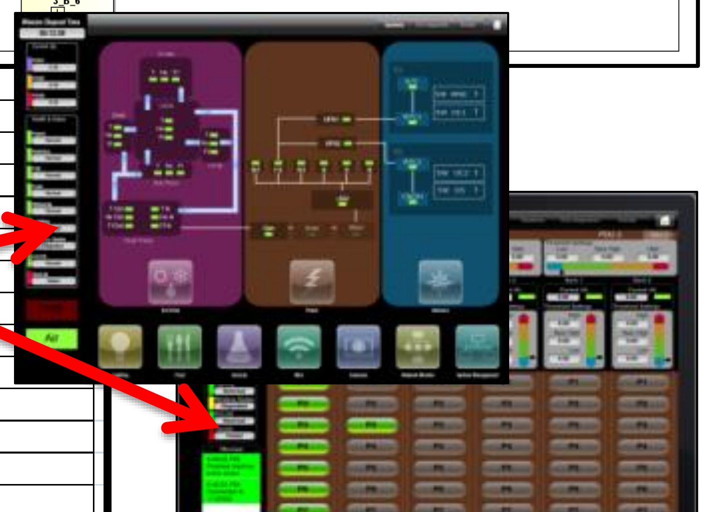
SysML Models



Magic Draw Plug-Ins

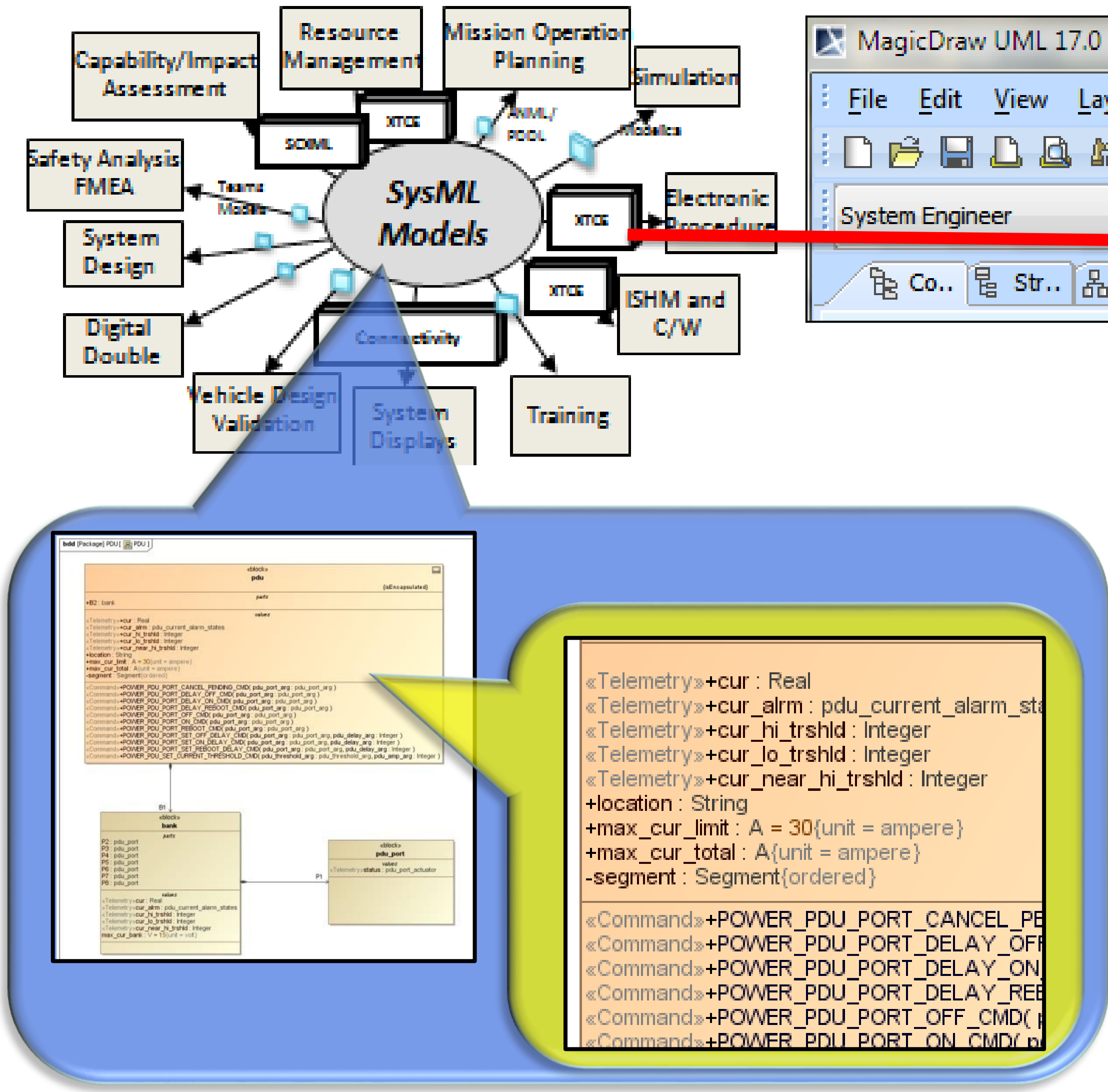
Connectivity

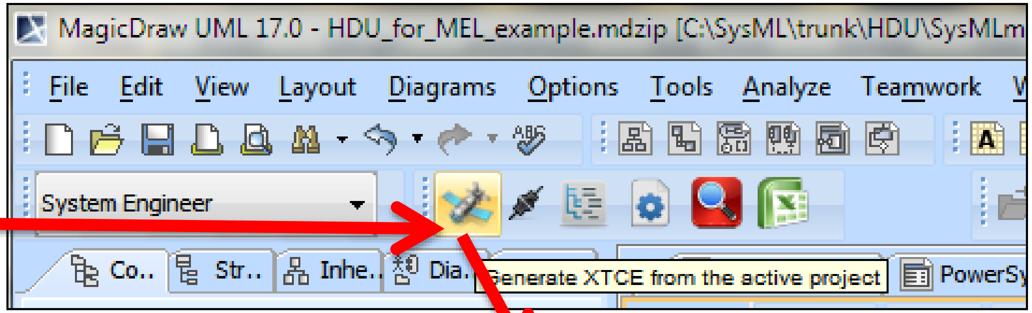
A	B	C		
source	destination	source port		
PDU__1H_1	Hot_TB__1H_B_1	B2_P3		
PDU__1A_1	Dplx_Outlet__1E2_M_1	B2_P7		
Hot_TB__1E2_1	O2Sensor__1E2_RT_1	o		
PDU__1B_2	Dplx_Outlet__1B_B_2	B1_P4	in	Power
Green_NwkSwitch__2C_F_1	Cam_VS__2C_F_1	P7	Gigabit	Data
Green_NwkSwitch__2C_F_1	Laptop__2_1	P13	1	Data
Spotlight_Switch__1A_M_2	Spotlight__1D_Ext_1		28Vdcin	Power
PDU__1A_1	Dplx_Outlet__1F_B_1	B2_P2	in	Power
Dplx_Outlet__1A3_B_5	Dplx_Outlet__1A3_B_6	P2	in	Po
Blue_NwkSwitch__1E_F_1	GB_Eth_Hub__1H_1	P14	1	Data
Hot_TB__1E2_1	CO_Relay__1E2_RM_1	o	120 VACin	Po er
Dplx_Outlet__1A_C_1	PlantLED__1B_C_1	P2	120 VACin	Power
Pwr_Connector__1D_F_1	RPC__1D_F_1		1in	Power
Pwr_Connector__1D_F_1	RPC__1D_F_1		2in	Power
Signal_TB	SmokeRelay__1H_F_1	smoke		Data
Dplx_Outlet__1F_F_2	28_VDC_PS__1F_F_1	P1		Power
PDU__1A_1	Dplx_Outlet__1B_B_1	B2_P3	in	Power
Hot_TB__1H_B_1	Smoke_CO_Sensor__1D_T_1	o	120 VACin	Power
28_VDC_PS__1F_F_1	28_VDC_TB__1F_F_1	o	in	Power



Utilized in Connectivity Applications

Created tool to extract XTCE



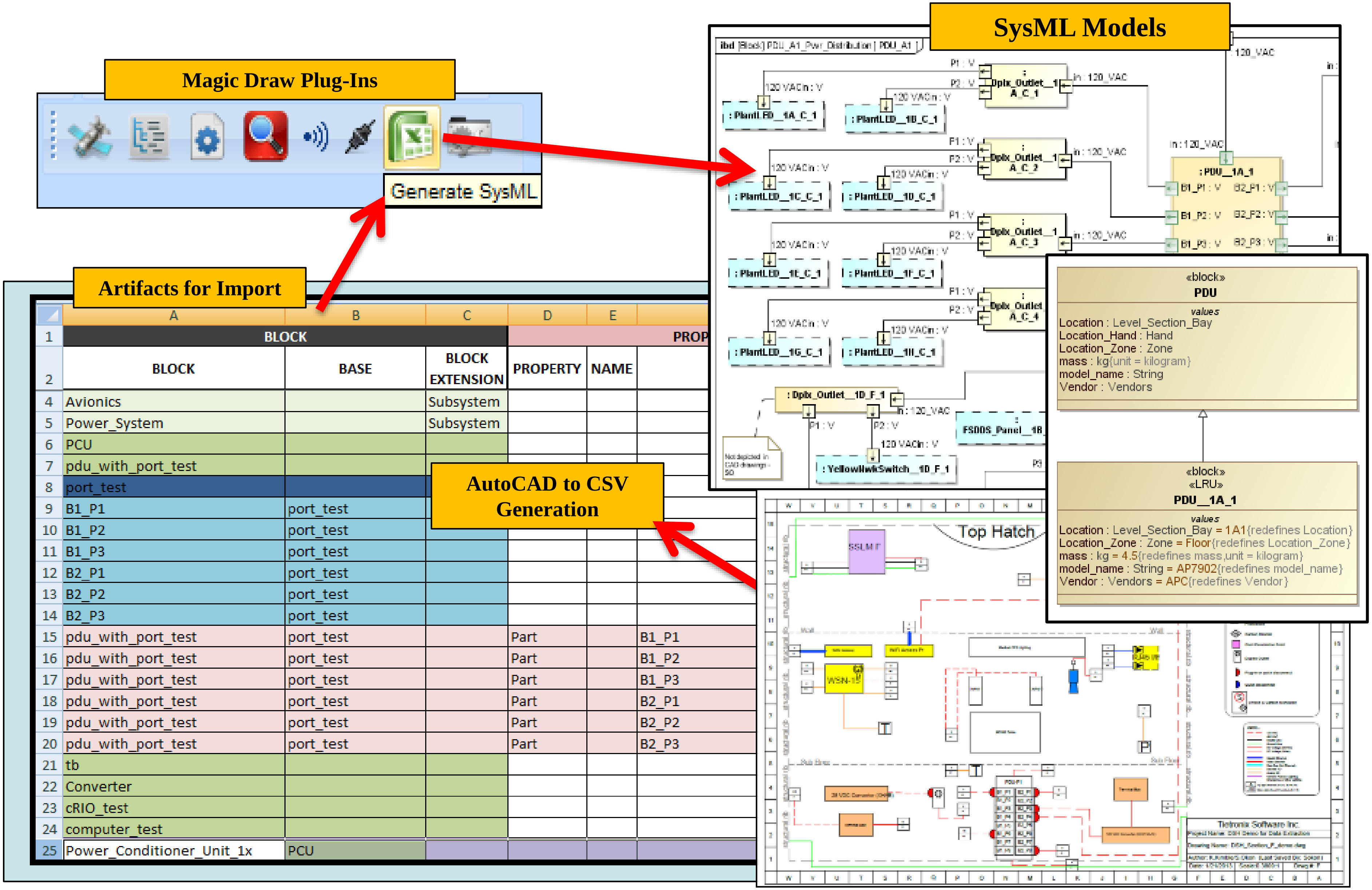


XML Telemetric and Command Exchange (XTCE) : OMG standard for Spacecraft T&C


```
<SpaceSystem name="RIU2">
    <AliasSet>
      <Alias alias="02" nameSpace="id"/>
      <Alias alias="020602" nameSpace="interface"/>
    </AliasSet>
    <Header classification="INTERFACE"/>
    <TelemetryMetaData>
      <ParameterSet>
        <Parameter parameterTypeRef="HUMIDITY_DEWPOINT_SENSOR"
shortDescription="GEOLAB_GB_HUMIDITY1_DEWPOINT_SENSOR"
name="020602018001">
          <ParameterProperties dataSource="telemetry">

<SystemName>CORE.GEOLAB.RIU2.HUMIDITY_DEWPOINT_SENSOR.1</System
Name>
          </ParameterProperties>
        </Parameter>
        <Parameter parameterTypeRef="VALIDITY" name="020602054001">
          <ParameterProperties dataSource="telemetry">
            <SystemName>CORE.GEOLAB.RIU2.VALIDIDY.1</SystemName>
          </ParameterProperties>
        </Parameter>
        <Parameter parameterTypeRef="HUMIDITY_PRESSURE_SENSOR"
</Parameter>
```

Created a tool to import data and generate SysML models



Case Study 2 - Integrated Power, Avionics and Software (iPAS)

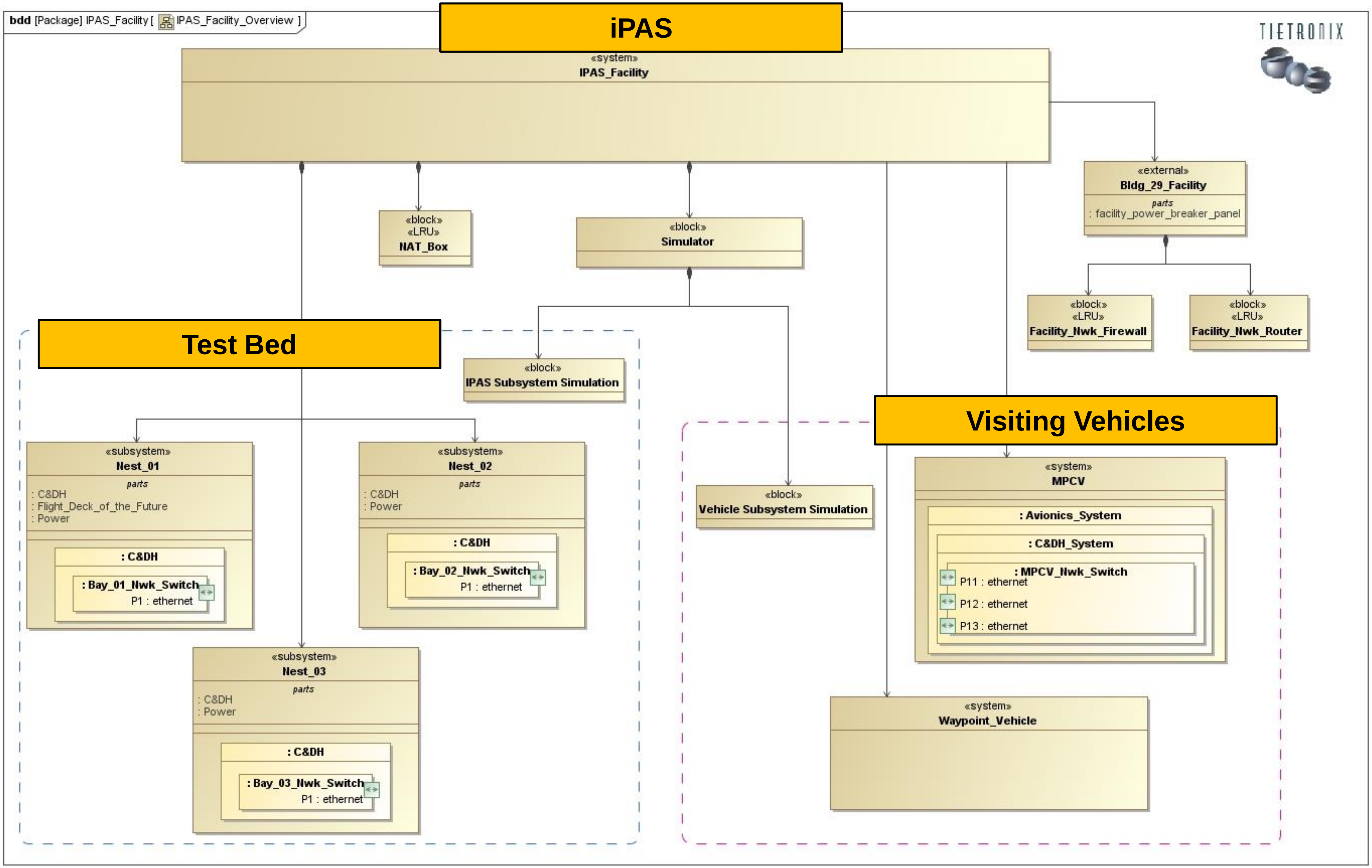
- iPAS is a testing facility focusing on the integration of visiting vehicles to test new technologies

- The import tool, built for the previous HDU project, was used to build the iPAS SysML models
  - Model included Power, Avionics, Command & Data Handling, and Propulsion systems
  - The iPAS model captured system architecture, connectivity and command and telemetry attributes

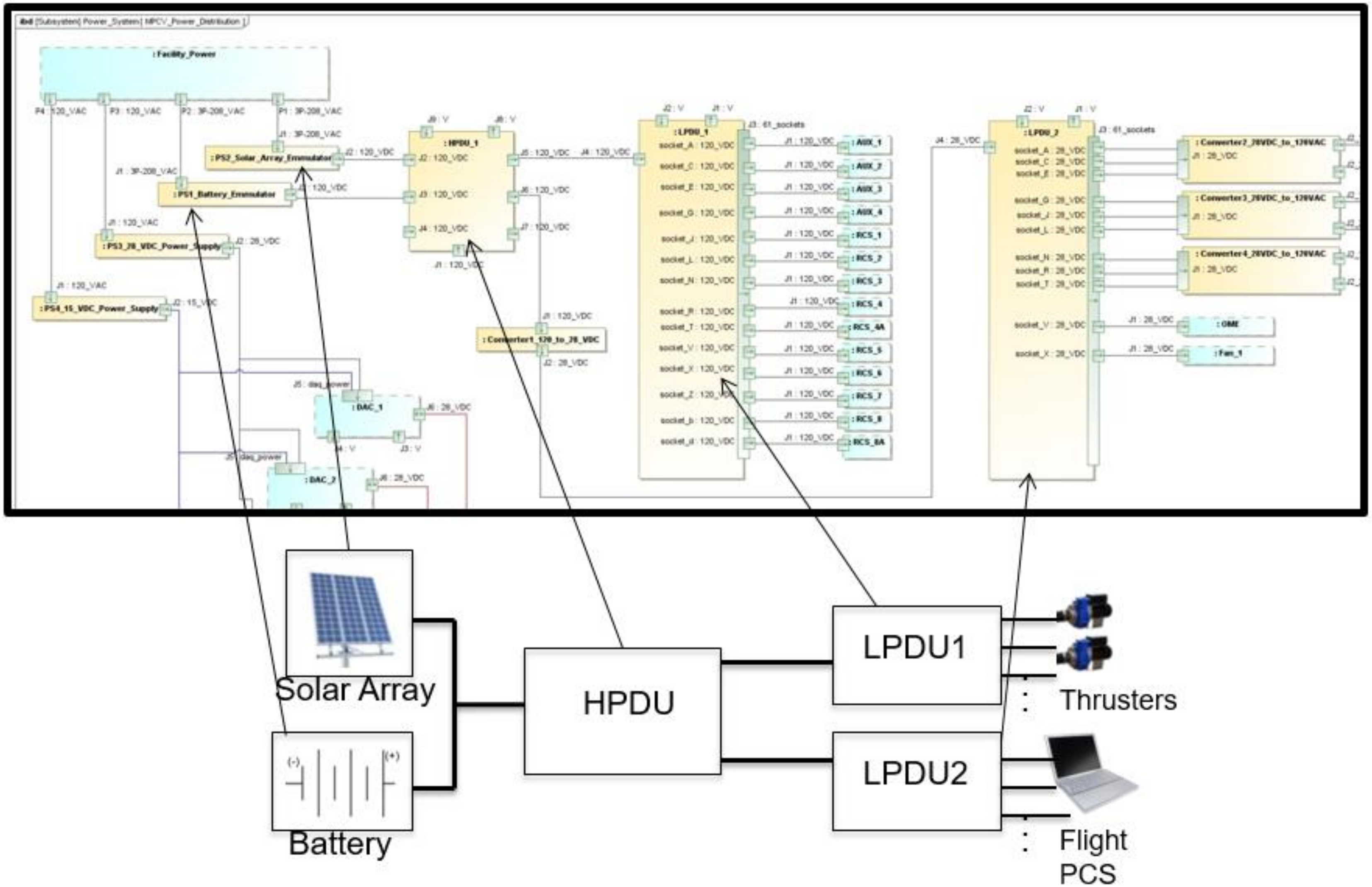
- The project used the tools to extract master equipment list, connectivity, and XTCE information from the model.

- Using the tools and established modeling method, the model development and data extraction was completed in a week.

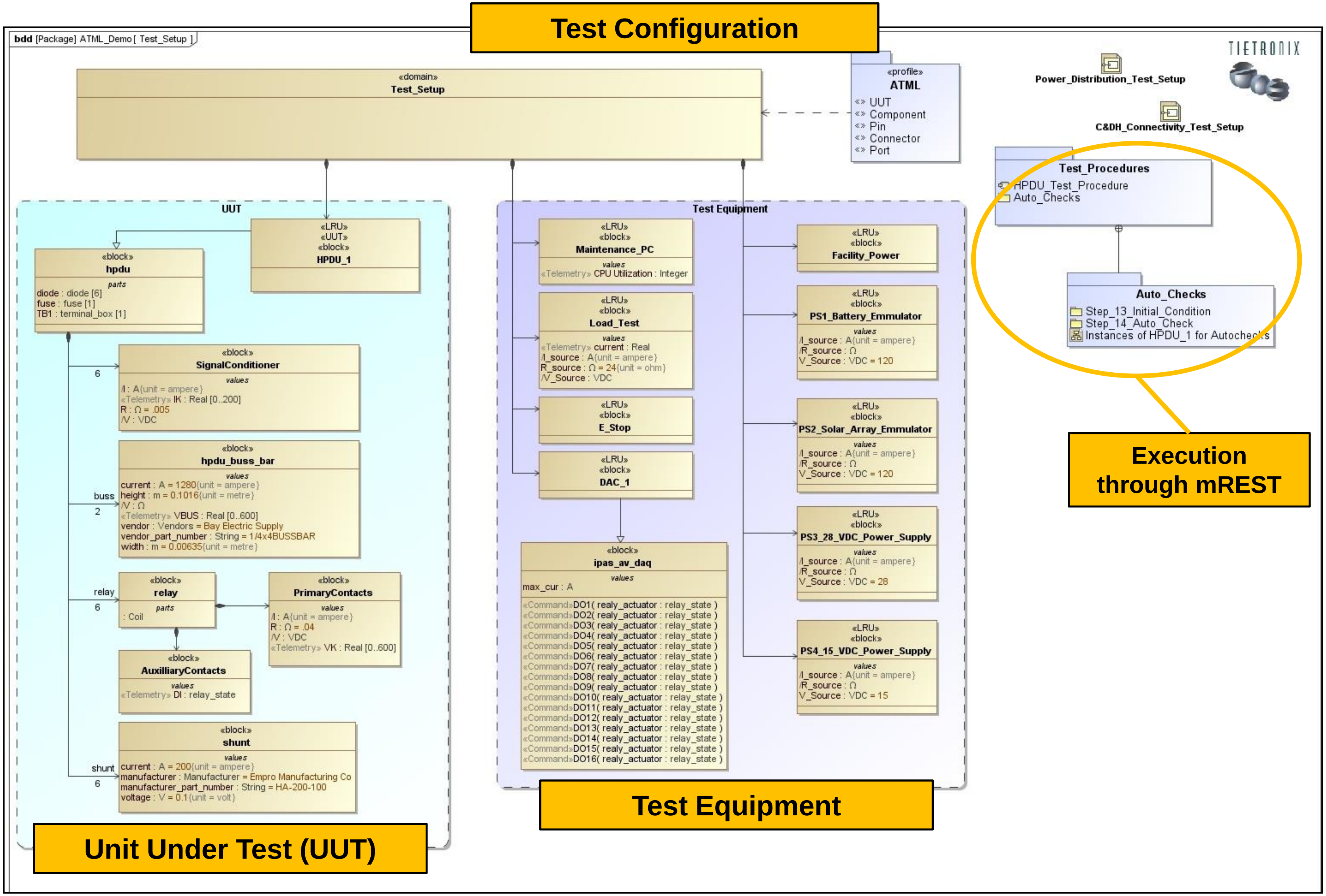
iPAS Facility (Avionics Focus)



iPAS Power Distribution Model for MPCV



iPAS – Model Design for ATML and mREST



Case Study 3 – Cascade Distillation System (CDS) Life Support System

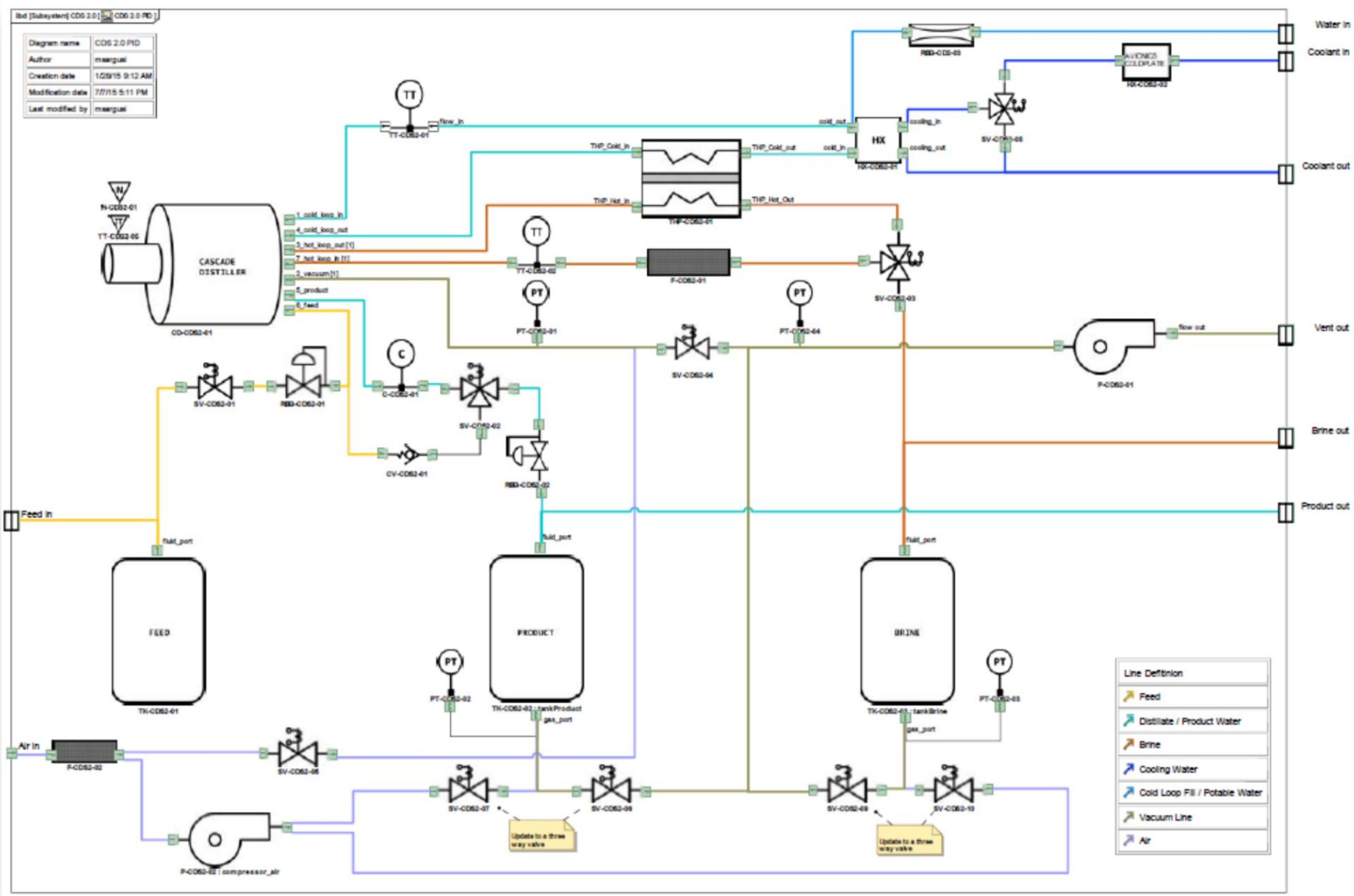
- The CDS is a water recovery system designed to support future human exploration missions beyond low earth orbit.

- The CDS system model was created using the same modeling method and tools.
  - Derived model artifacts in support of CDS system and software design
  - The project used the tools to extract master equipment list, connectivity, and XTCE information from the model.

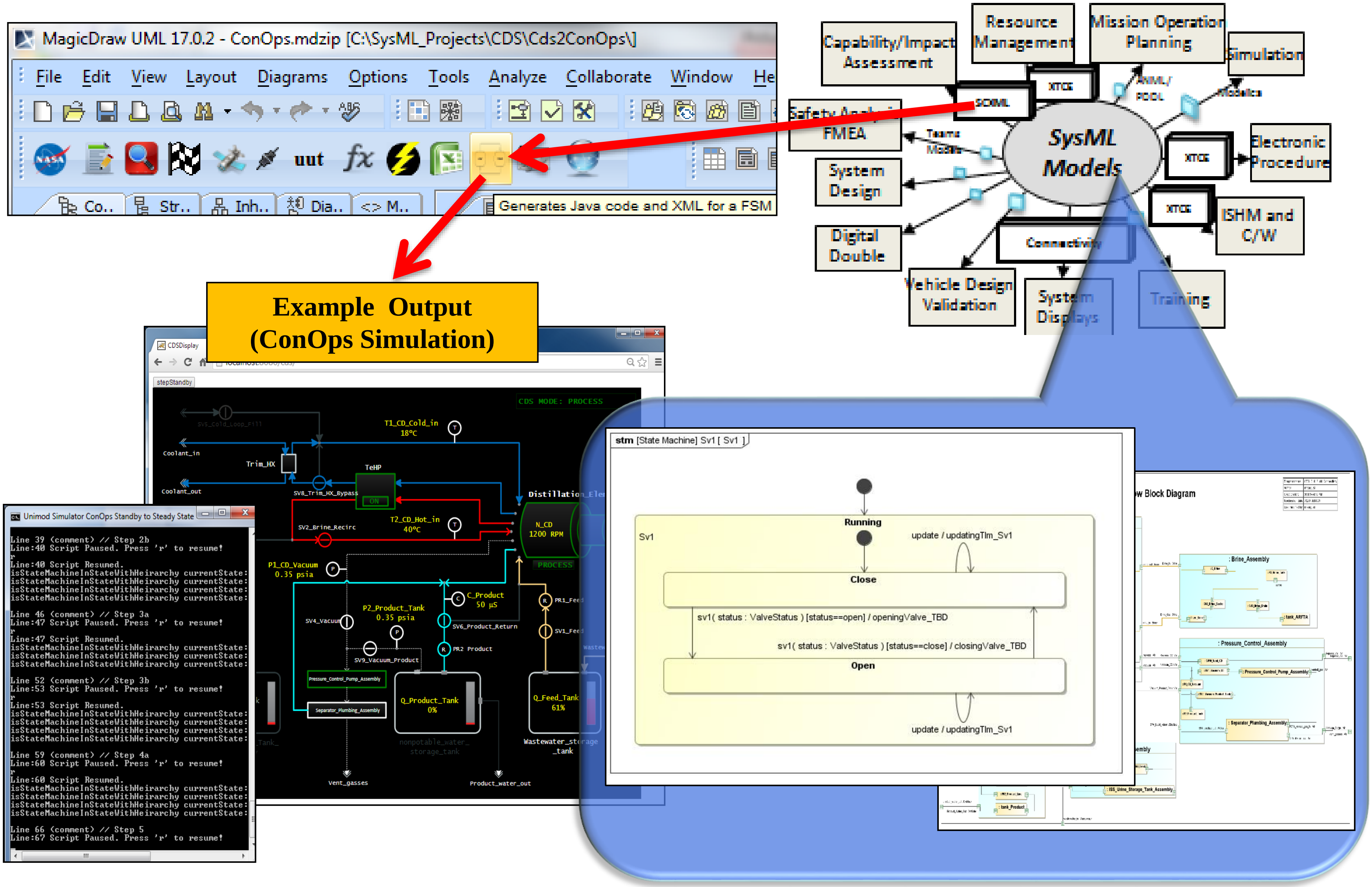
- The design utilized the Fault Management (FM) methodology to incorporate FM elements into the architecture.
  - The behavior of each component was captured in state machine models using the methodology.

- The FMECA and Fault Tree tools were used to perform a risk analysis

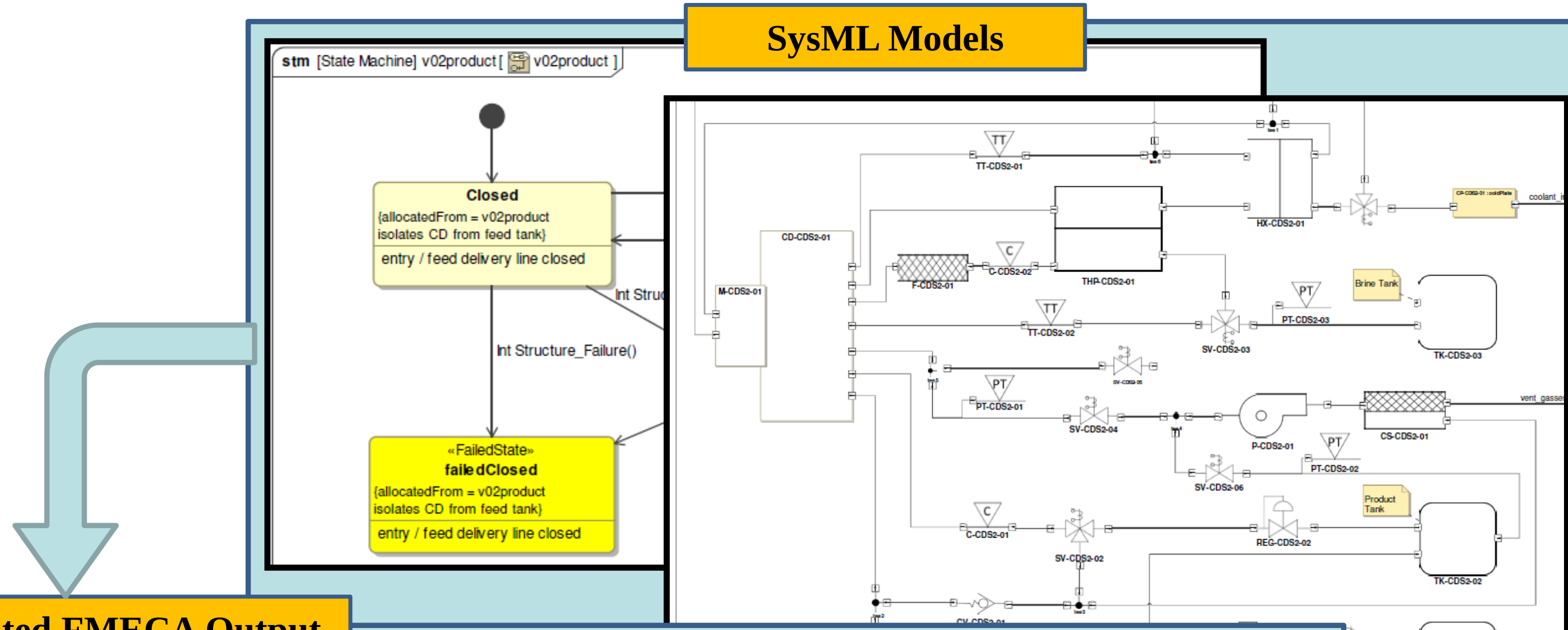
CDS SysML Schematic (Physical Architecture)



Extracted State Machine Data for ConOps and Risk Analysis



FMECA Extraction



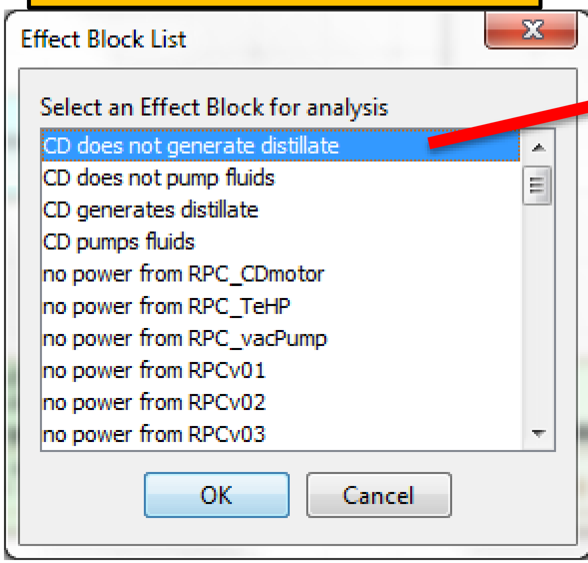
Generated FMECA Output

LRU/ Assembly Name	Item Name	Item Function	Potential Failure Mode	Effect				CRIT LEVEL	Potential Causes
				Immediate Failure Effect	End Effect	Number of Independent Failures	Other Independent Failures		
v02product	solenoid_valve_2way		failedClosed	v02product isolates CD from feed tank	CD does not generate distillate	1		3	Int Structure_Failure
v02product	solenoid_valve_2way		failedClosed	v02product isolates CD from feed tank	CD pumps fluids	1		3	Loss of Magnetic Field
v02product	solenoid_valve_2way		failedClosed	v02product isolates CD from feed tank	CD does not generate distillate	1		3	Loss of Magnetic Field
v04vacCD	nc_solenoid_valve		Failed Closed	v04vacCD isolates CD from vacuum	CD pumps fluids	1		3	Loss of Magnetic Field
v04vacCD	nc_solenoid_valve		Failed Closed	v04vacCD isolates CD from vacuum	CD does not generate distillate	1		3	Loss of Magnetic Field
v04vacCD	nc_solenoid_valve		Failed Closed	v04vacCD isolates CD from vacuum	CD pumps fluids	1		3	Int Structure_Failure
v04vacCD	nc_solenoid_valve		Failed Closed	v04vacCD isolates CD from vacuum	CD does not generate distillate	1		3	Int Structure_Failure
v04vacCD	nc_solenoid_valve		Failed Open	v04vacCD opens CD to vacuum		1		4	Int Structure_Failure
v04vacCD	nc_solenoid_valve		Failed Open	v04vacCD opens CD to		[illegible]		[illegible]	SpringFailure

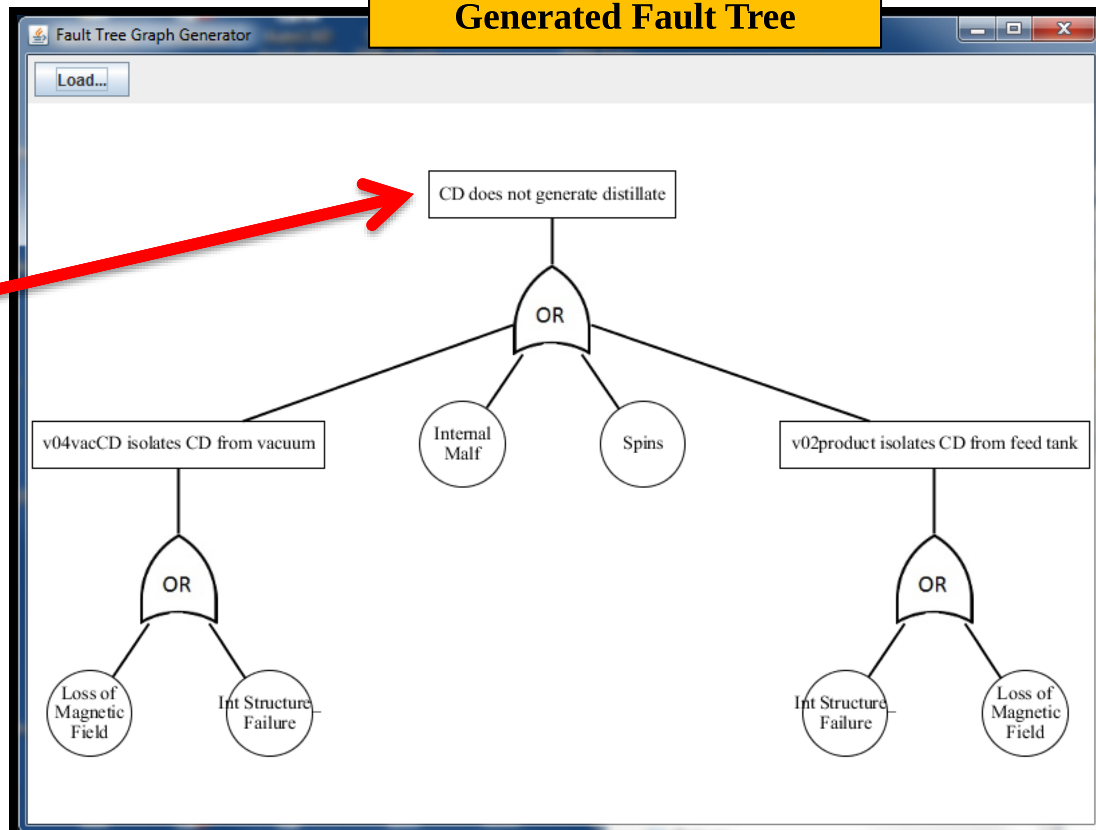
FTA (Fault Tree Analysis) Extraction Tool

Magic Draw Plug-Ins

Select Top Level Event from Model to Analyze



Generated Fault Tree



Conclusion and Forward Work

Conclusion:

- A combination of education and outreach, institutional support, and a set of modeling guidelines and tools, has been successfully applied to multiple projects at JSC
- These initial successes are showing the path to the generalized adoption of MBSE
- Benefits of MBSE adoption include:
  - Significant time and effort savings to generate the operational products
  - Providing a single source of knowledge with the latest system configuration
  - Improving communication between multiple disciplines such as software, hardware, systems engineers, and CAD model developers

Forward Work:

- Continue to enhance the import tools to import data into the model from local sources used by multiple stakeholders (Visio, Power Point, CAD)
- Explore the development of flexible tools by leveraging the latest technologies in Ontology development and reasoning engines to enable the tools to be independent of the selected modeling method