Integrated System Health Management: Foundational Concepts, Approach, and Implementation

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Acknowledgements

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Outline

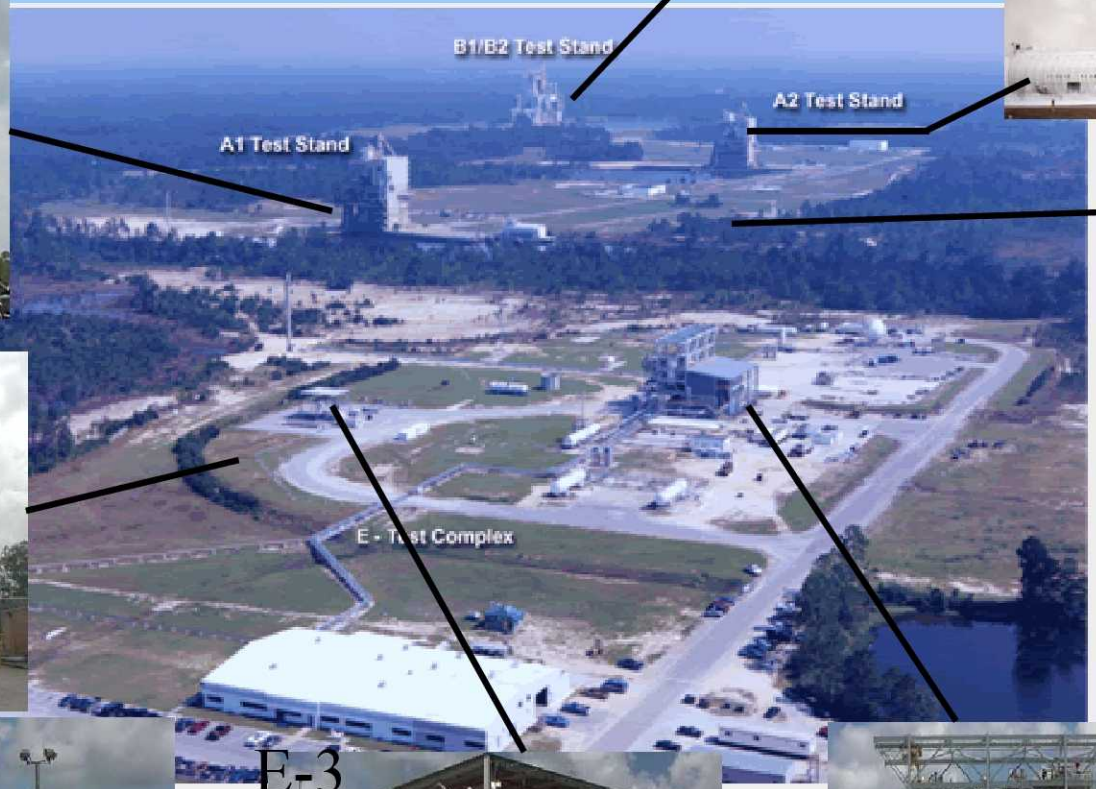
- Motivation
- Concepts and Approaches
  - ISHM: Background/Definition
  - ISHM Model of a system
  - Detection of anomaly indicators.
  - Determination and confirmation of anomalies.
  - Diagnostic of causes and determination of effects.
  - Consistency checking cycle.
  - Management of health information
  - User Interfaces
- Implementation
- Conclusions

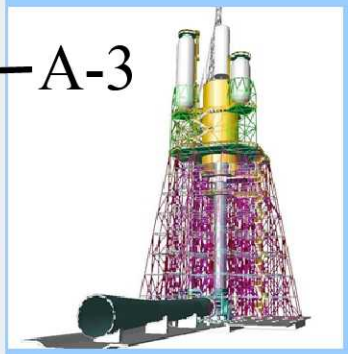
Support rocket engine test mission with highly reliable, accurate measurements; reduced costs; etc.

B-1/B-2

A-1

A-2





A-3

Others:
- High-pressure Gas
- Industrial Water

E-2

E-3

E-1

Requirements Driving ISHM

Through comprehensive and continuous vigilance

- Improve quality
  - By more accurately understanding the state of a system.
- Minimize costs
  - Of configuration
  - Of repair and calibration
  - Of operations
- Avoid downtime
  - By predicting impending failures
  - By timely intervention
  - By faster diagnosis and recovery
- Increase safety (protect people and assets)

ISHM Objectives

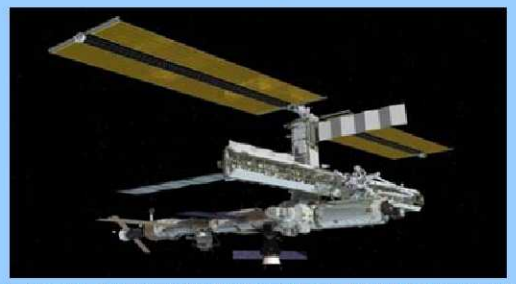
- Use available data, information, and knowledge to
  - Identify system state
  - Detect anomalies
  - Determine anomaly causes
  - Predict system impacts
  - Predict future anomalies
  - Recommend timely mitigation steps
  - Evolve to incorporate new knowledge

ISHM implementation is a problem of "management" of data, information, and knowledge (DIaK) focused on achieving the objectives of ISHM

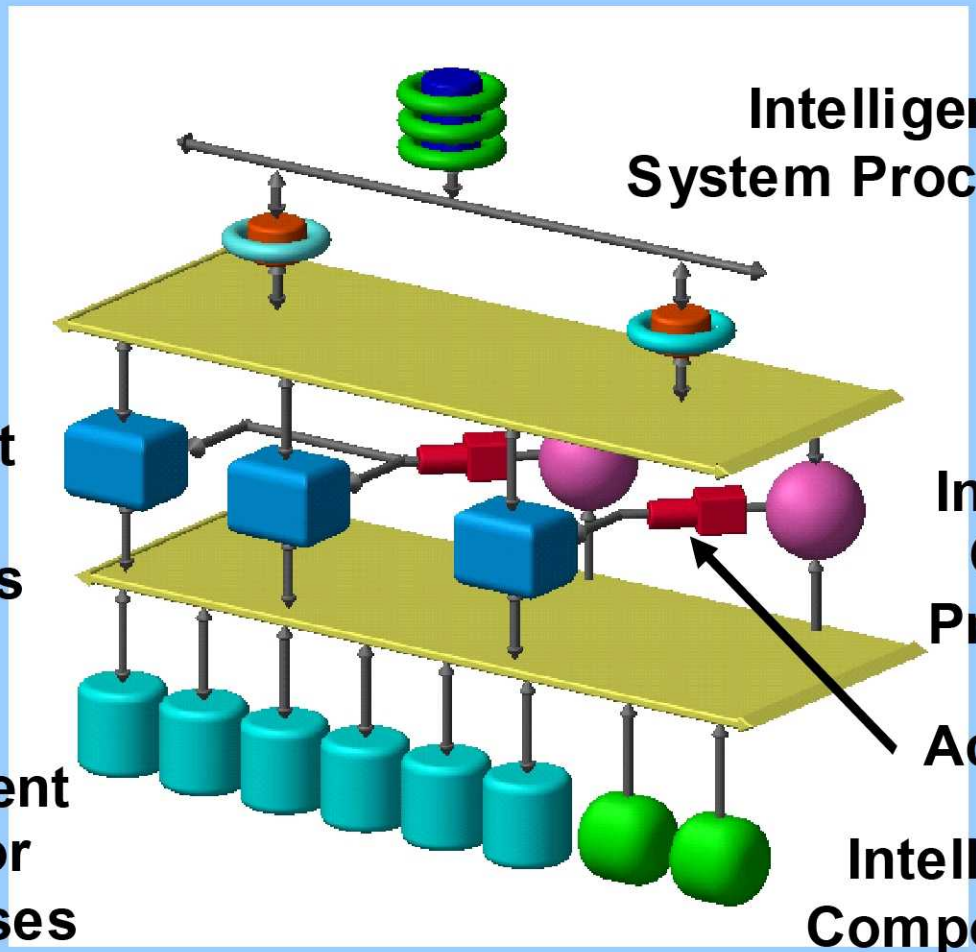
Concepts and Approach

ISHM is Being Done Now … But

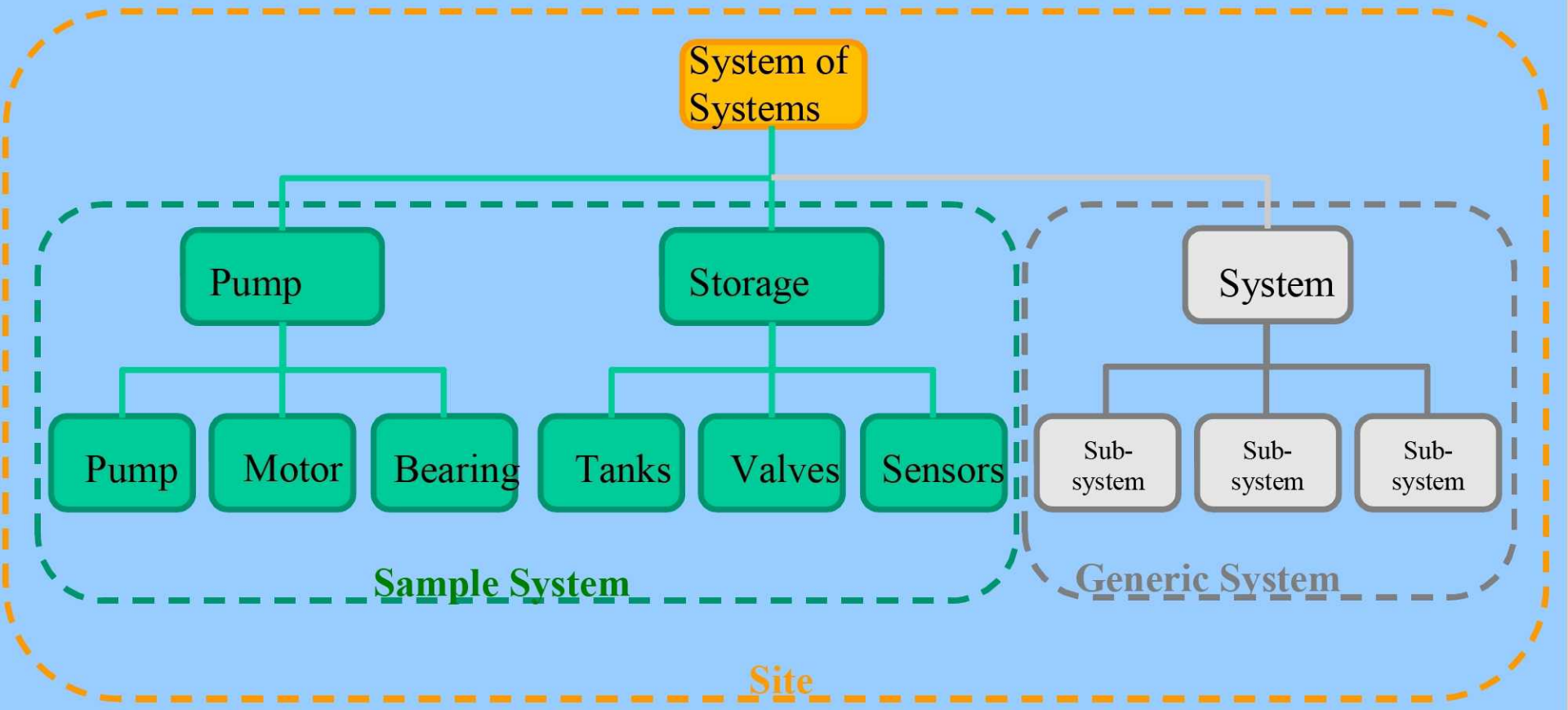
MOVE CAPABILITY TOWARD LEVELS 2 AND 1

	International Space Station	Rocket Engine Test Stand	
Layer 1 Vehicle/ Test Stand			Signal threshold violation detection
Layer 2 Astronaut/ Test Conductor			Added DIaK from on-board users.
Layer 3 Control Room			Added DIaK from broad group of experts.
Layer 4 Back Control Room			Added DIaK resources from larger community

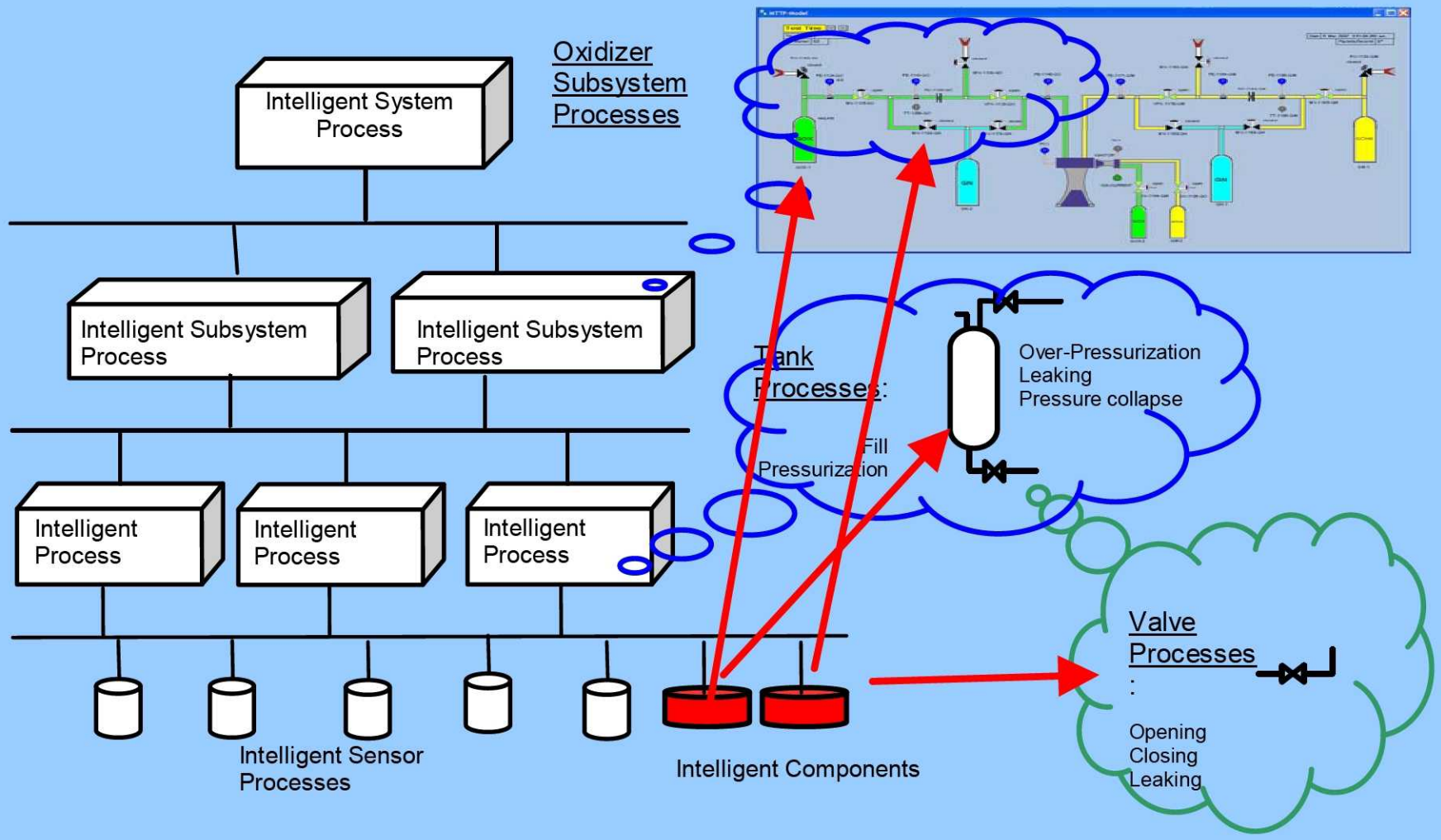
Data, Information, and Knowledge Management Architecture for ISHM (Information Architecture)



Classic architecture describing how systems are built



Correspondence between elements in the ISHM Information Architecture and processes taking place in a system



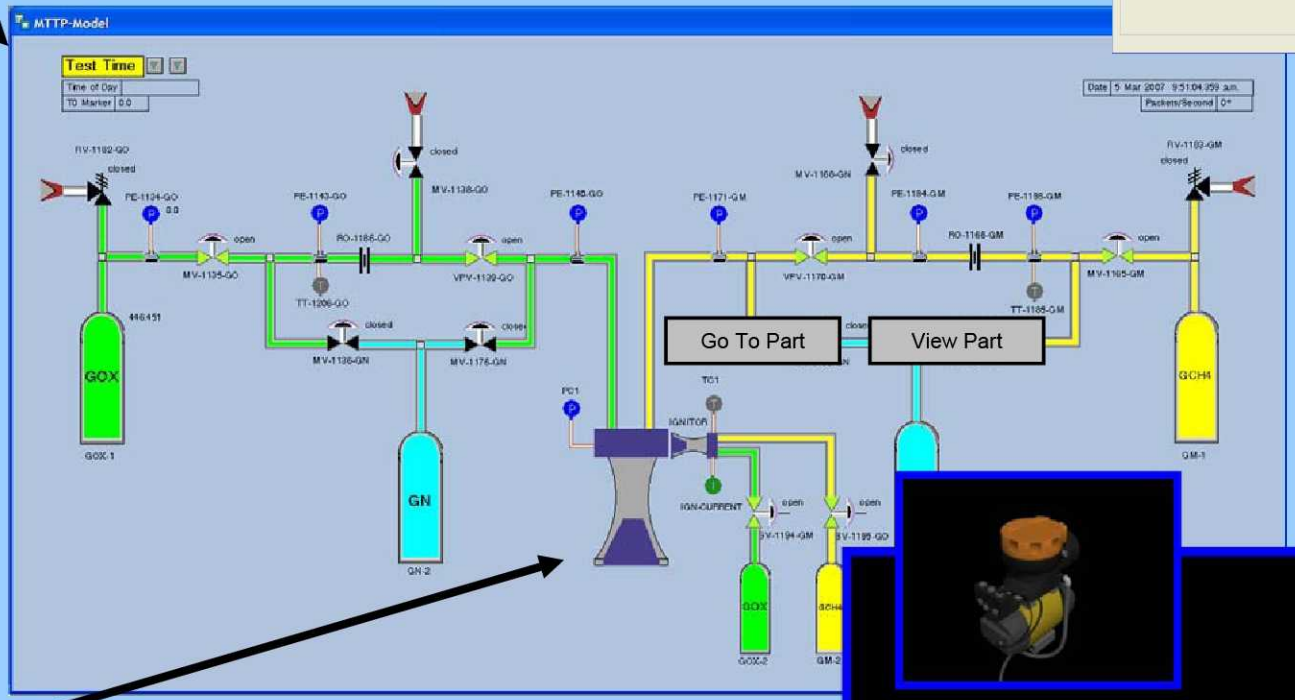
SSC Integrated System Health Management (ISHM) Capabilities

ISHM Models (Embedded Data, Information, and Knowledge):
MTTP Implementation

Health Anomaly Database:
Health Electronic Data Sheets
Repository of anomalies

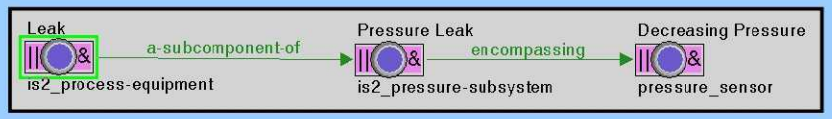
Anomaly Detection:
Leaks, etc.

Intelligent Sensors: IEEE Standard+Health

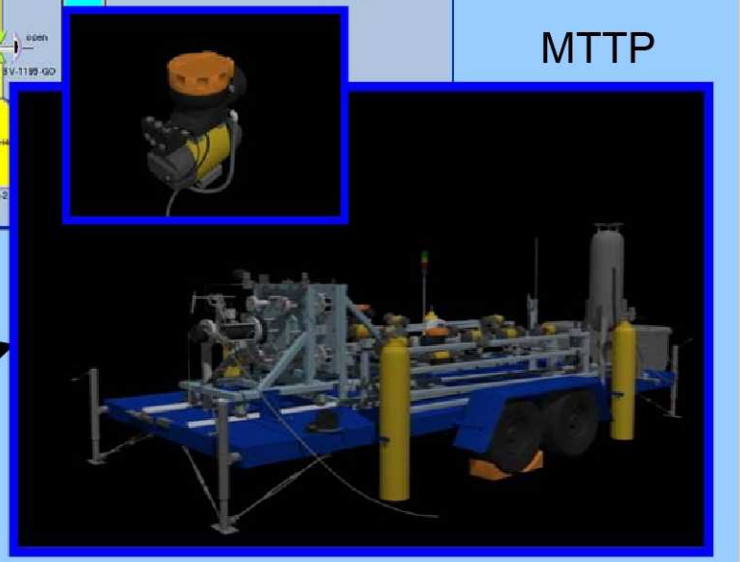


Embedding of Predictive Models

Root Cause Analysis



Integrated Awareness:
3-D Health Visualization of MTTP



MTTP

John C. Stennis Space Center
ISHM Partnerships for Rocket Propulsion testing

Rocket Engine Test Stand

PENNSTATE

NASA KSC

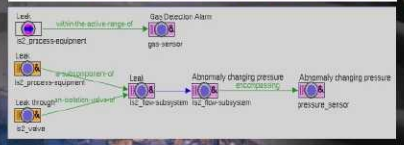
Open Systems Architectures

Prognostics & Anomaly Detection

Pratt & Whitney
A United Technologies Company

NASA ARC

GENERAL ATOMICS
ELECTROMAGNETIC SYSTEMS



Root Cause Analysis

Test Article

Integrated Awareness

IEEE 1451 Smart & Intelligent Sensors

MOBITRUM
Brings you mobility®

NASA KSC

ATK

INVOCON, INC.
Innovative Concepts in Systems Engineering

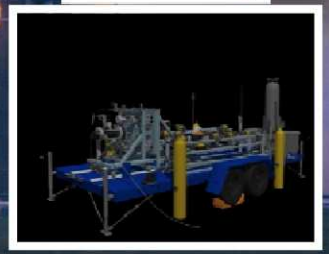
NVE
NVE CORPORATION

Rowan University

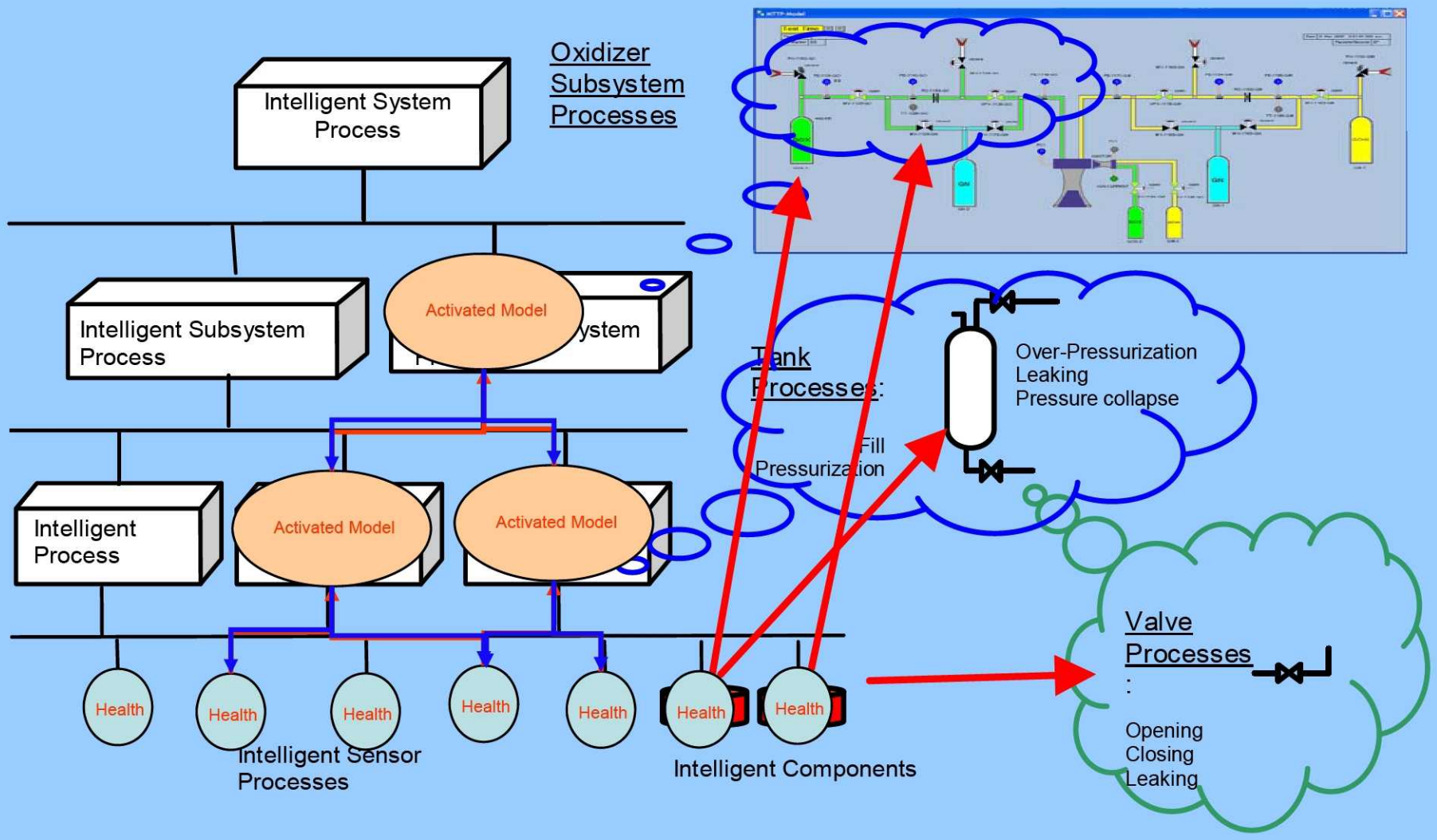
COLLEGE OF TECHNOLOGY
University of Houston

TOSS
plug-and-play

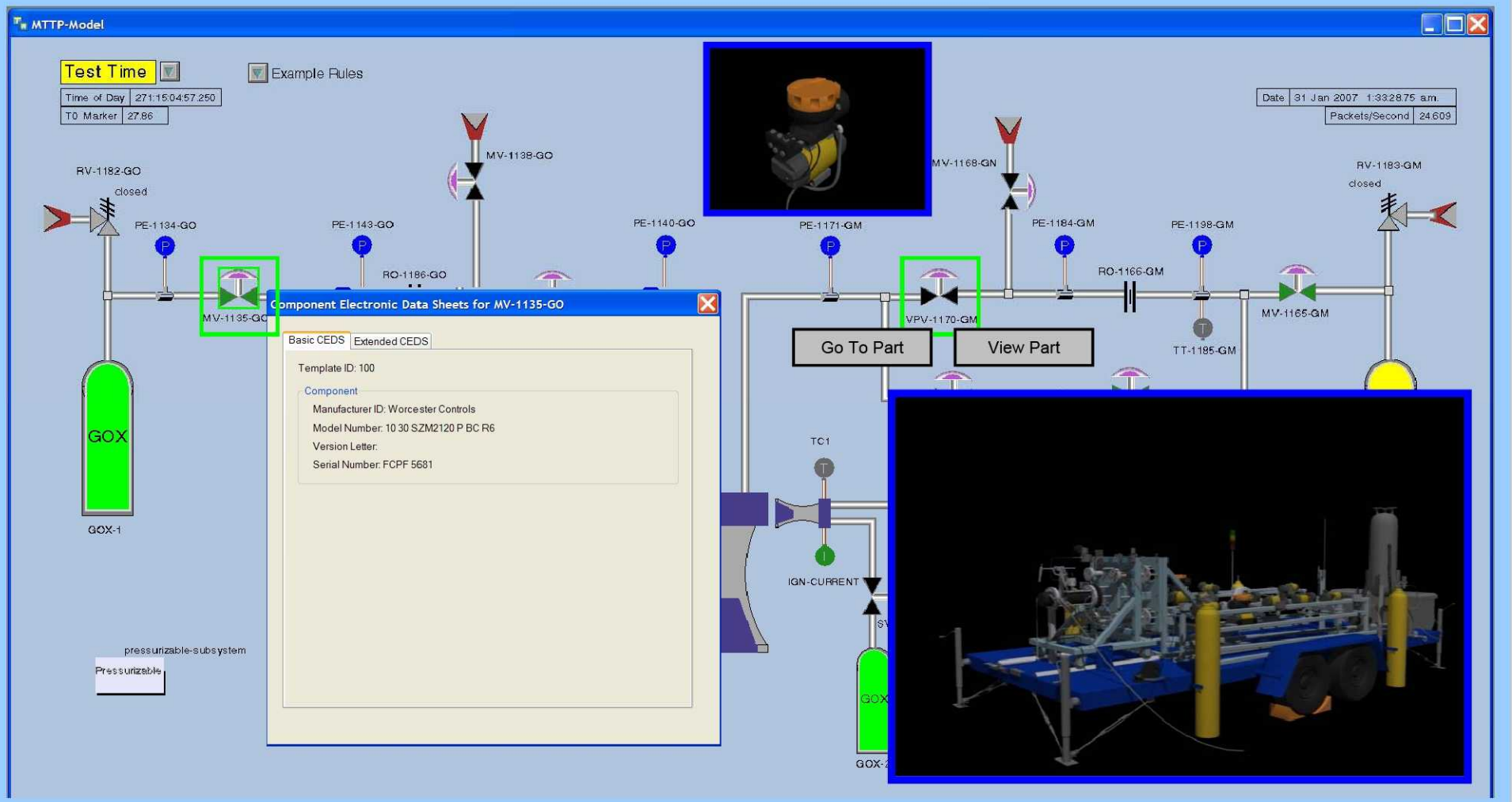
Rowan University



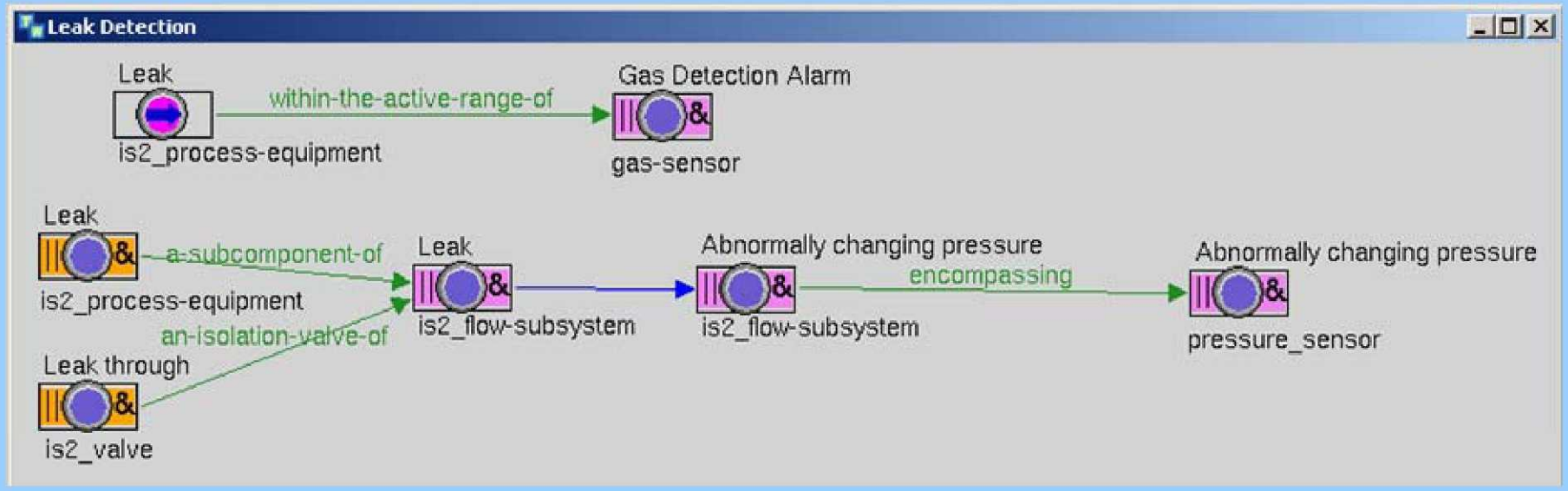
Detection and Confirmation of Anomalies Consistency Checking Cycle



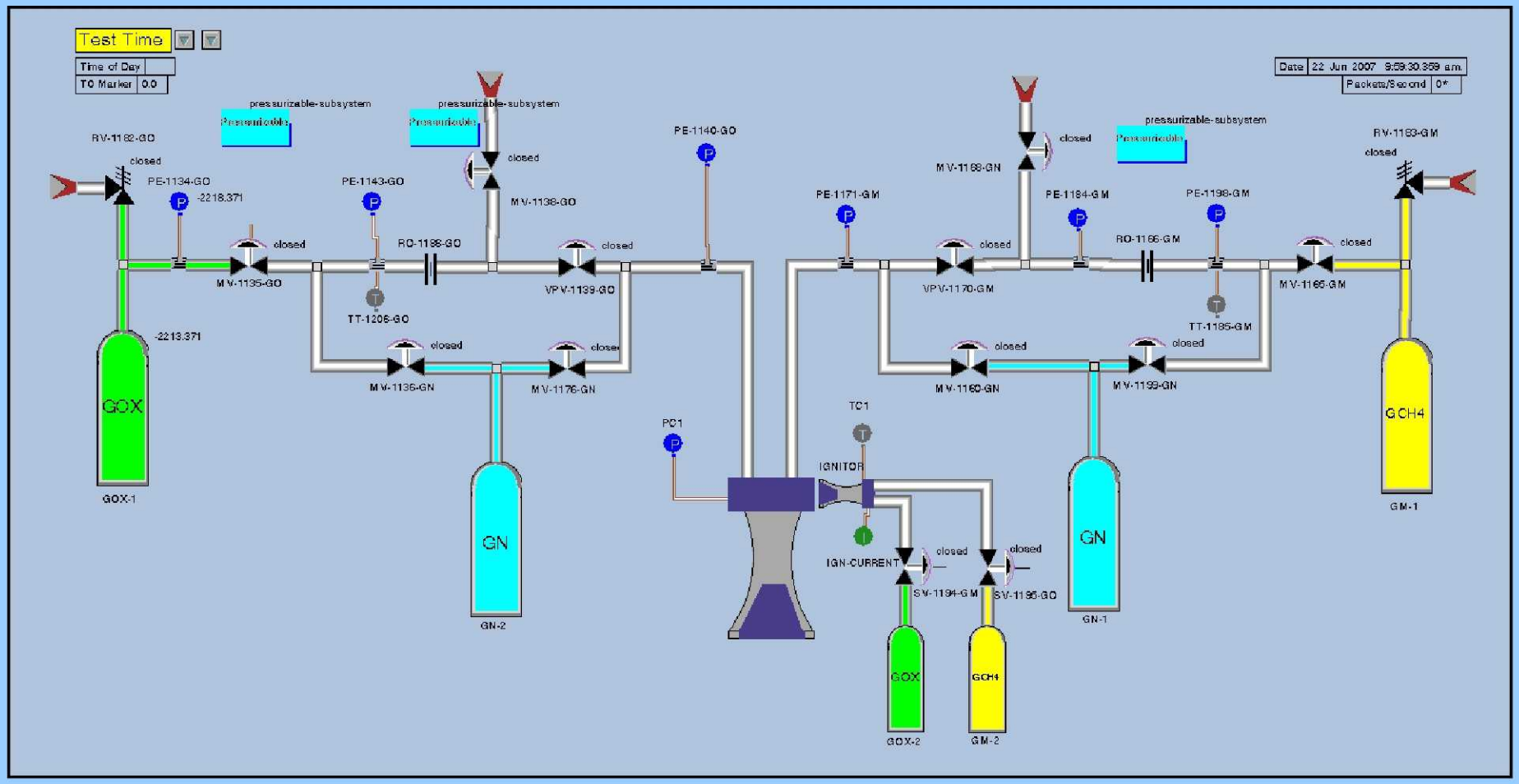
MTTP Embedded DlaK



Root-Cause Tree

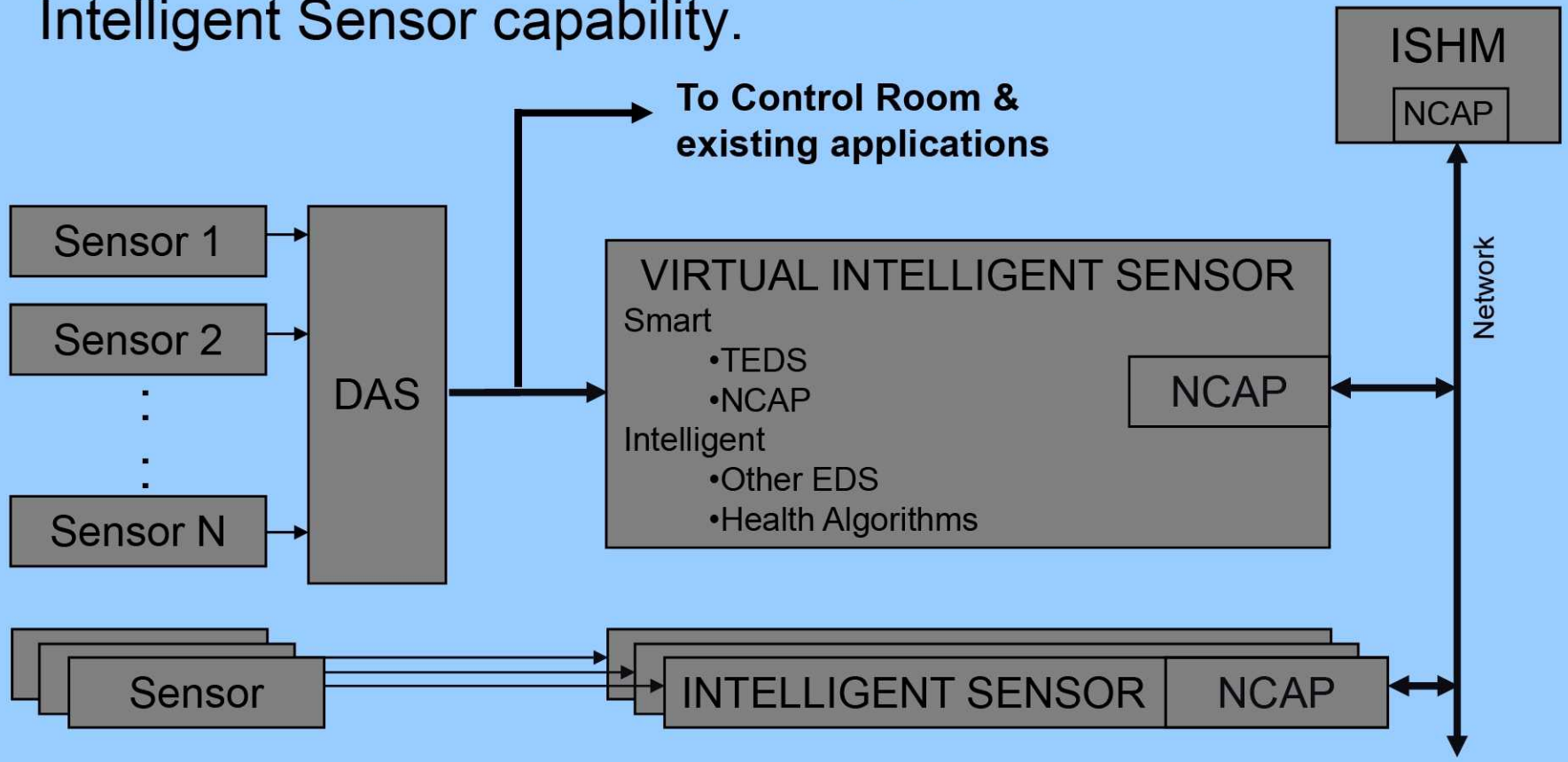


ISHM Enabling Technologies: Root Cause Analysis



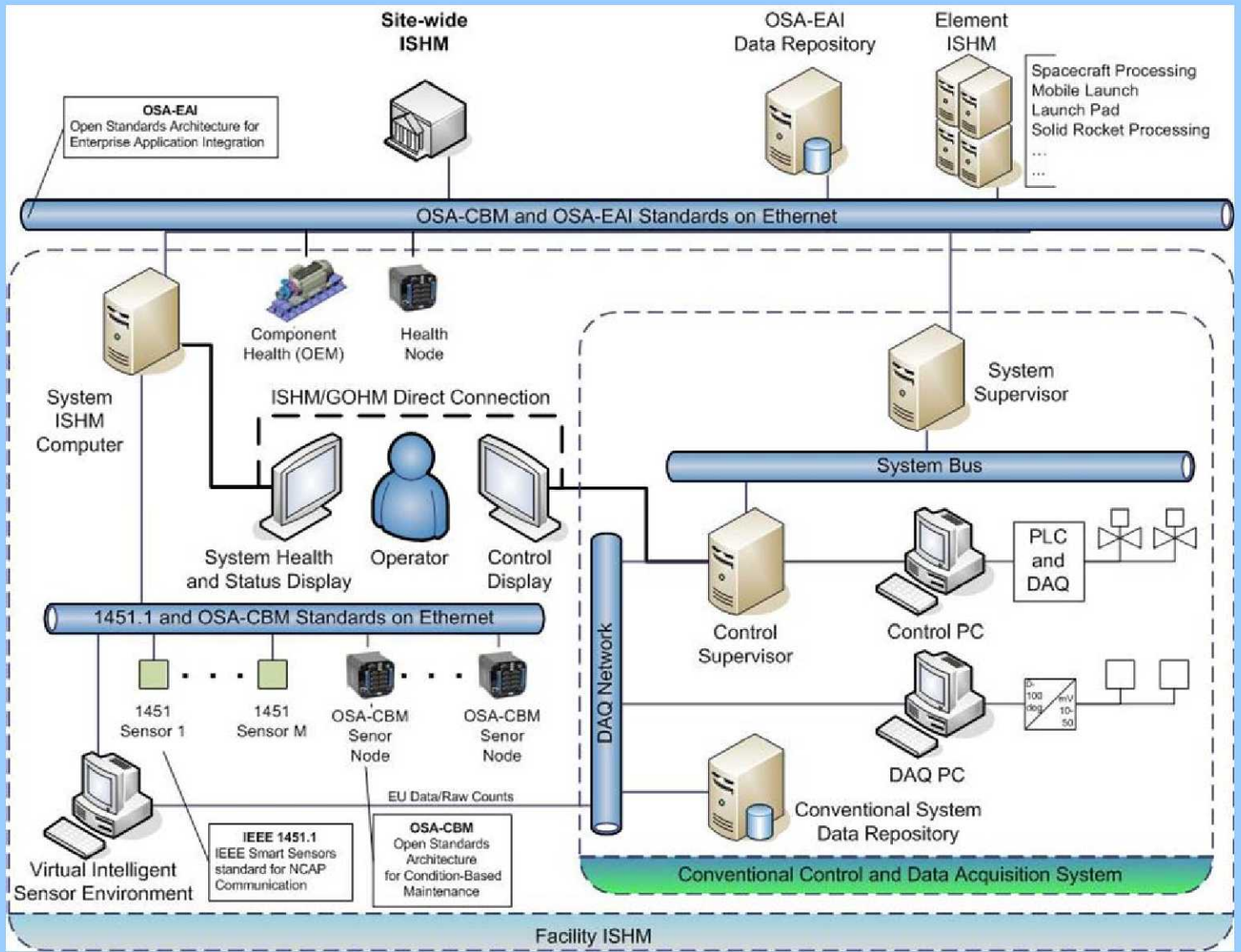
Virtual Intelligent Sensors

- Provides benefits of ISHM capabilities to existing data acquisition systems by adding Virtual Intelligent Sensor capability.

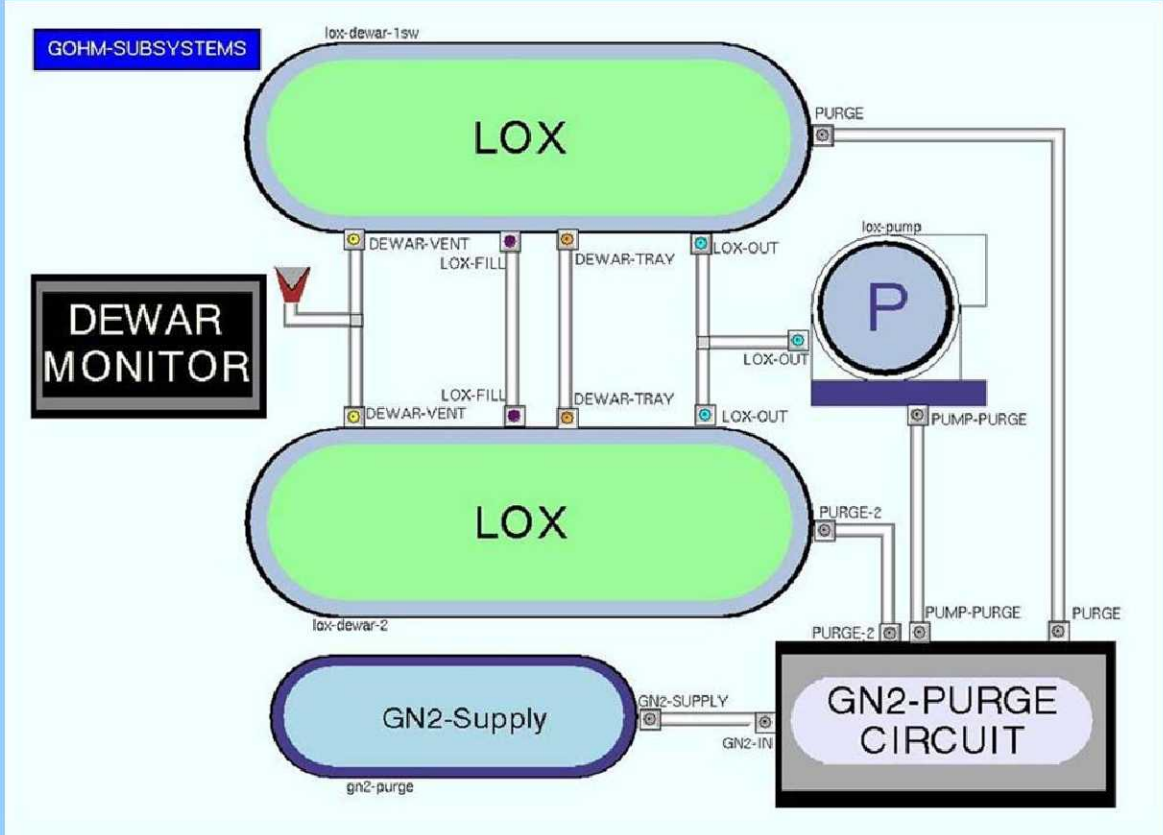


ISHM Implementations

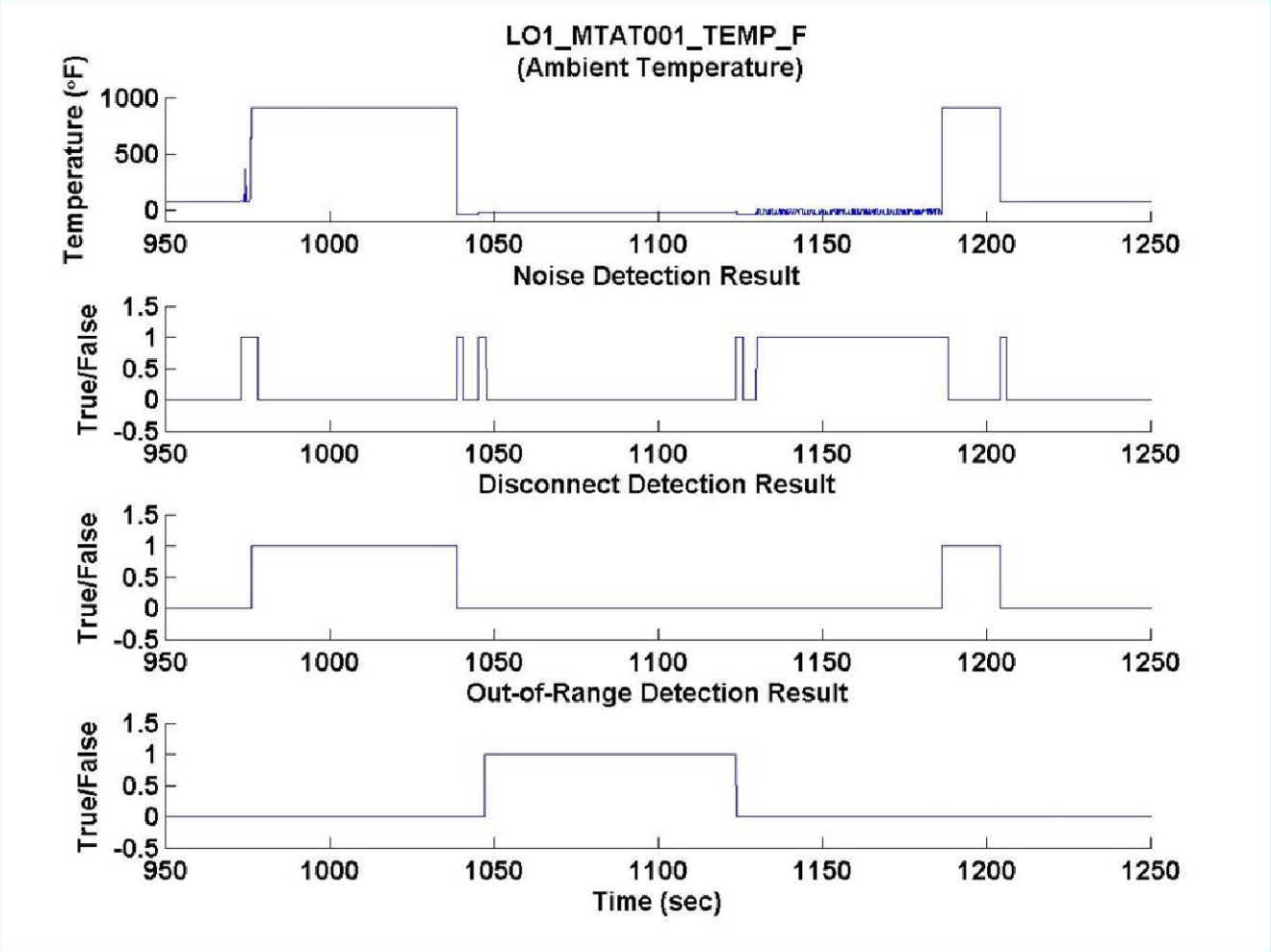
Generic Architecture to implement ISHM capability for systems with conventional equipment, with option to incorporate advanced smart/intelligent sensors and actuators.



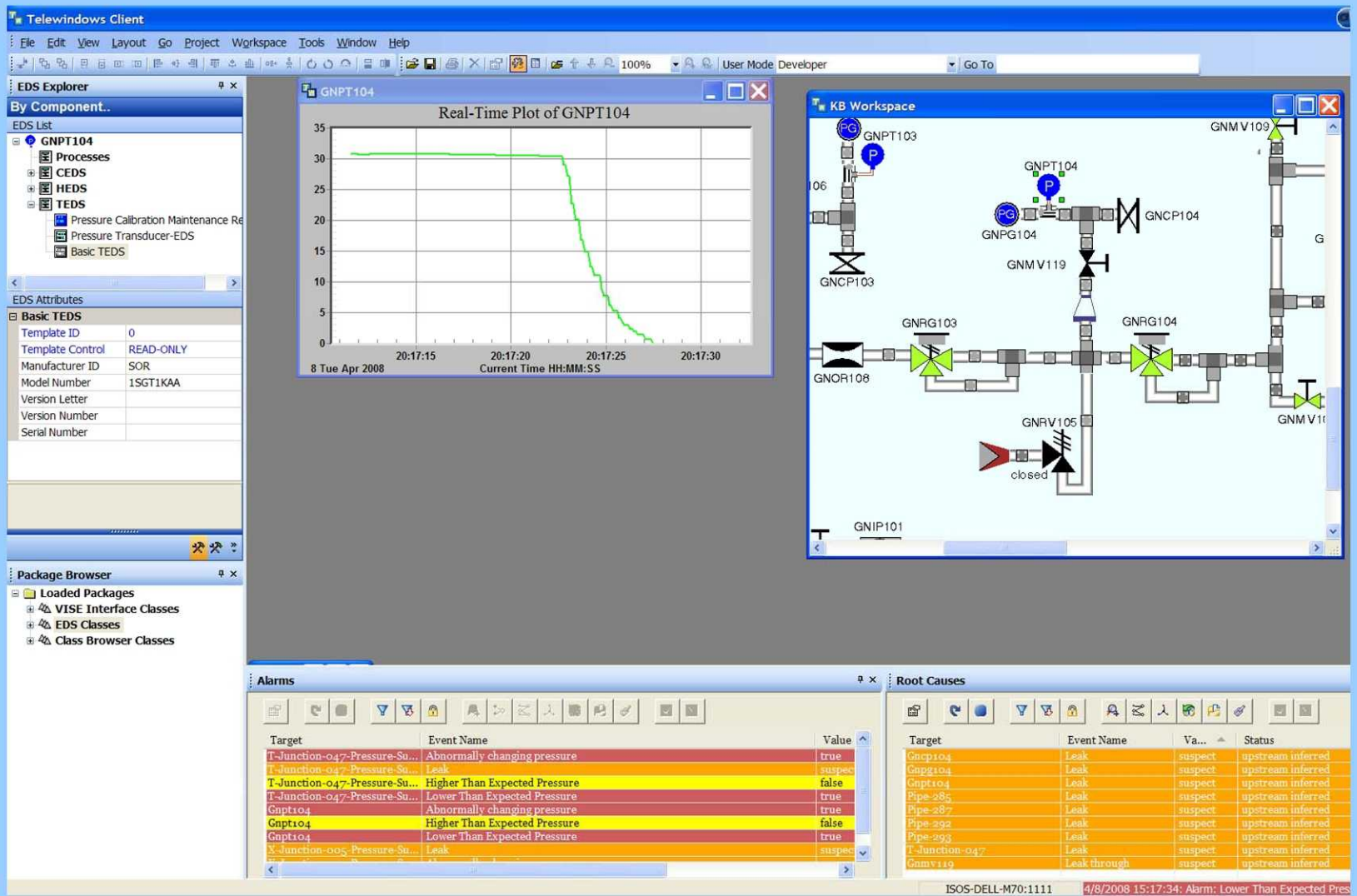
Top level view of the ISHM model of the Launch Complex 20 Facility at NASA Kennedy Space Center



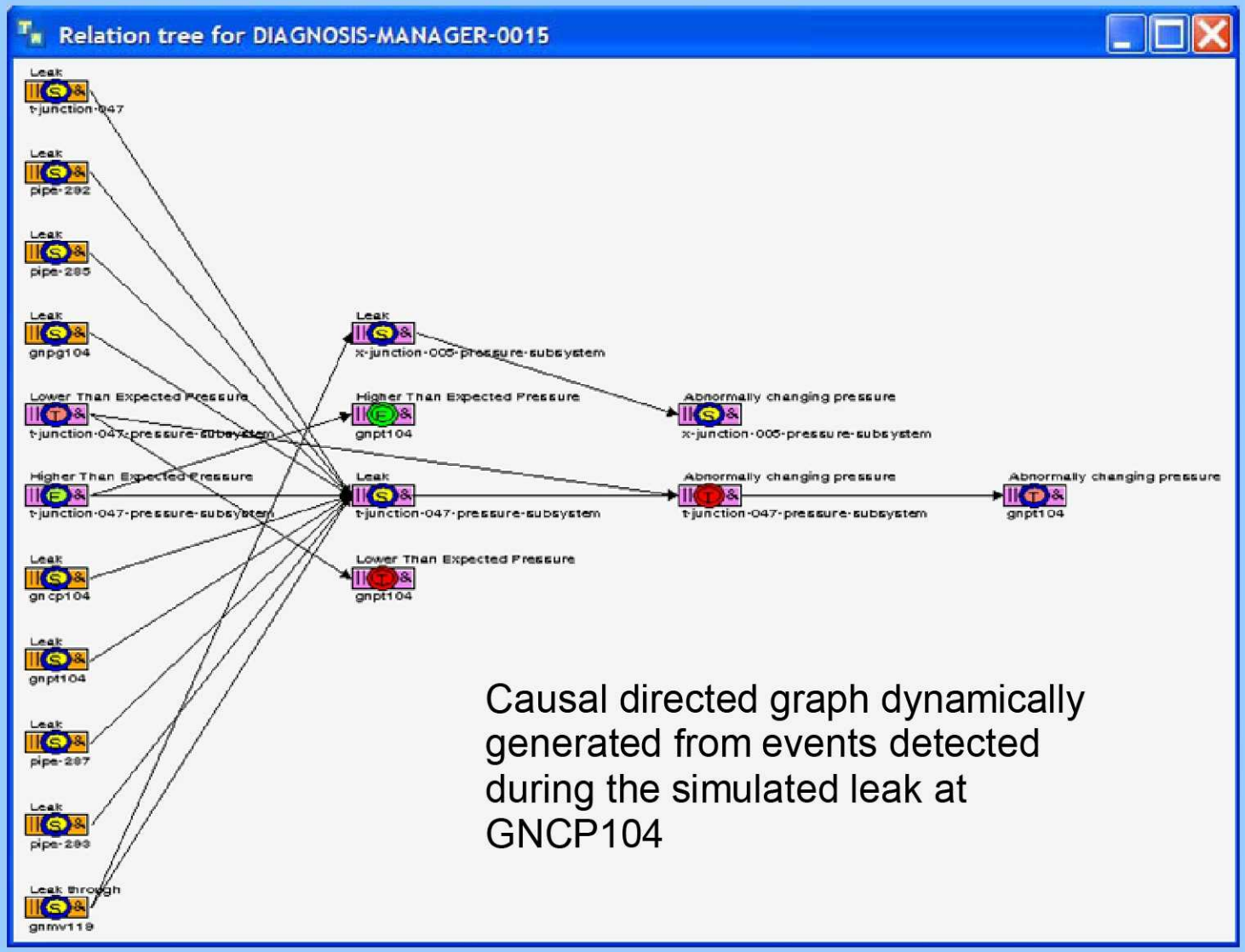
Sensor anomaly indicators detected by an intelligent sensor during a pump test using the LC-20 facility at NASA Kennedy Space Center



Screenshot of the ISHM model of the LC-20 facility at KSC showing detection of a valve leak created by opening the valve manually

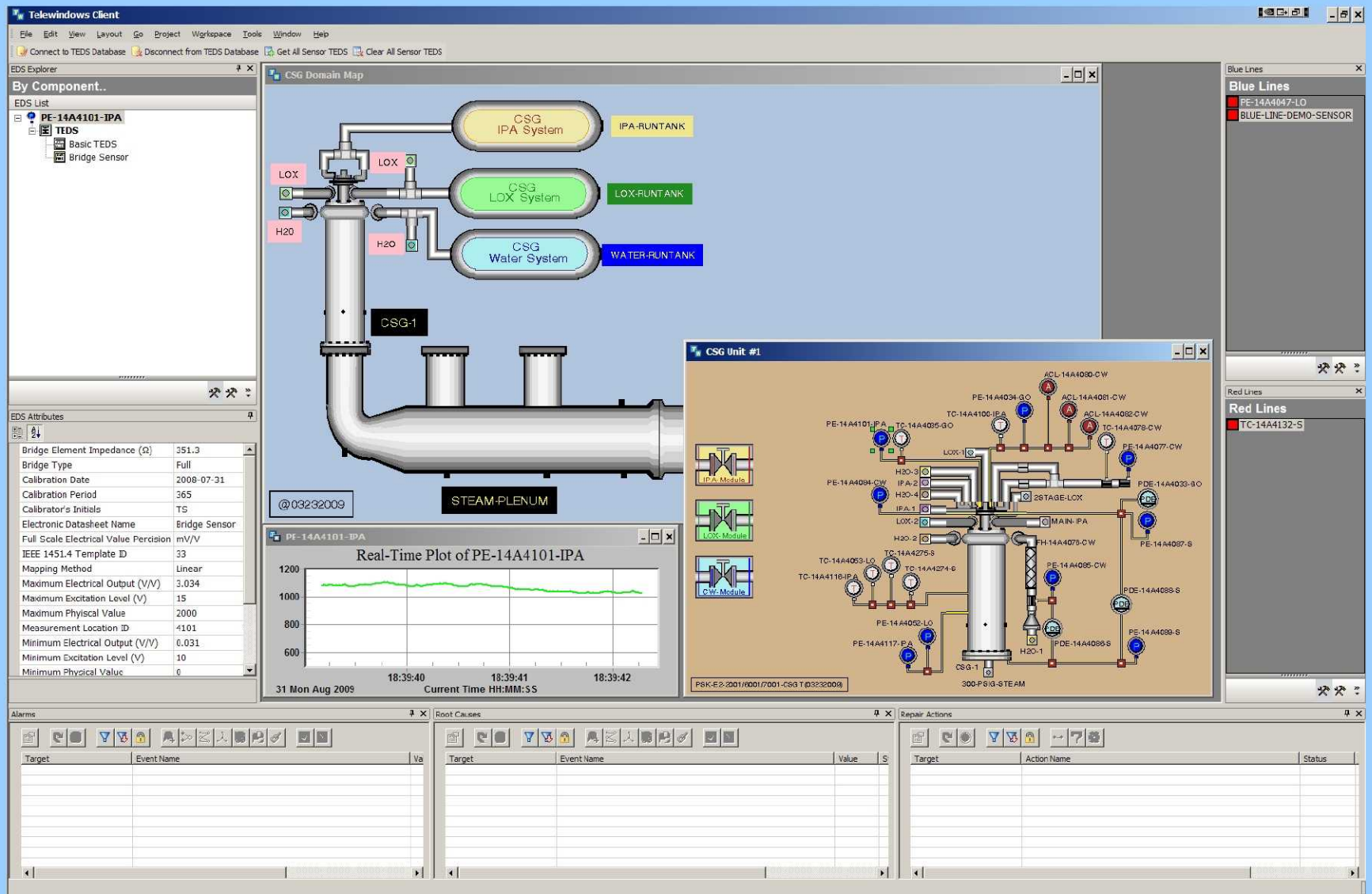


Expanded causal-directed graph generated by the detection of a leak in the subsystem where a valve was opened manually (injected leak)



Causal directed graph dynamically generated from events detected during the simulated leak at GNCP104

Pilot ISHM Implementation
Chemical Steam Generator (CSG)



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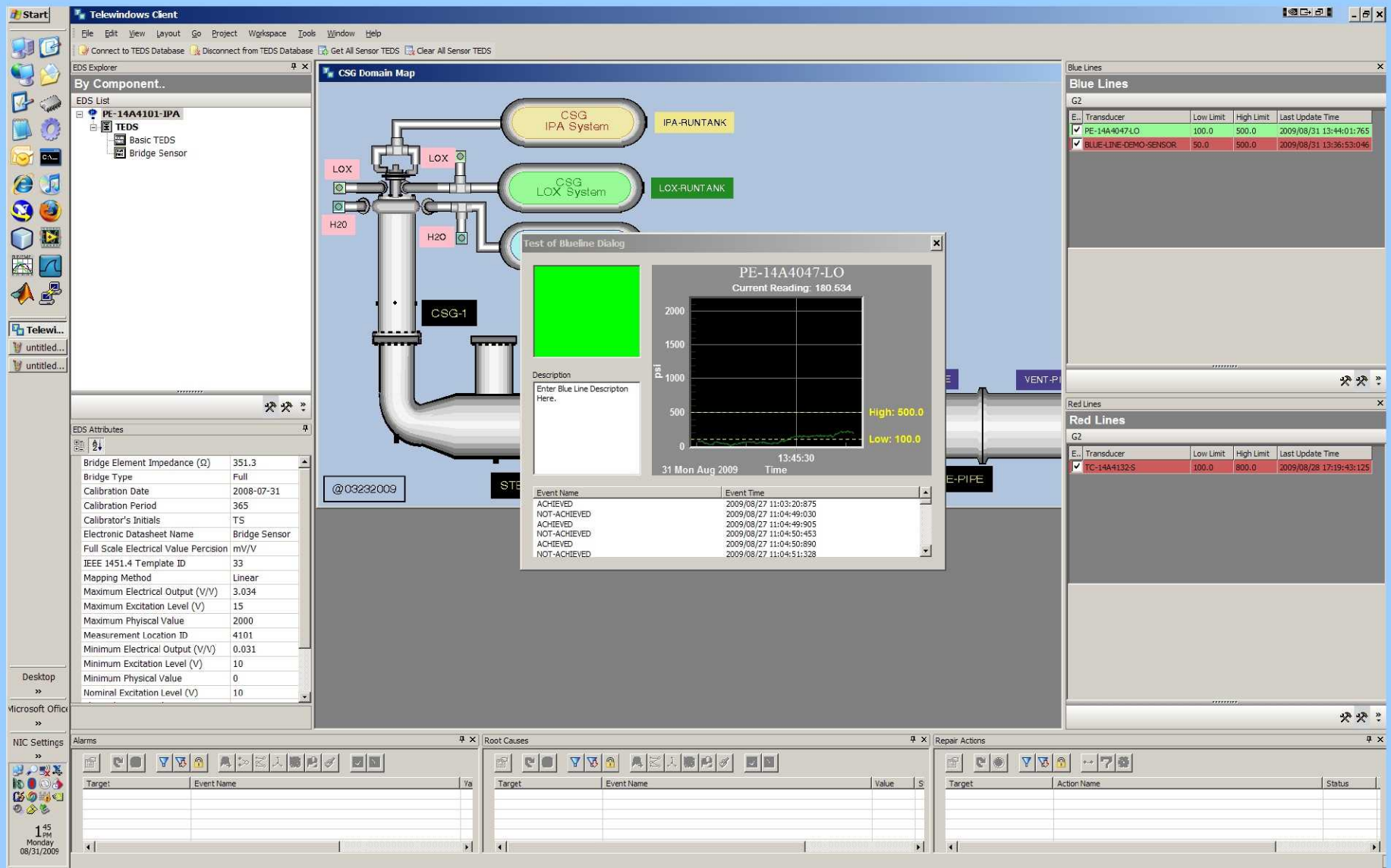

Pilot ISHM Implementation
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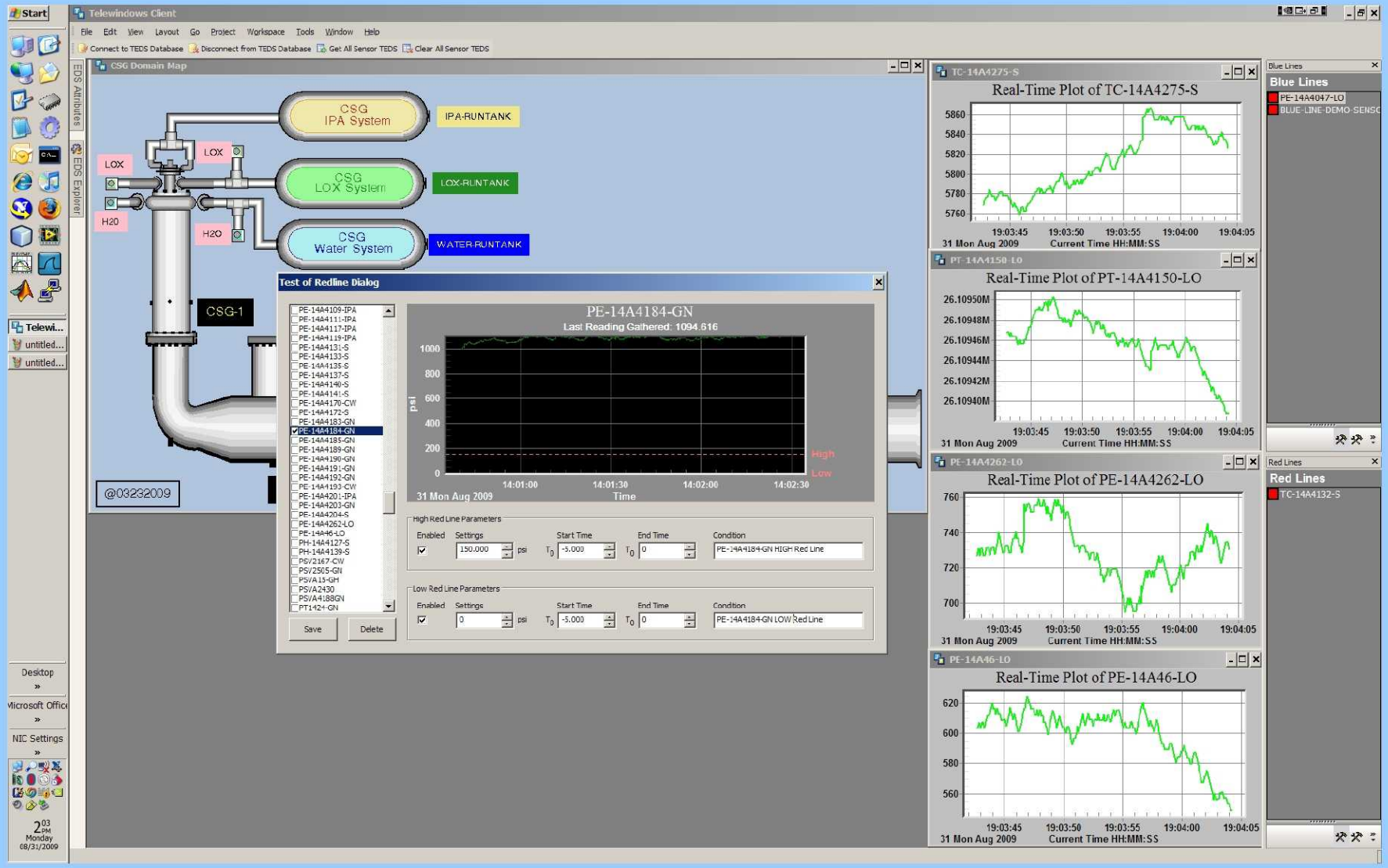


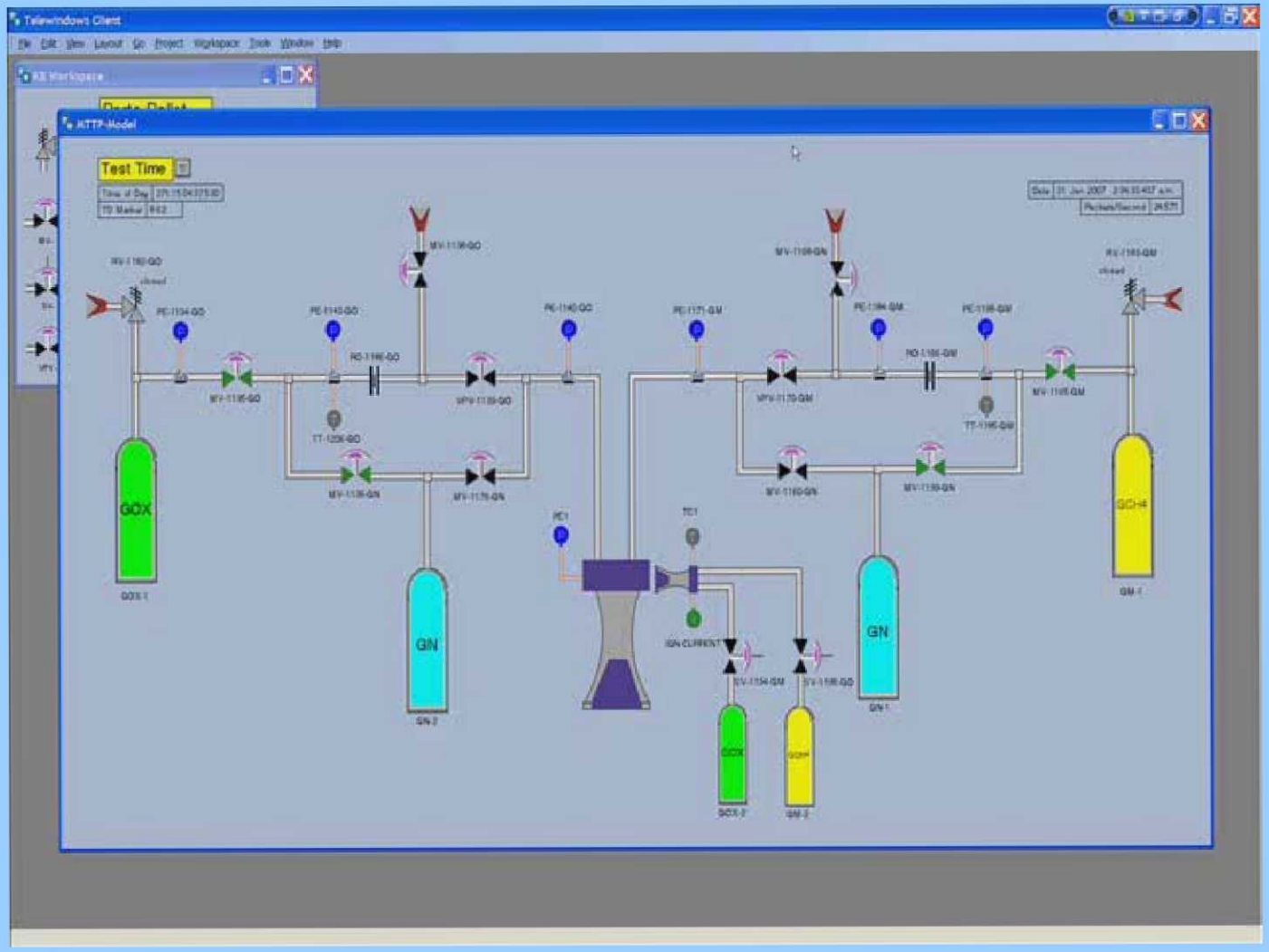
Conclusions

- A sound basis to guide the community in the conception and implementation of ISHM capability in operational systems was provided.
- The concept of “ISHM Model of a System” and a related architecture defined as a unique Data, Information, and Knowledge (DIaK) architecture were described. The ISHM architecture is independent of the typical system architecture, which is based on grouping physical elements that are assembled to make up a subsystem, and subsystems combine to form systems, etc.
- It was emphasized that ISHM capability needs to be implemented first at a low functional capability level (FCL), or limited ability to detect anomalies, diagnose, determine consequences, etc. As algorithms and tools to augment or improve the FCL are identified, they should be incorporated into the system. This means that the architecture, DIaK management, and software, must be modular and standards-based, in order to enable systematic augmentation of FCL (no ad-hoc modifications).
- A set of technologies (and tools) needed to implement ISHM were described. One essential tool is a software environment to create the ISHM Model. The software environment encapsulates DIaK, and an infrastructure to focus DIaK on determining health (detect anomalies, determine causes, determine effects, and provide integrated awareness of the system to the operator). The environment includes gateways to communicate in accordance to standards, specially the IEEE 1451.1 Standard for Smart Sensors and Actuators

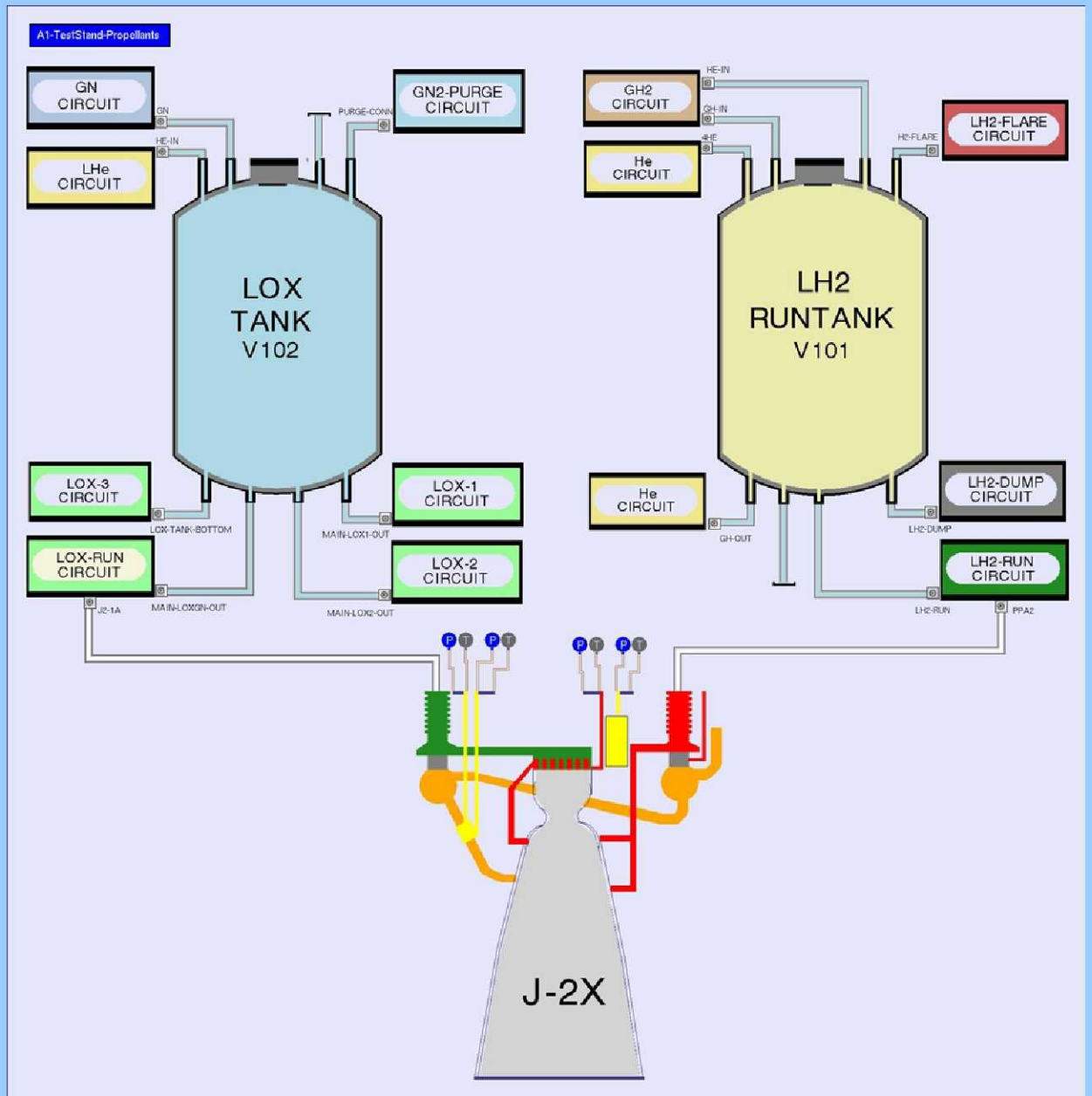
Backup Slides

MTTP End-to-End System

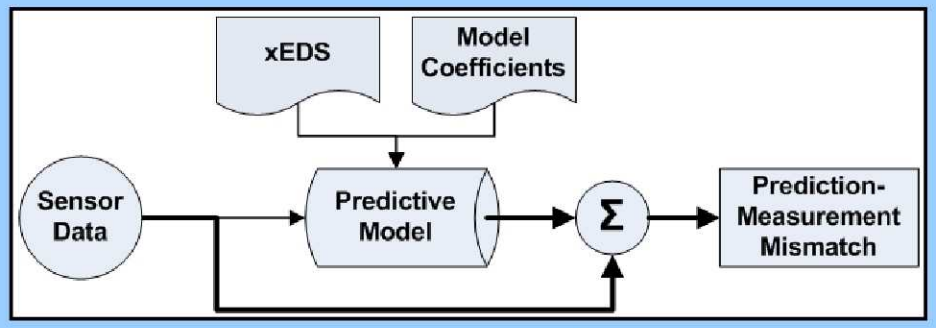
Methane Thruster Testbed Project

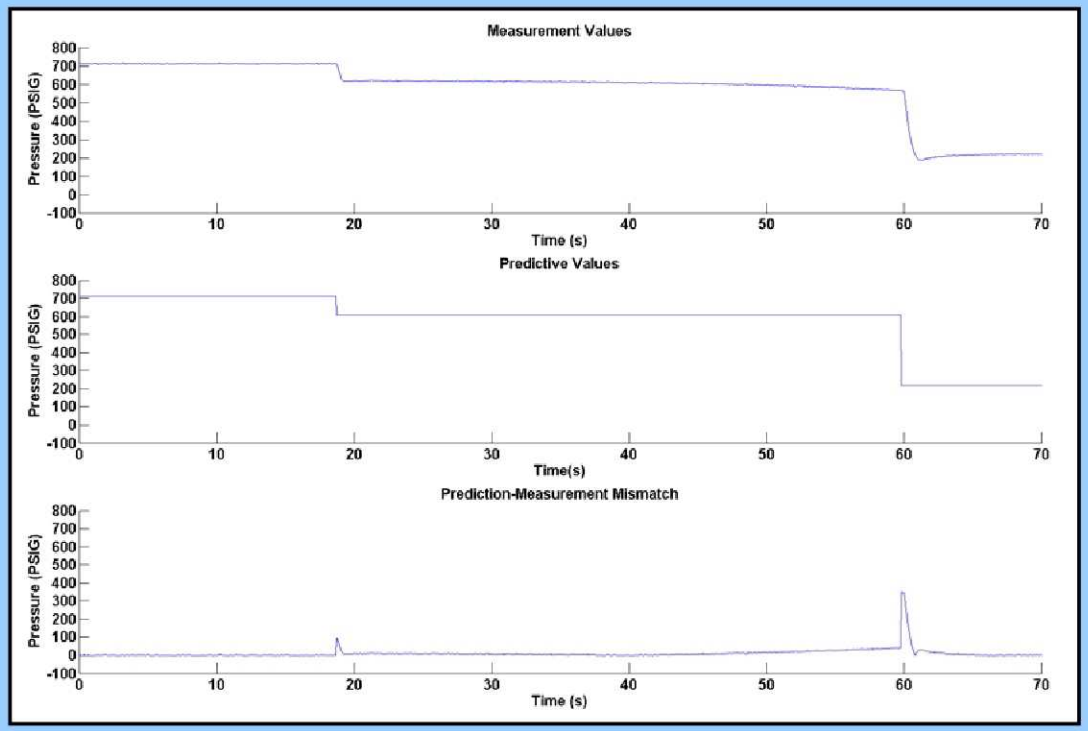


A1 and J2-X ISHM MODEL

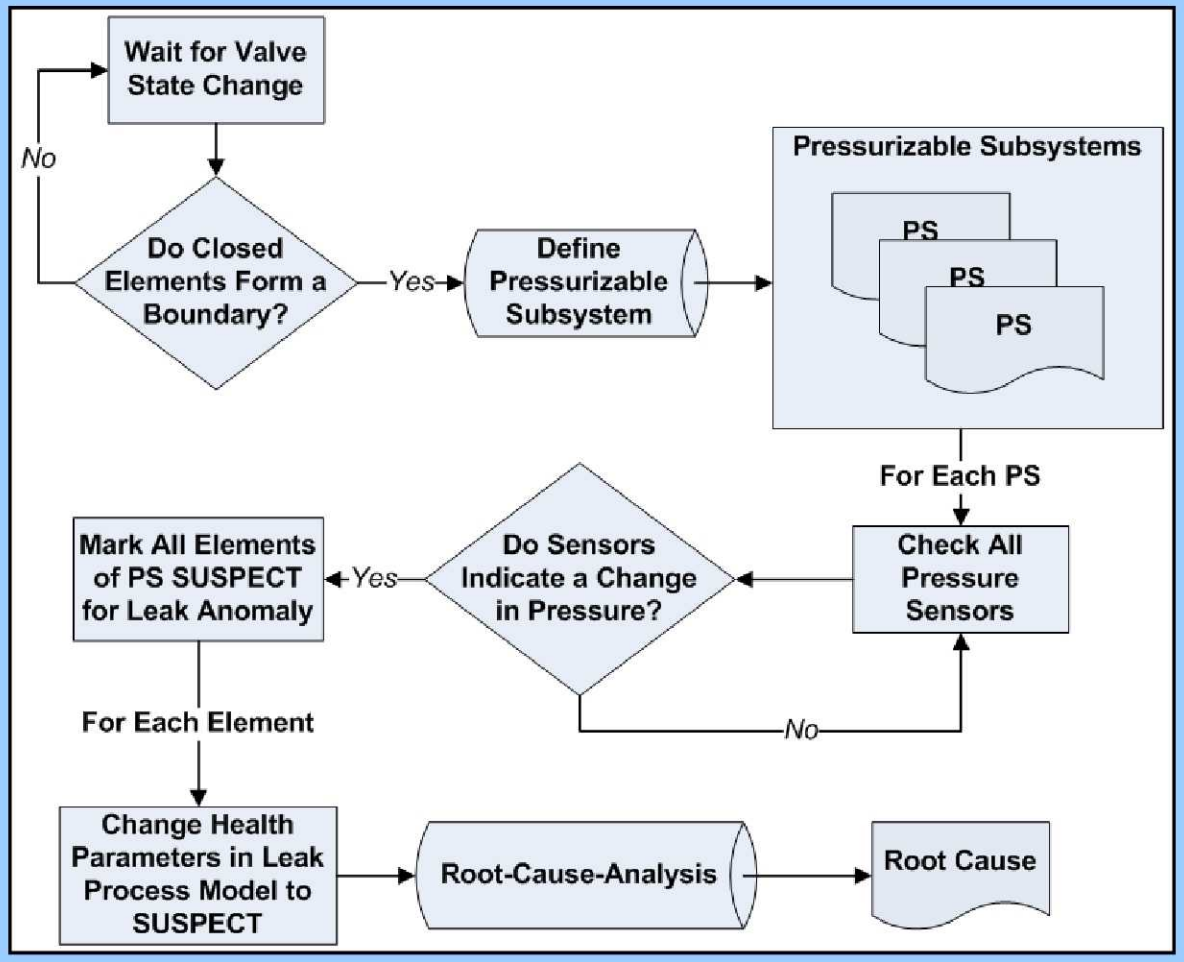


Runtime Predictive Modeling





Checking for Pressure Leaks

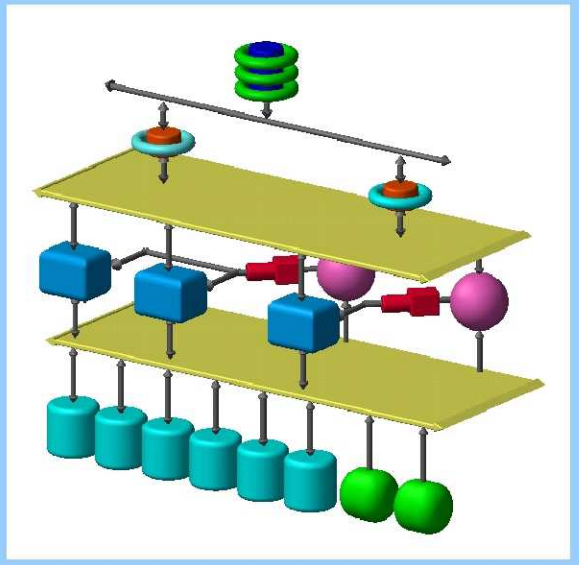


Electronic Datasheets

- Electronic Data Sheets (EDS)
  - Transducer Electronic Data Sheets (TEDS)
    - Calibration
  - Health Electronic Data Sheet (HEDS)
    - Codified fault conditions and system phases
    - Key detection algorithms w/ parameters
  - Component EDS (CEDS)
    - Manufacturing details
    - Engineering data
    - Traceability
  - Other EDS

Intelligent Sensors

- Smart sensor
  - NCAP (Go Active, Announce)
  - Publish data
  - Set/Get TEDS
- Intelligent sensor
  - Set/Get HEDS
  - Publish health
- Detect classes of anomalies using:
  - Using statistical measures
    - Mean
    - Standard deviation
    - RMS
  - Polynomial fits
  - Derivatives (1st, 2nd)
  - Filtering—e.g., Butterworth HP
  - FFT—e.g., 64-point
  - Algorithms for
    - Flat
    - Impulsive ("spike") noise
    - White noise
  - Other (ANN, etc.)



Intelligent Sensors have embedded ISHM functionality and support ***Smart Sensor*** standards