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

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Acknowledgements

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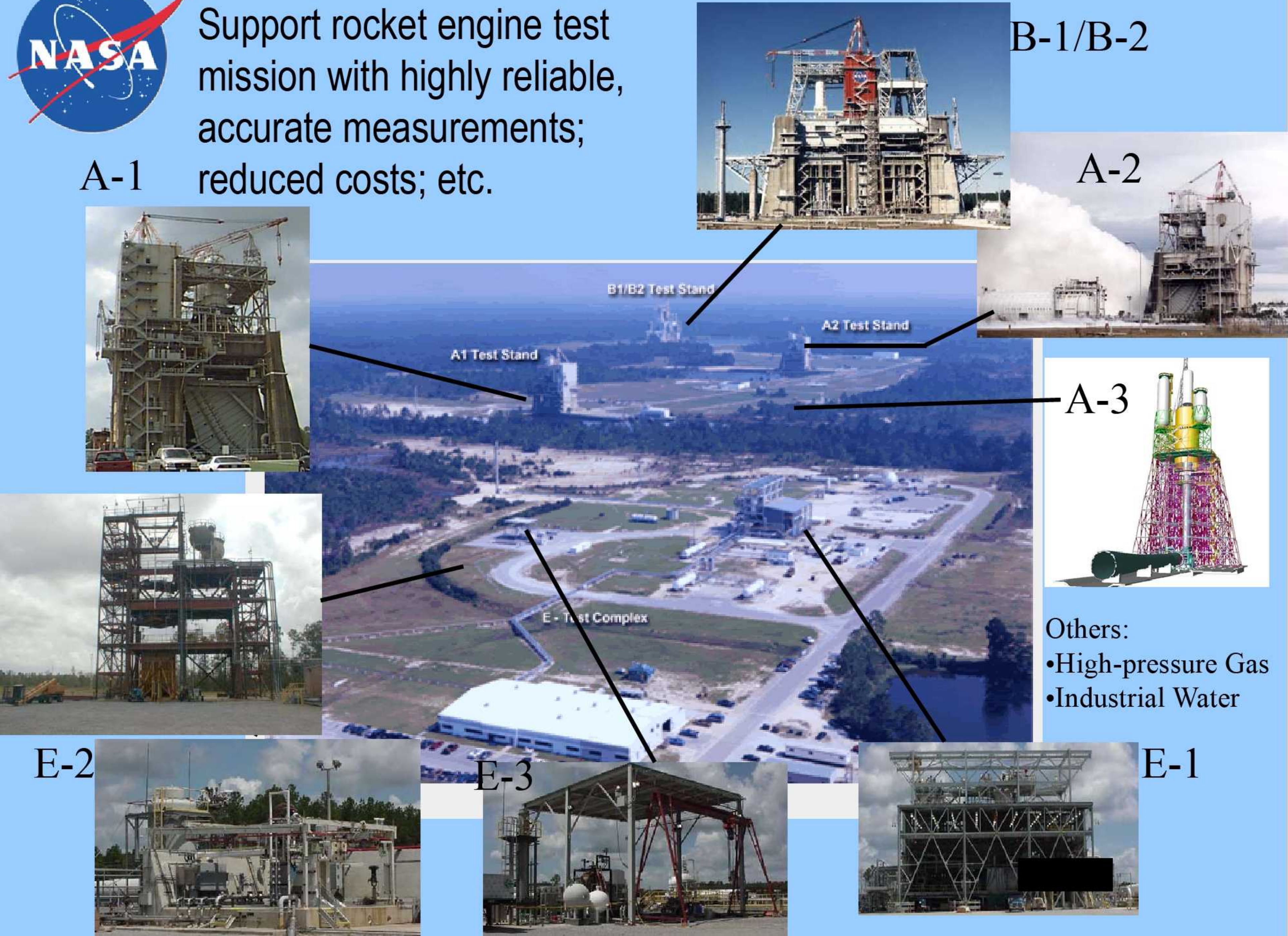
Outline

- 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.



[redacted]

Others:
- High-pressure Gas
- Industrial Water

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

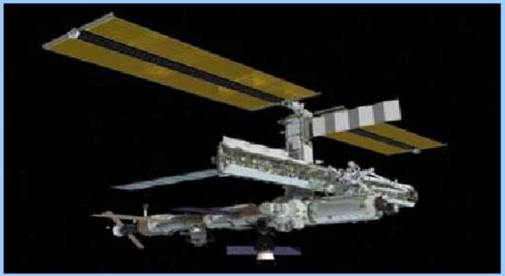
- Use available data, information, and knowledge to
  - Identify system state
  - Detect anomalies
  - Determine anomaly causes
  - Predict system impacts
  - Predict future anomalies
  - Recommend timely mitigation steps
  - Evolve to incorporate new knowledge

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

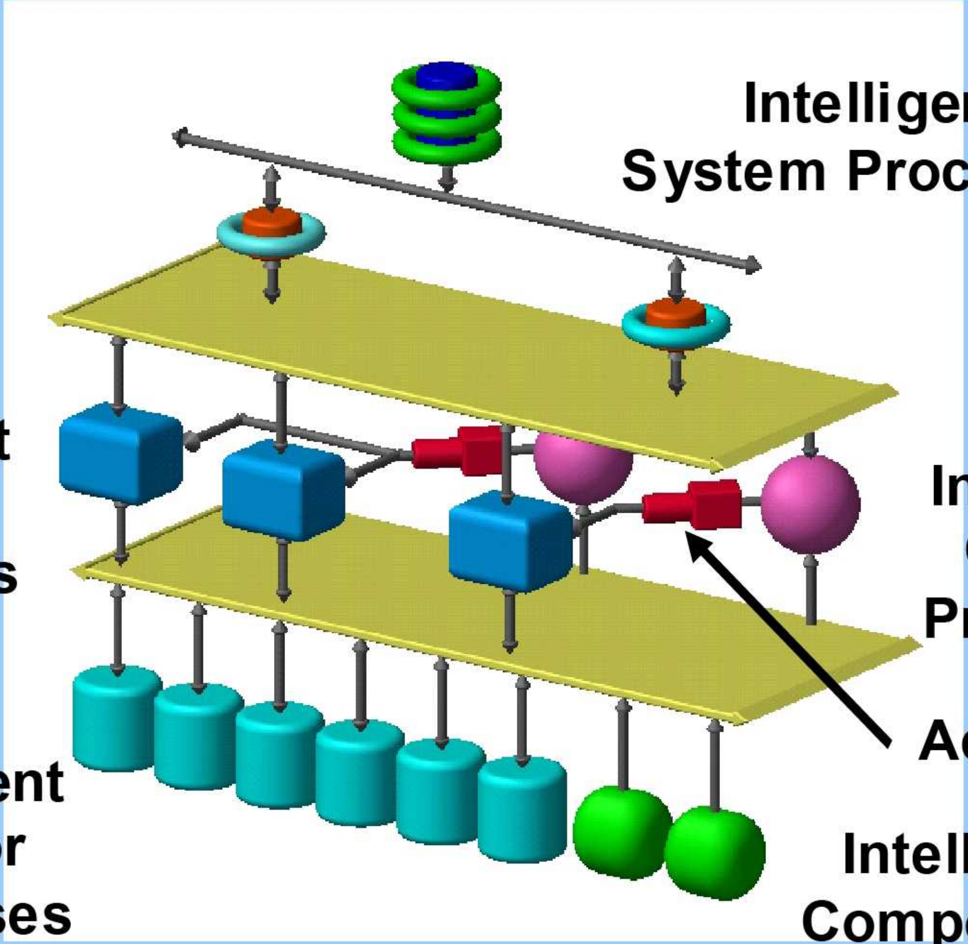
Concepts and Approach

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)



Intelligent System Processes

Intelligent Subsystem Processess

Intelligent Element Processes

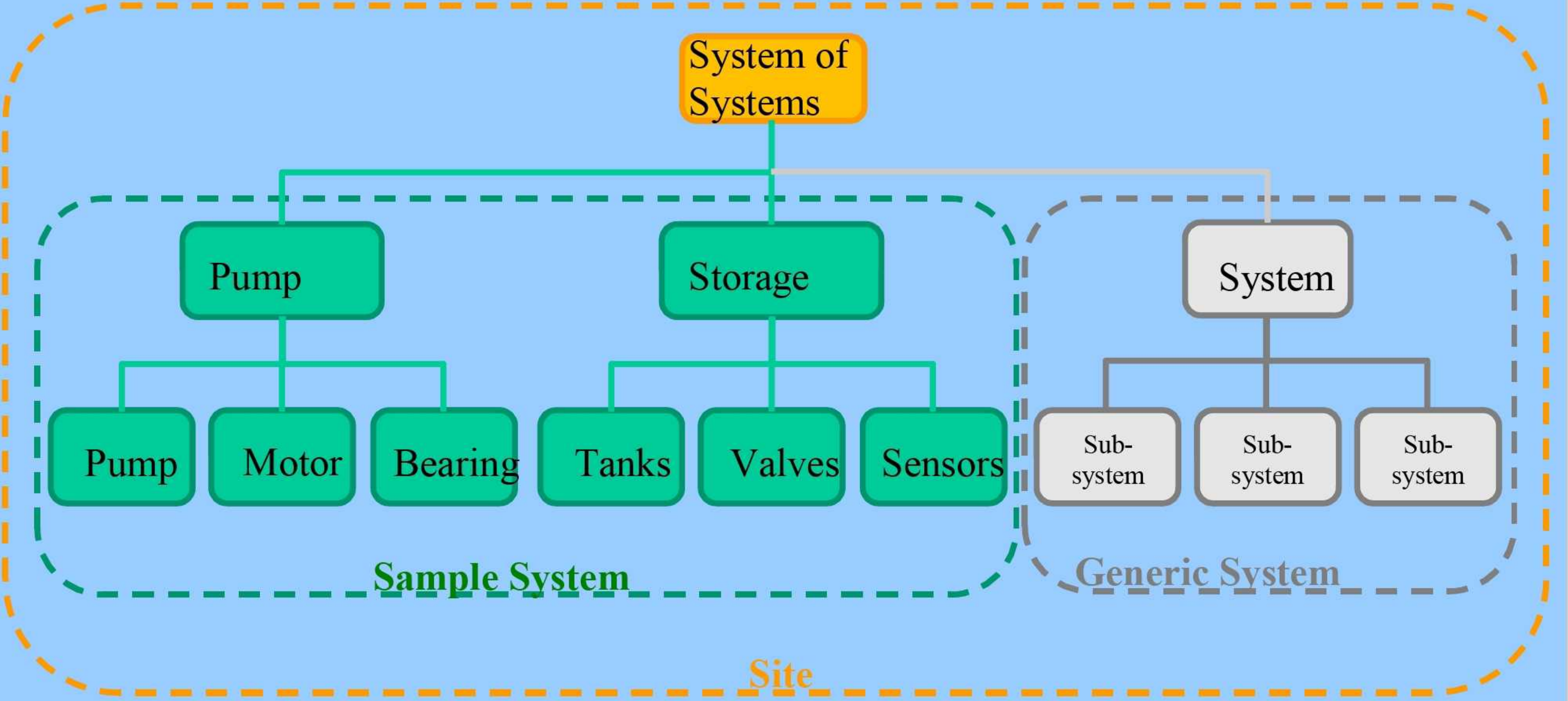
Intelligent Control Processes

Actuator

Intelligent Sensor Processes

Intelligent Components

Classic architecture describing how systems are built



System of Systems

Pump

Storage

System

Pump

Motor

Bearing

Tanks

Valves

Sensors

Sub-system

Sub-system

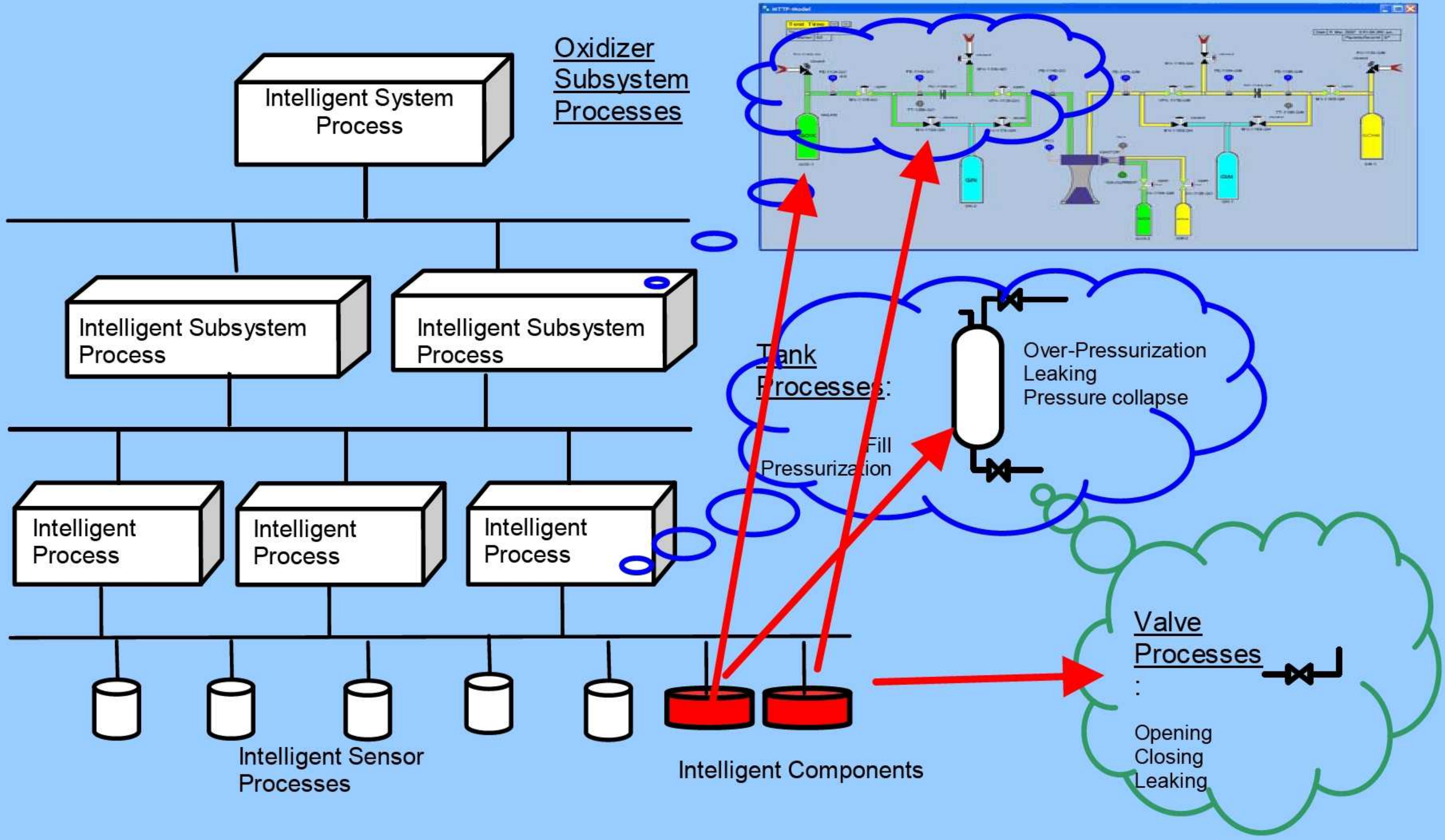
Sub-system

Sample System

Generic System

Site

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



Intelligent System Process

Oxidizer Subsystem Processes

Intelligent Subsystem Process

Intelligent Subsystem Process

Tank Processes:

Fill

Pressurization

Over-Pressurization
Leaking
Pressure collapse

Intelligent Process

Intelligent Process

Intelligent Process

Valve Processes:

Opening
Closing
Leaking

Intelligent Sensor Processes

Intelligent Components

SSC Integrated System Health Management (ISHM) Capabilities

Health Anomaly Database:
Health Electronic Data Sheets
Repository of anomalies

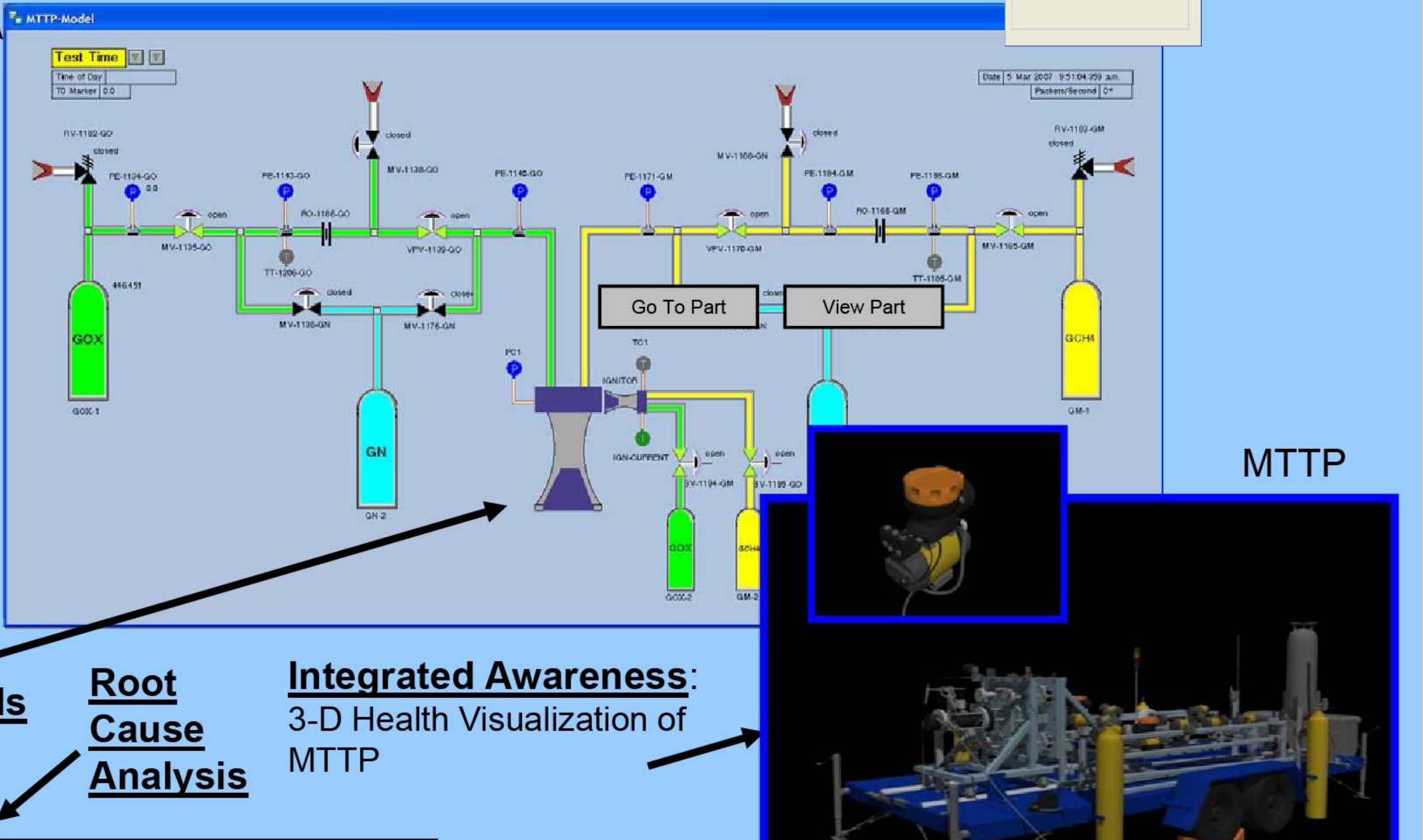
Component Electronic Data Sheet for MV-1135-GO

Basic CEDS | Extended CEDS

Manufacture ID: Worcester Controls

Version Letter

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



Anomaly Detection:
Leaks, etc.

Intelligent Sensors: IEEE Standard+Health

Embedding of Predictive Models

Root Cause Analysis

Integrated Awareness:
3-D Health Visualization of MTTP

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

PENNSTATE

NASA KSC

Open Systems Architectures

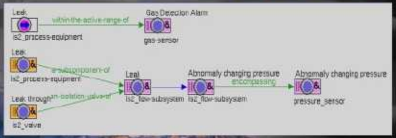
Rocket Engine Test Stand

Prognostics & Anomaly Detection

Pratt & Whitney
A United Technologies Company

NASA ARC

GENERAL ATOMICS
ELECTROMAGNETIC SYSTEMS

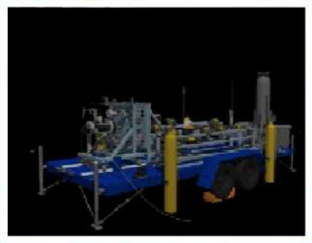


Root Cause Analysis

Test Article

Integrated Awareness

Rowan University



IEEE 1451 Smart & Intelligent Sensors

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ATK

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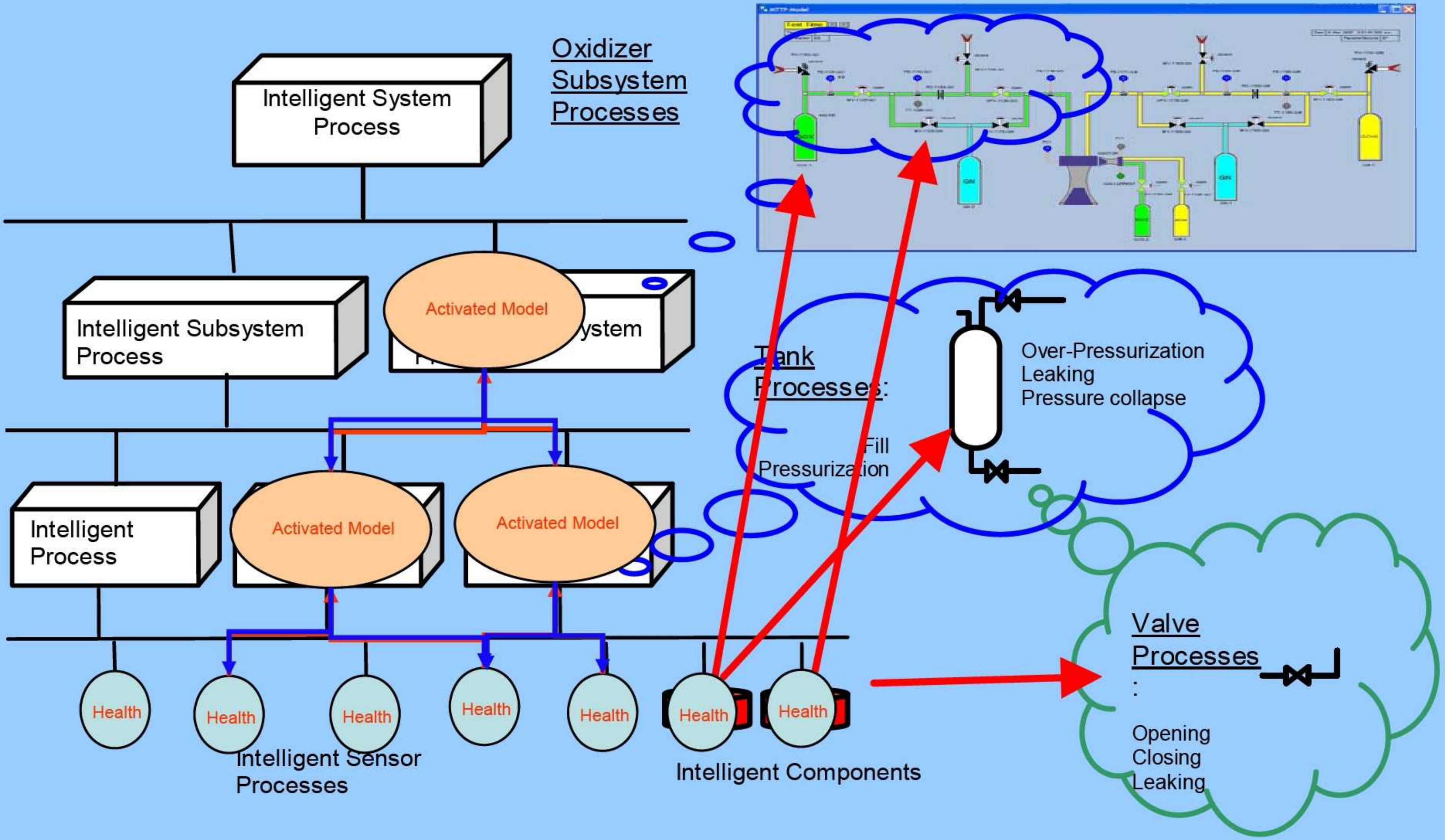
Innovative Concepts in Systems Engineering

NVE
NVE CORPORATION

Rowan University

COLLEGE OF TECHNOLOGY
University of Houston

Detection and Confirmation of Anomalies Consistency Checking Cycle



Intelligent System Process

Oxidizer Subsystem Processes

Intelligent Subsystem Process

Intelligent Process

Tank Processes:

Fill

Pressurization

Over-Pressurization
Leaking
Pressure collapse

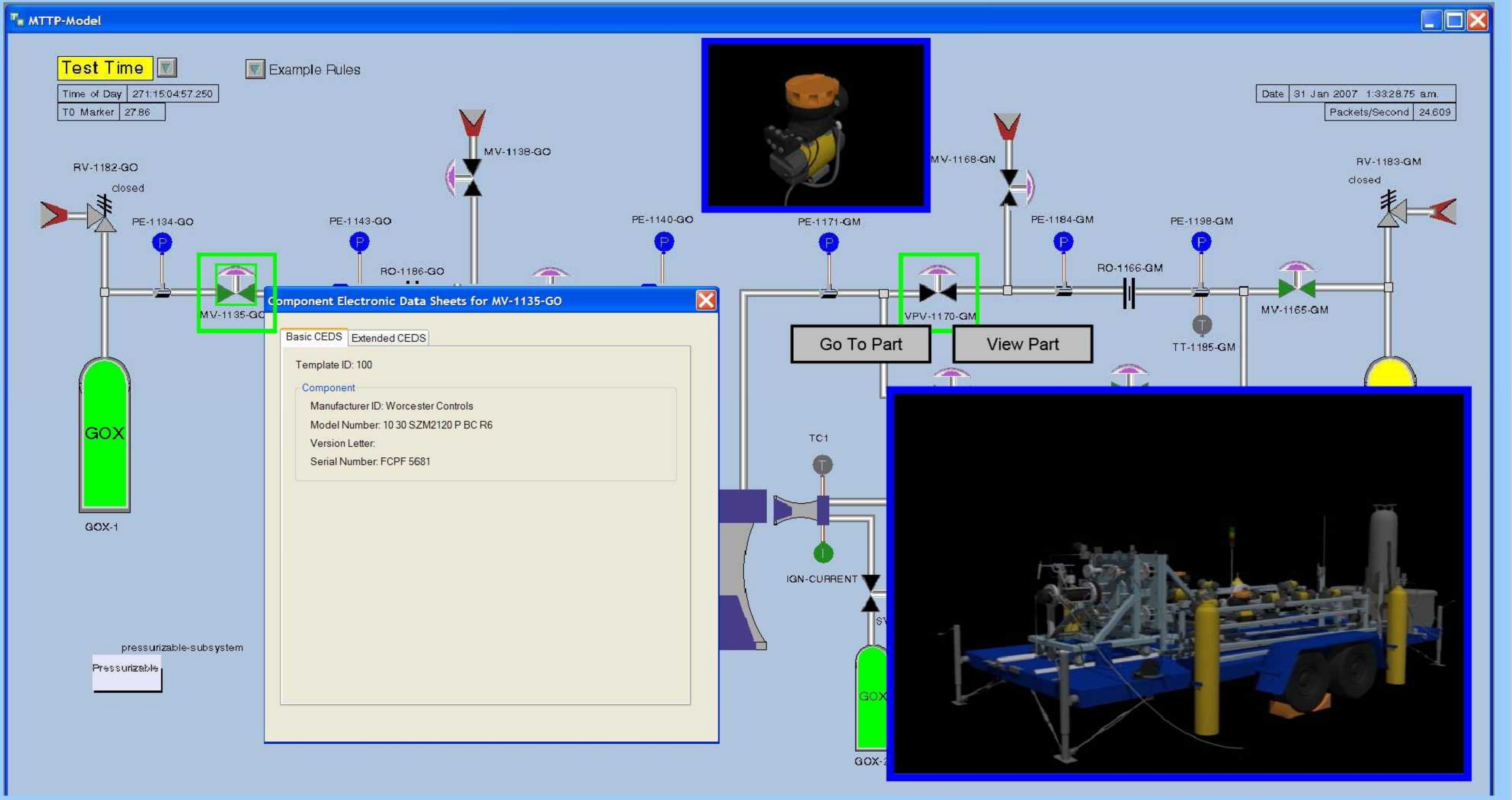
Valve Processes:

Opening
Closing
Leaking

Intelligent Sensor Processes

Intelligent Components

MTTP Embedded DIaK



Time of Day	271:15:04:57.250
T0 Marker	27.86

Date	31 Jan 2007 1:33:28.75 a.m.
Packets/Second	24.609

Component Electronic Data Sheets for MV-1135-GO

Template ID: 100

Component

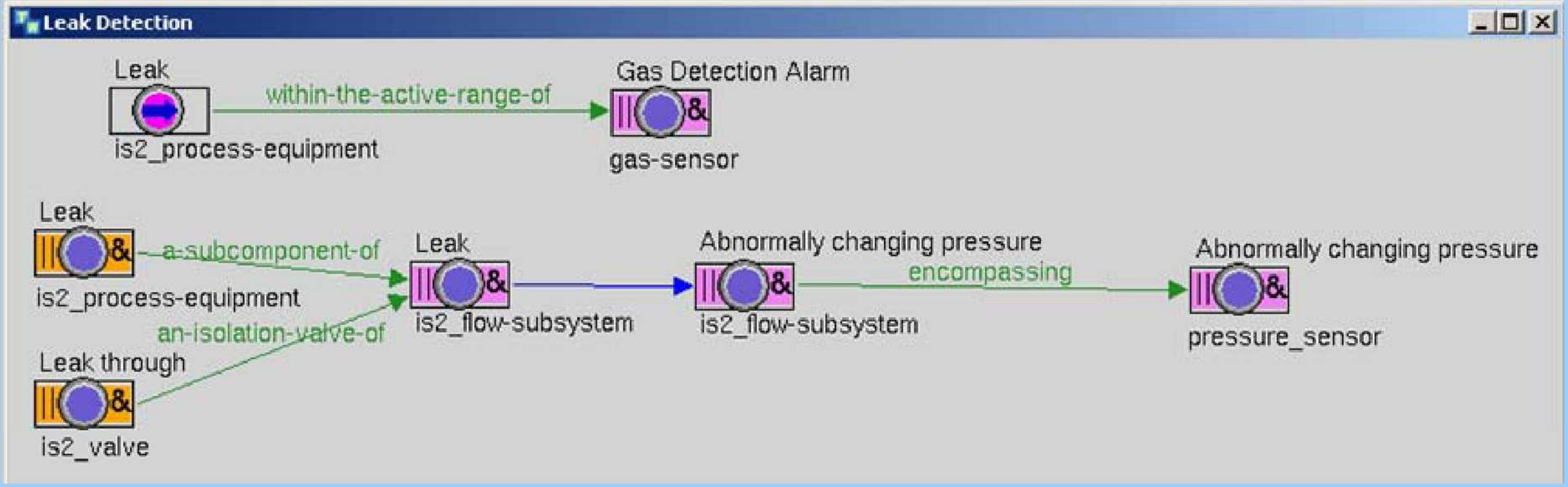
Manufacturer ID: Worcester Controls

Model Number: 10 30 SZM2120 P BC R6

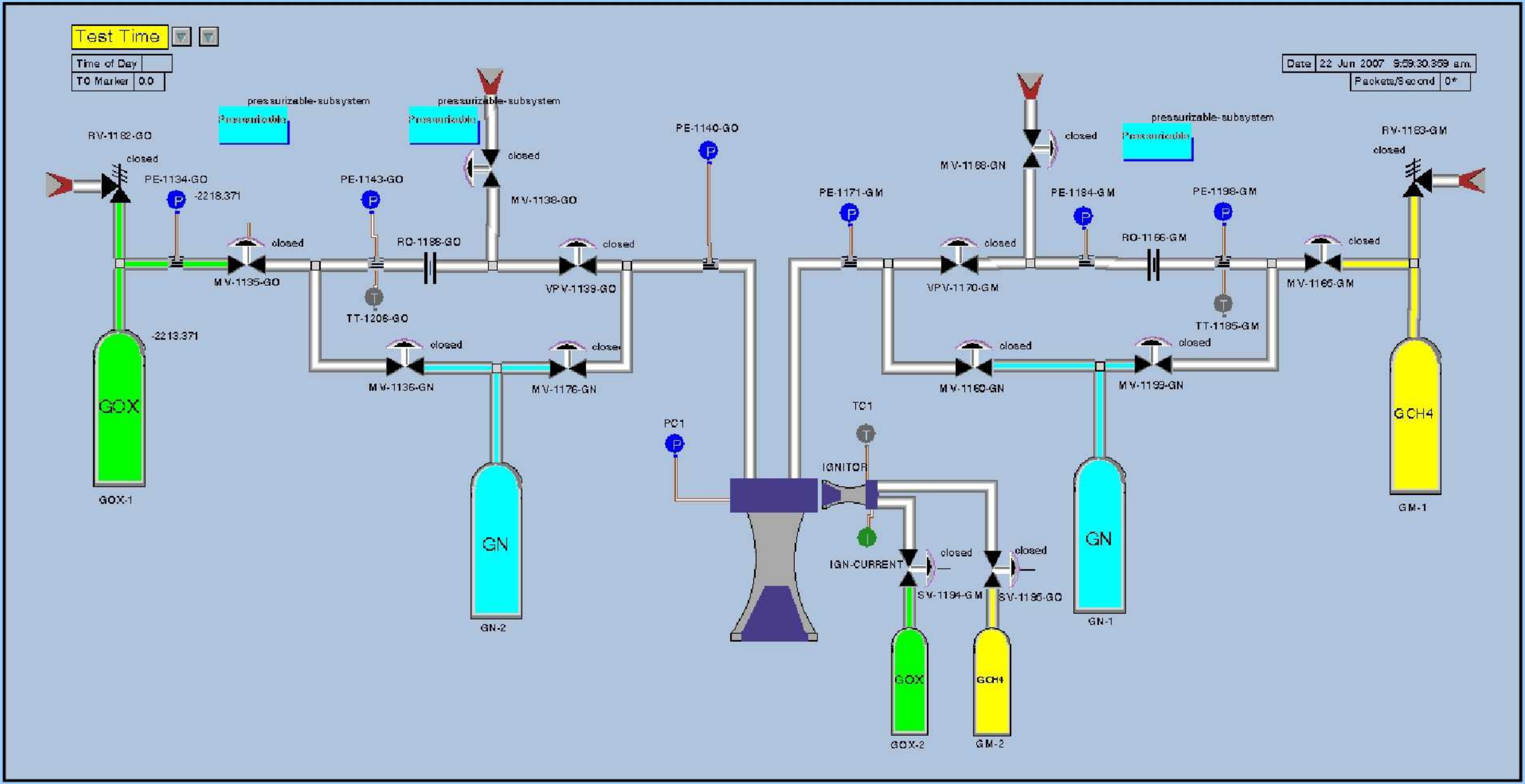
Version Letter:

Serial Number: FCPF 5681

Root-Cause Tree



ISHM Enabling Technologies: Root Cause Analysis



Test Time

Time of Day

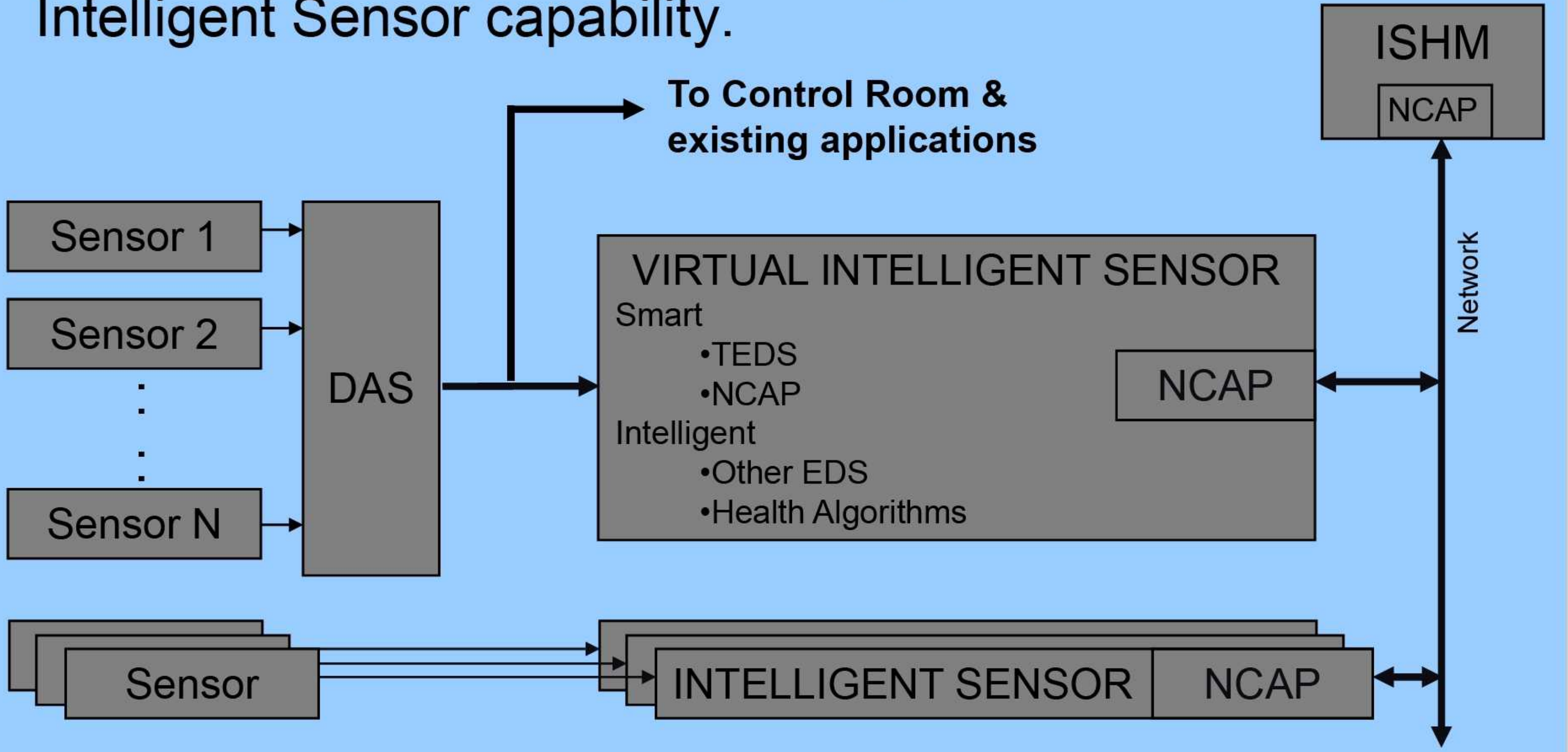
T0 Marker 0.0

Date 22 Jun 2007 9:59:30.359 a.m.

Packets/Second 0*

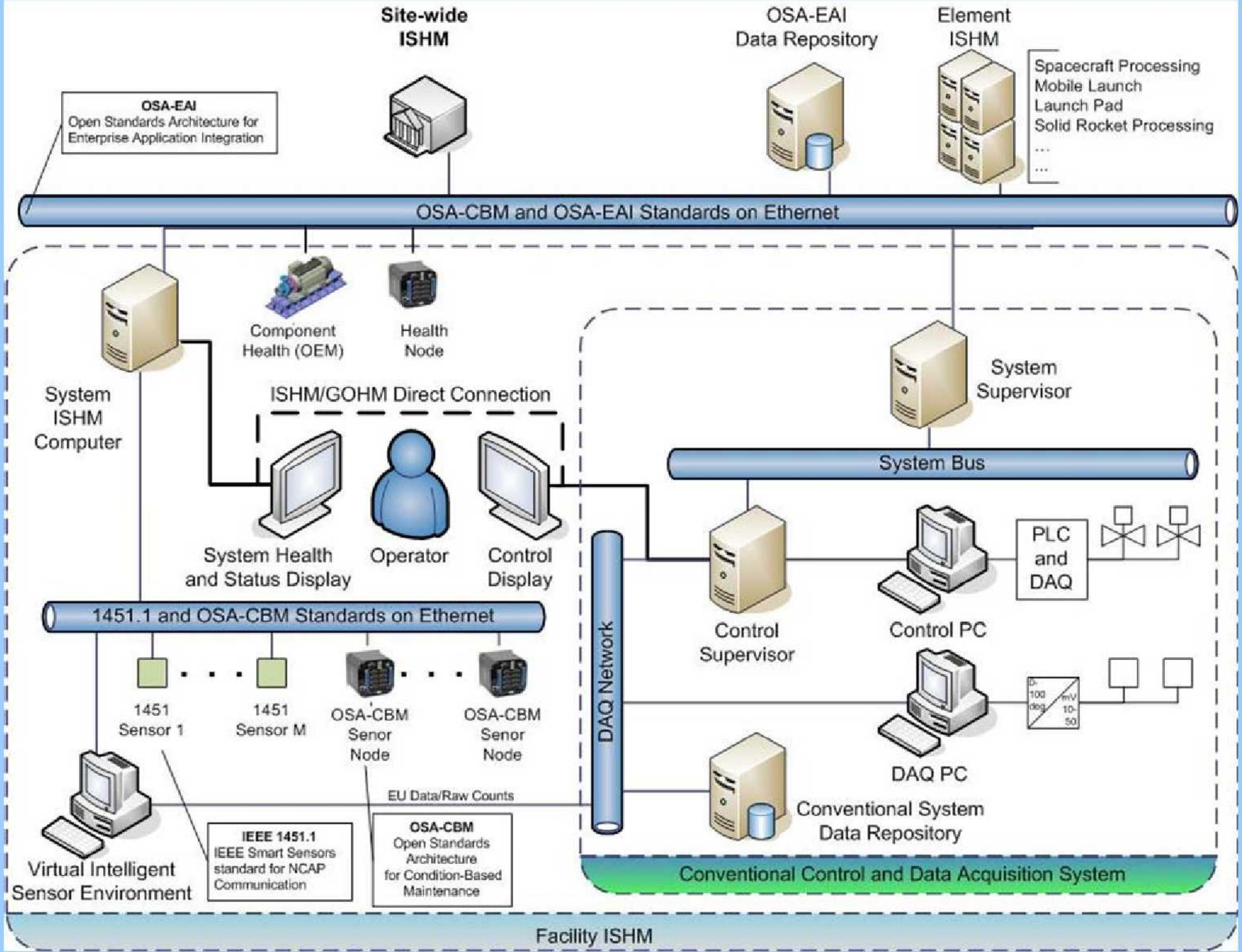
Virtual Intelligent Sensors

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

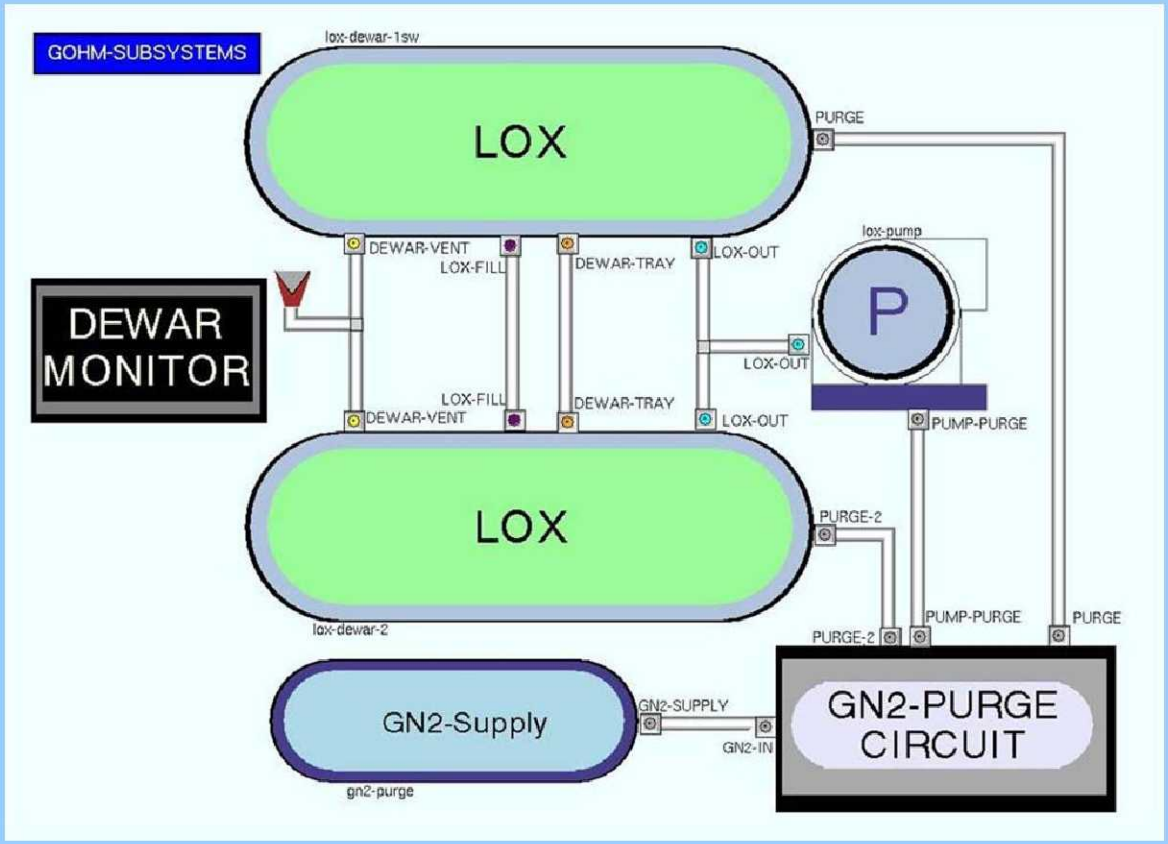


ISHM Implementations

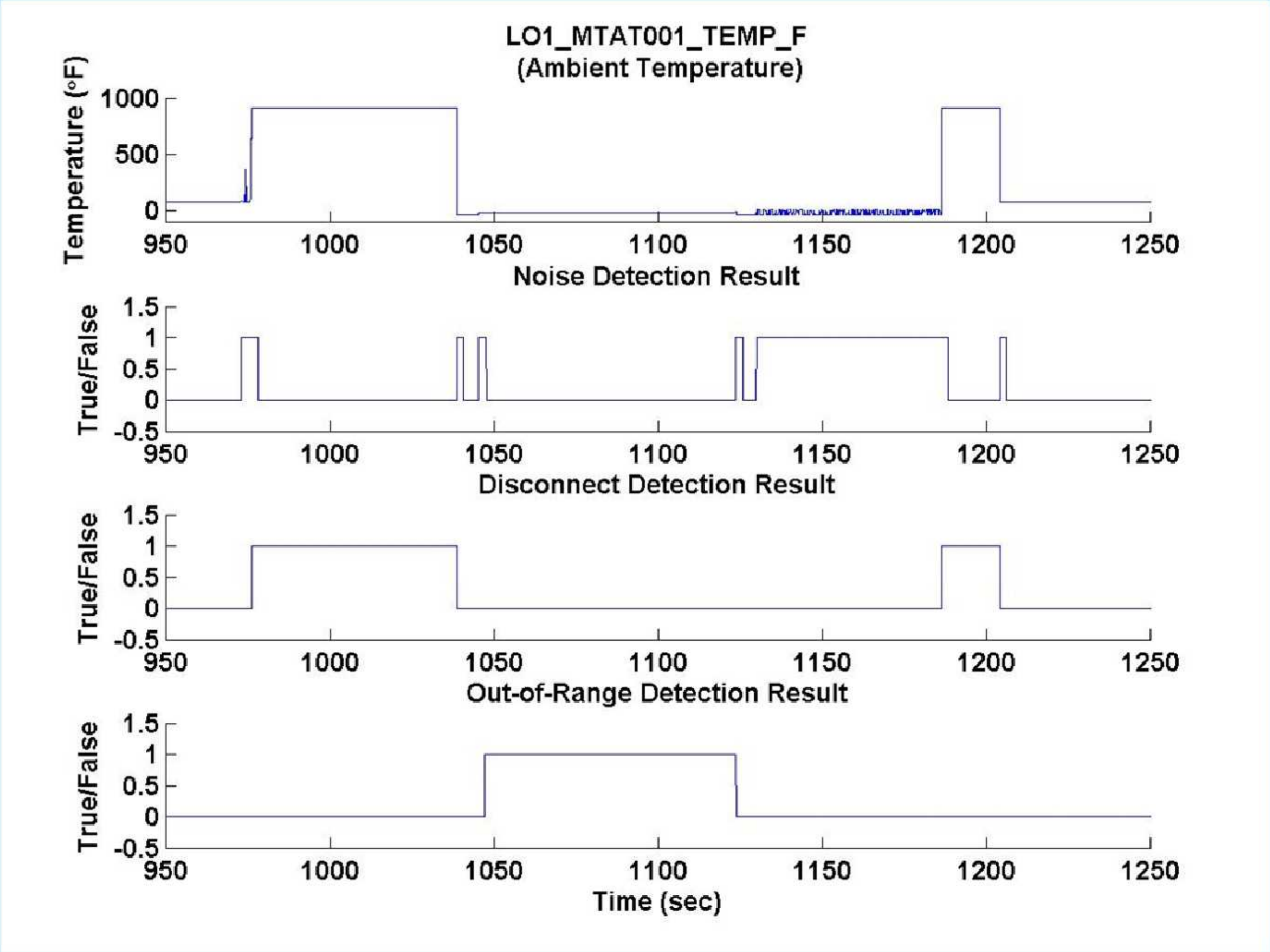
Generic Architecture to implement ISHM capability for systems with conventional equipment, with option to incorporate advanced smart/intelligent sensors and actuators.



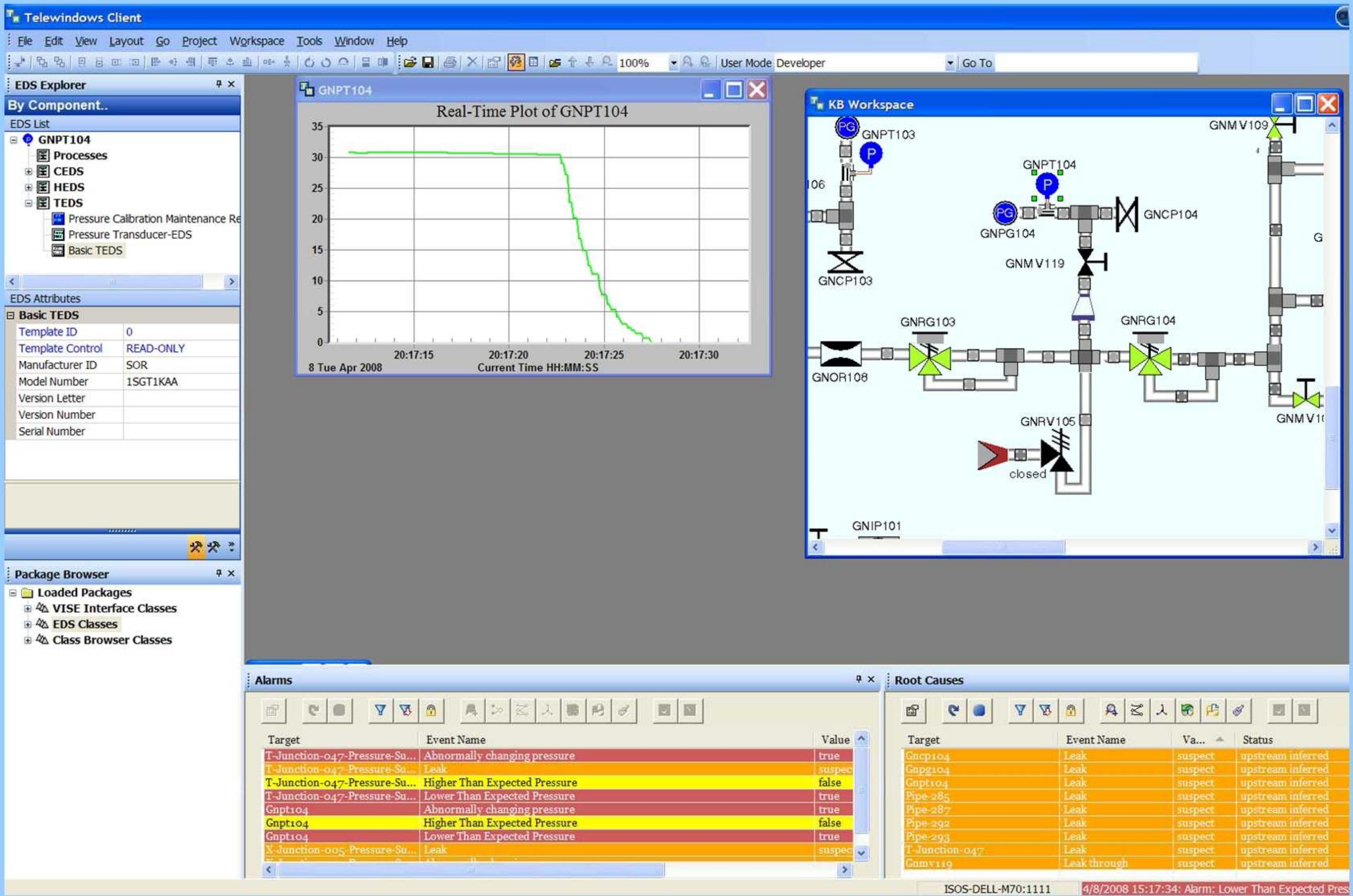
Top level view of the ISHM model of the Launch Complex 20 Facility at NASA Kennedy Space Center



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



User Mode: Developer

Basic TEDS

Template ID	0
Template Control	READ-ONLY
Manufacturer ID	SOR
Model Number	1SGT1KAA
Version Letter	
Version Number	
Serial Number	

Alarms

Target	Event Name	Value
T-Junction-047-Pressure-Su...	Abnormally changing pressure	true
T-Junction-047-Pressure-Su...	Leak	suspec
T-Junction-047-Pressure-Su...	Higher Than Expected Pressure	false
T-Junction-047-Pressure-Su...	Lower Than Expected Pressure	true
Gnpt104	Abnormally changing pressure	true
Gnpt104	Higher Than Expected Pressure	false
Gnpt104	Lower Than Expected Pressure	true
X-Junction-005-Pressure-Su...	Leak	suspec

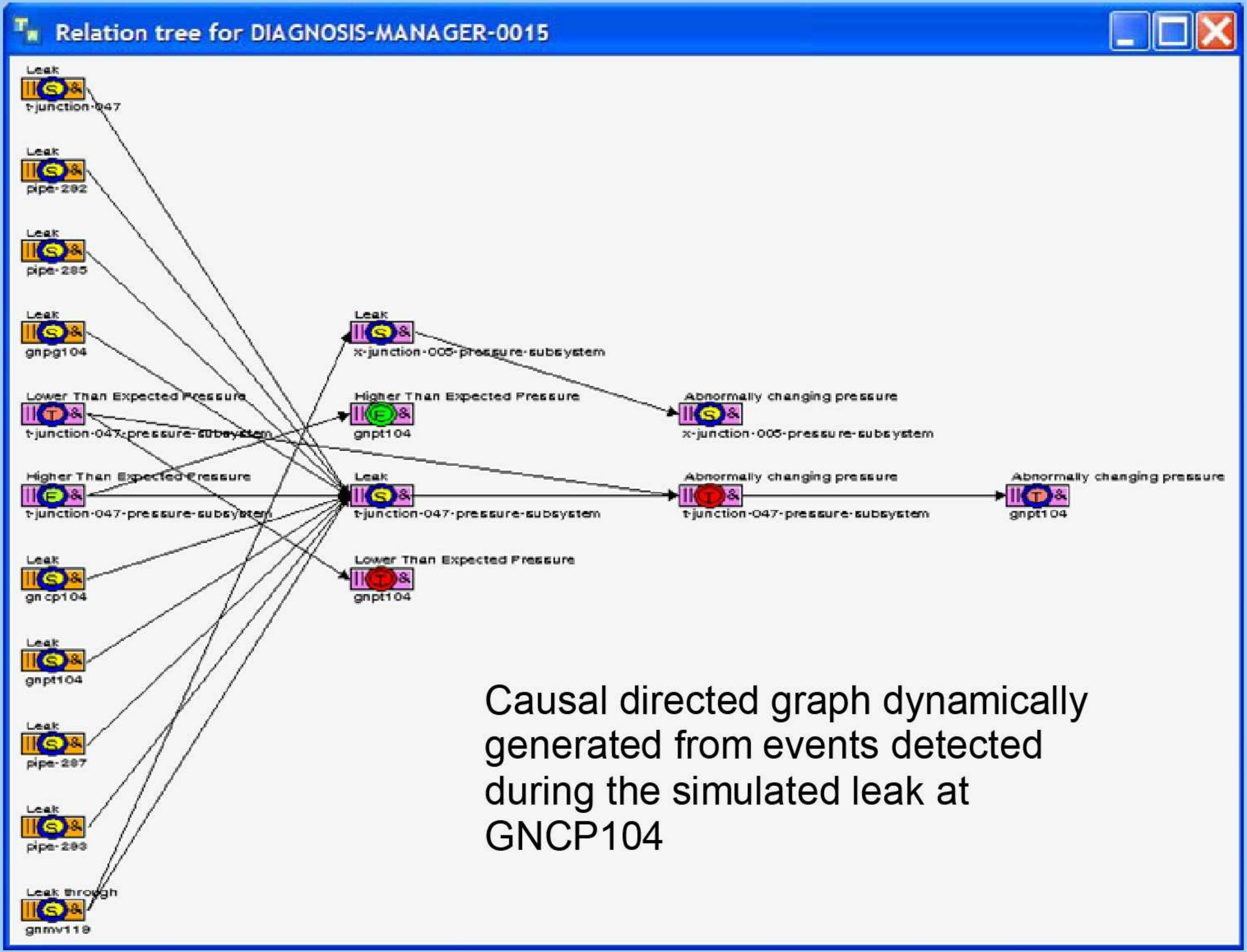
Root Causes

Target	Event Name	Va...	Status
Gncp104	Leak	suspect	upstream inferred
Gnpg104	Leak	suspect	upstream inferred
Gnpt104	Leak	suspect	upstream inferred
Pipe-285	Leak	suspect	upstream inferred
Pipe-287	Leak	suspect	upstream inferred
Pipe-292	Leak	suspect	upstream inferred
Pipe-293	Leak	suspect	upstream inferred
T-Junction-047	Leak	suspect	upstream inferred
Gnmv119	Leak through	suspect	upstream inferred

ISOS-DELL-M70:1111

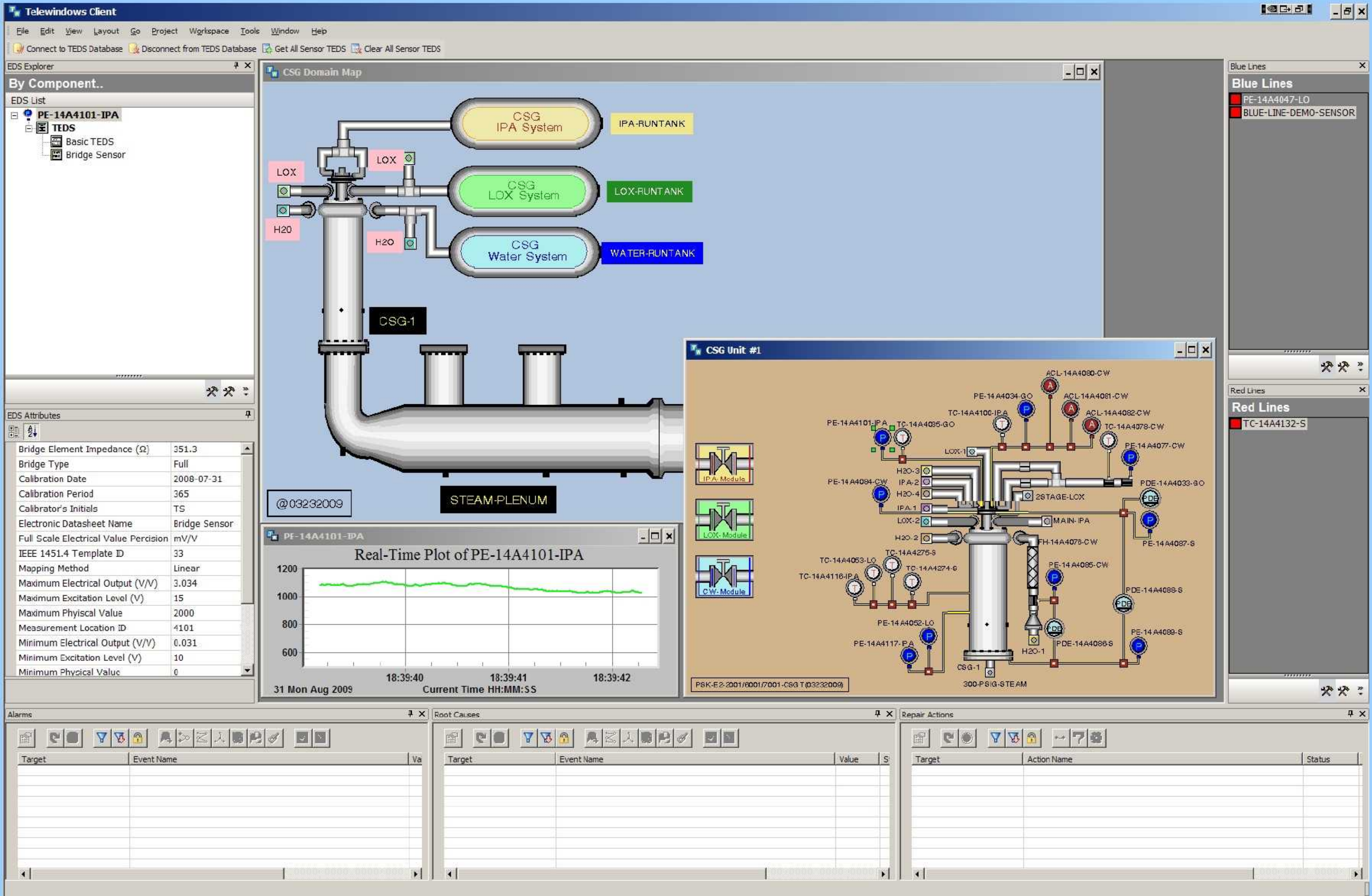
4/8/2008 15:17:34: Alarm: Lower Than Expected Pres

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

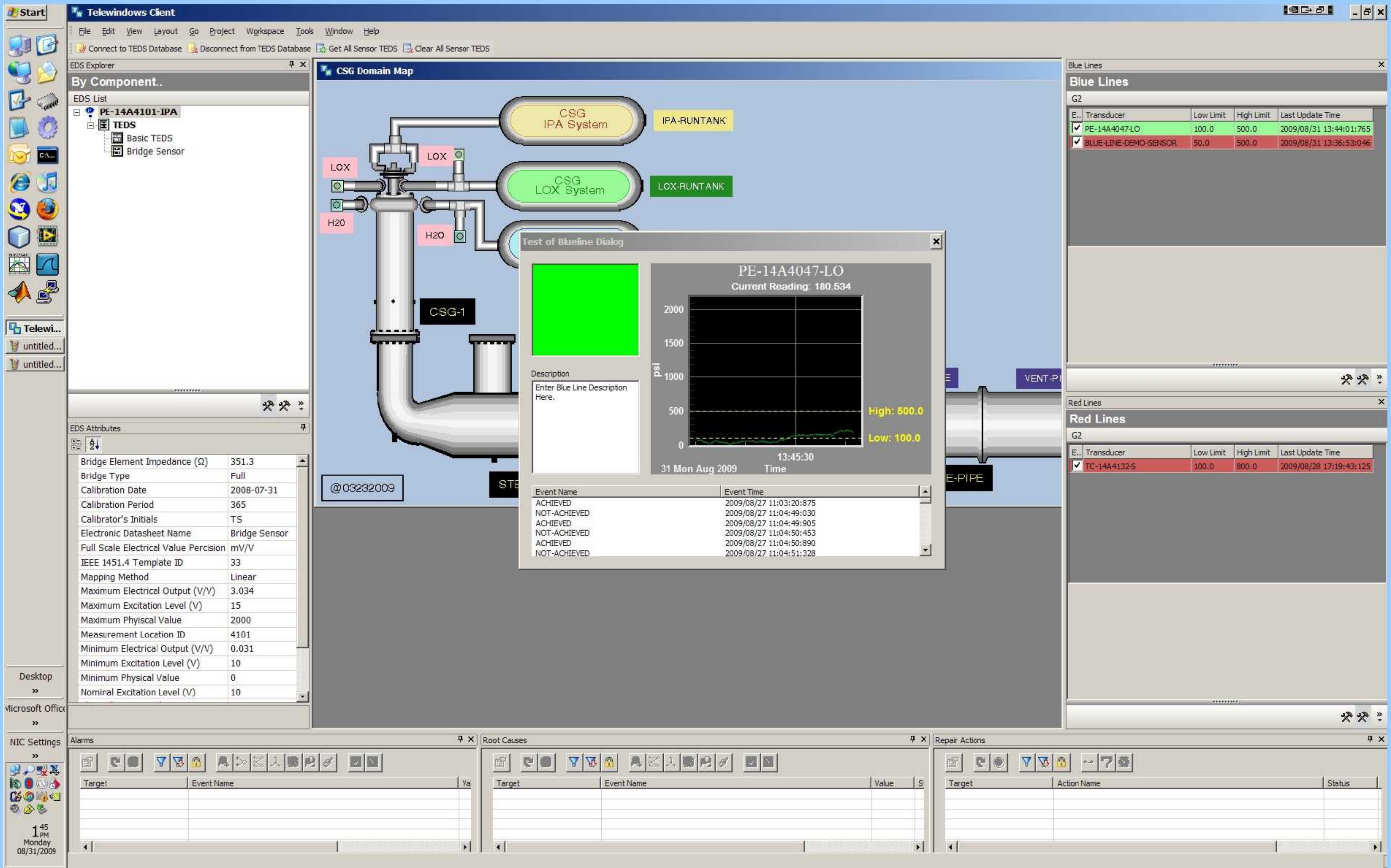
Pilot ISHM Implementation
Chemical Steam Generator (CSG)



EDS Attributes

Bridge Element Impedance (Ω)	351.3
Bridge Type	Full
Calibration Date	2008-07-31
Calibration Period	365
Calibrator's Initials	TS
Electronic Datasheet Name	Bridge Sensor
Full Scale Electrical Value Percision	mV/V
IEEE 1451.4 Template ID	33
Mapping Method	Linear
Maximum Electrical Output (V/V)	3.034
Maximum Excitation Level (V)	15
Maximum Phyiscal Value	2000
Measurement Location ID	4101
Minimum Electrical Output (V/V)	0.031
Minimum Excitation Level (V)	10
Minimum Physical Value	0

Pilot ISHM Implementation
Chemical Steam Generator (CSG)



Description: Enter Blue Line Description Here.

Event Name	Event Time
ACHIEVED	2009/08/27 11:03:20:875
NOT-ACHIEVED	2009/08/27 11:04:49:030
ACHIEVED	2009/08/27 11:04:49:905
NOT-ACHIEVED	2009/08/27 11:04:50:453
ACHIEVED	2009/08/27 11:04:50:890
NOT-ACHIEVED	2009/08/27 11:04:51:328

EDS Attributes

Bridge Element Impedance (Ω)	351.3
Bridge Type	Full
Calibration Date	2008-07-31
Calibration Period	365
Calibrator's Initials	TS
Electronic Datasheet Name	Bridge Sensor
Full Scale Electrical Value Percision	mV/V
IEEE 1451.4 Template ID	33
Mapping Method	Linear
Maximum Electrical Output (V/V)	3.034
Maximum Excitation Level (V)	15
Maximum Phyiscal Value	2000
Measurement Location ID	4101
Minimum Electrical Output (V/V)	0.031
Minimum Excitation Level (V)	10
Minimum Physical Value	0
Nominal Excitation Level (V)	10

Blue Lines

G2

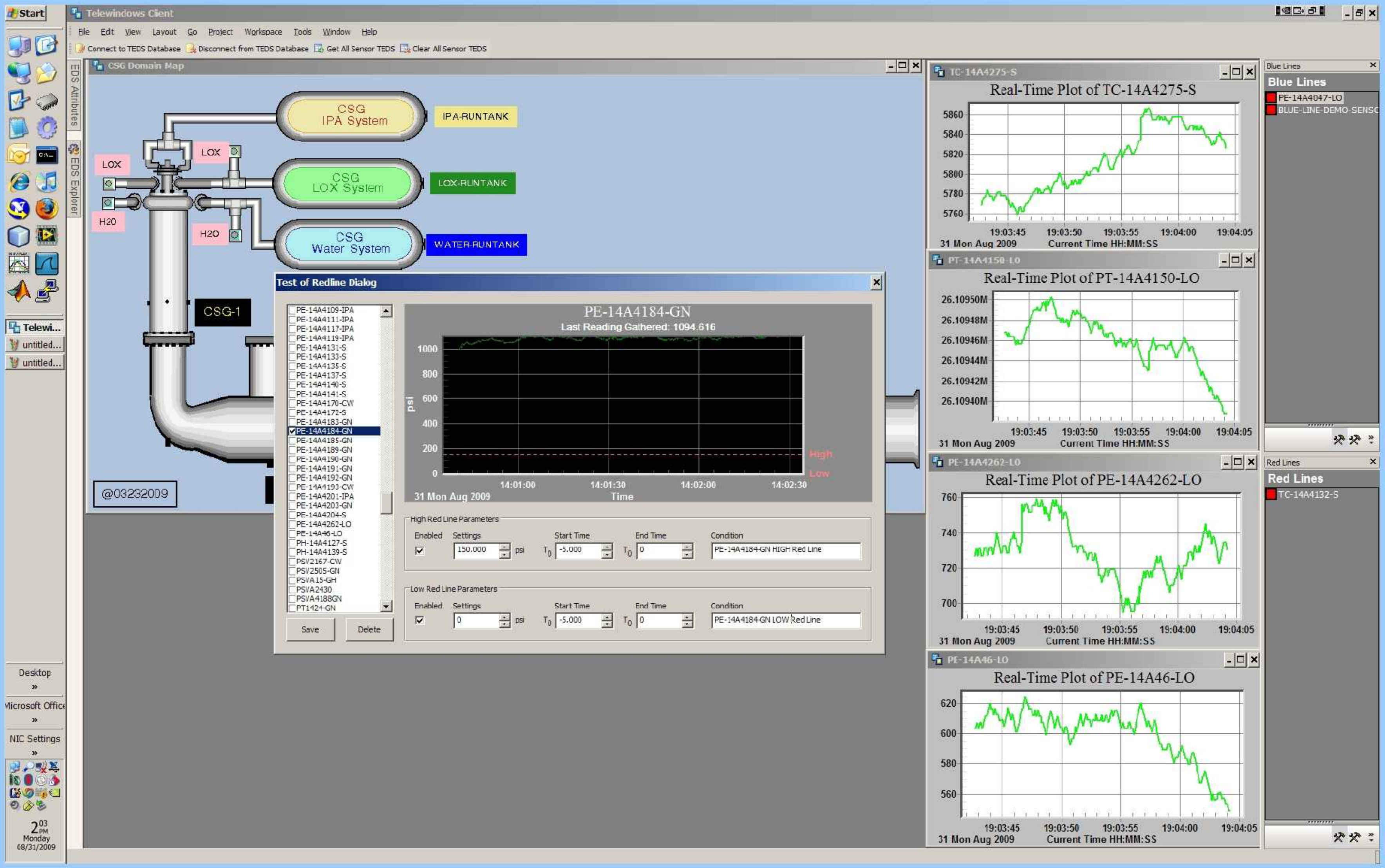
E..	Transducer	Low Limit	High Limit	Last Update Time
☑	PE-14A4047-LO	100.0	500.0	2009/08/31 13:44:01:765
☑	BLUE-LINE-DEMO-SENSOR	50.0	500.0	2009/08/31 13:36:53:046

Red Lines

G2

E..	Transducer	Low Limit	High Limit	Last Update Time
☑	TC-14A4132-S	100.0	800.0	2009/08/28 17:19:43:125

Pilot ISHM Implementation
Chemical Steam Generator (CSG)



Test of Redline Dialog

- ☐ PE-14A4109-IPA
- ☐ PE-14A4111-IPA
- ☐ PE-14A4117-IPA
- ☐ PE-14A4119-IPA
- ☐ PE-14A4131-S
- ☐ PE-14A4133-S
- ☐ PE-14A4135-S
- ☐ PE-14A4137-S
- ☐ PE-14A4140-S
- ☐ PE-14A4141-S
- ☐ PE-14A4170-CW
- ☐ PE-14A4172-S
- ☐ PE-14A4183-GN
- ☑ PE-14A4184-GN
- ☐ PE-14A4185-GN
- ☐ PE-14A4189-GN
- ☐ PE-14A4190-GN
- ☐ PE-14A4191-GN
- ☐ PE-14A4192-GN
- ☐ PE-14A4193-CW
- ☐ PE-14A4201-IPA
- ☐ PE-14A4203-GN
- ☐ PE-14A4204-S
- ☐ PE-14A4262-LO
- ☐ PE-14A46-LO
- ☐ PH-14A4127-S
- ☐ PH-14A4139-S
- ☐ PSI/2167-CW
- ☐ PSI/2505-GN
- ☐ PSI/A15-GH
- ☐ PSI/A2430
- ☐ PSI/A4188GN
- ☐ PT1424-GN

High Red Line Parameters

Enabled	Settings		Start Time	End Time	Condition
☑	150.000	psi	T_0 -5.000	T_0 0	PE-14A4184-GN HIGH Red Line

Low Red Line Parameters

Enabled	Settings		Start Time	End Time	Condition
☑	0	psi	T_0 -5.000	T_0 0	PE-14A4184-GN LOW Red Line

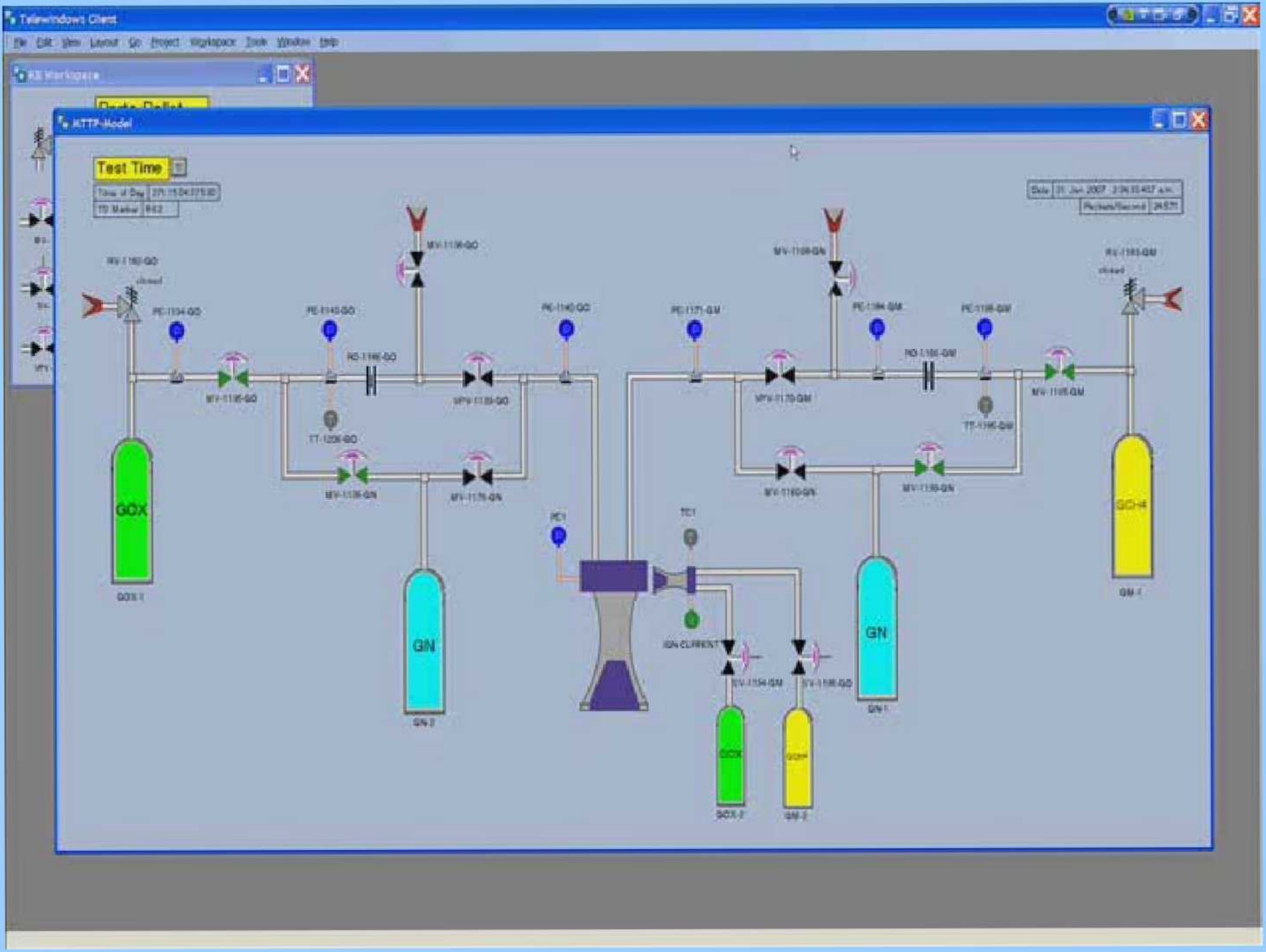
Conclusions

- 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

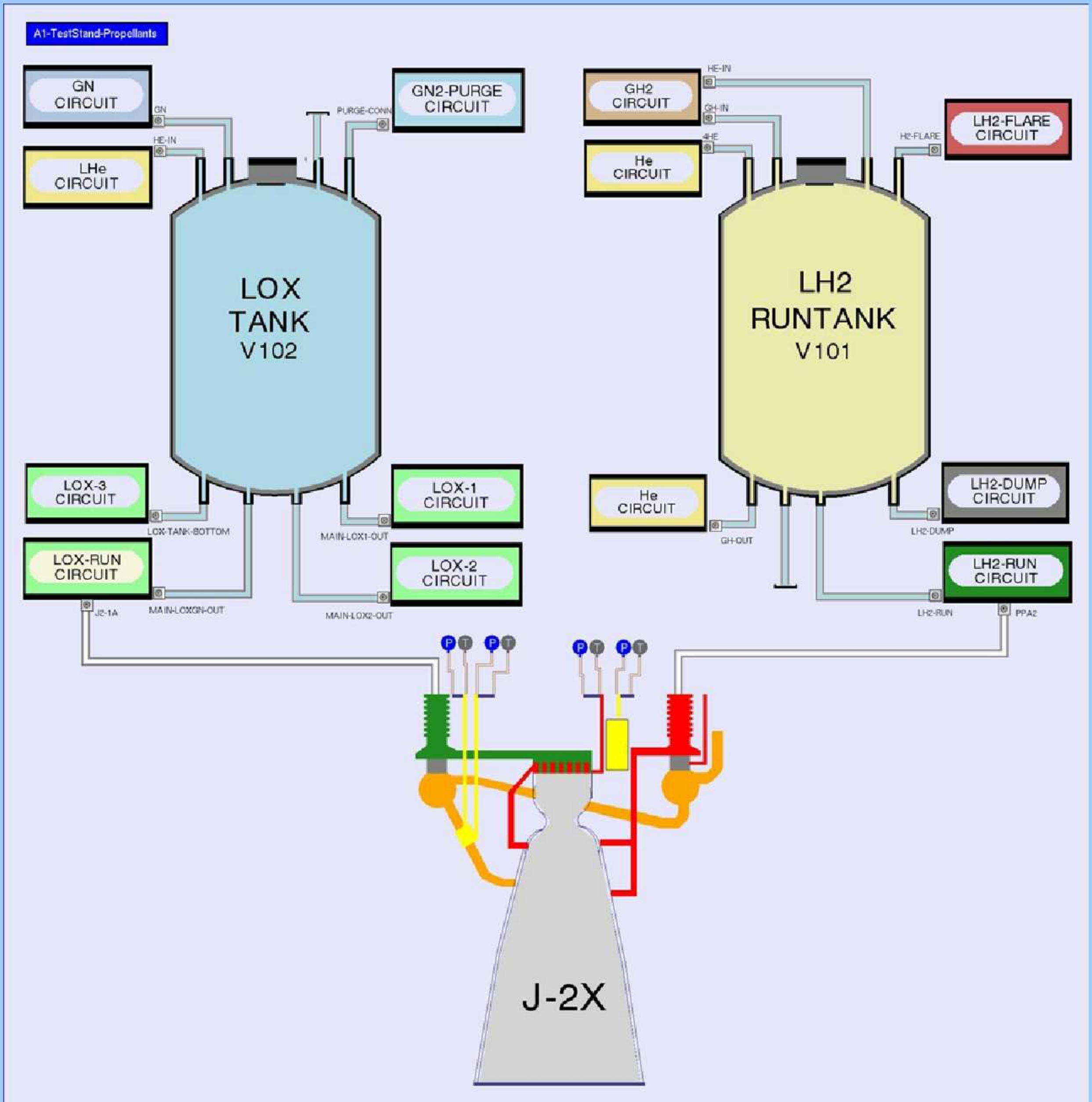
Backup Slides

MTTP End-to-End System

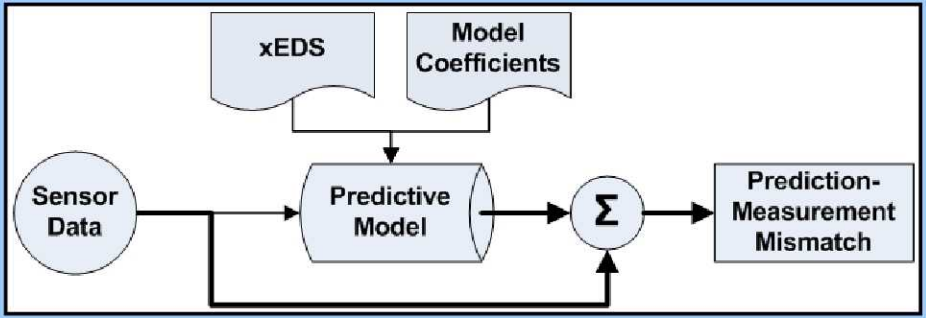
Methane Thruster Testbed Project



A1 and J2-X ISHM MODEL



Runtime Predictive Modeling



xEDS

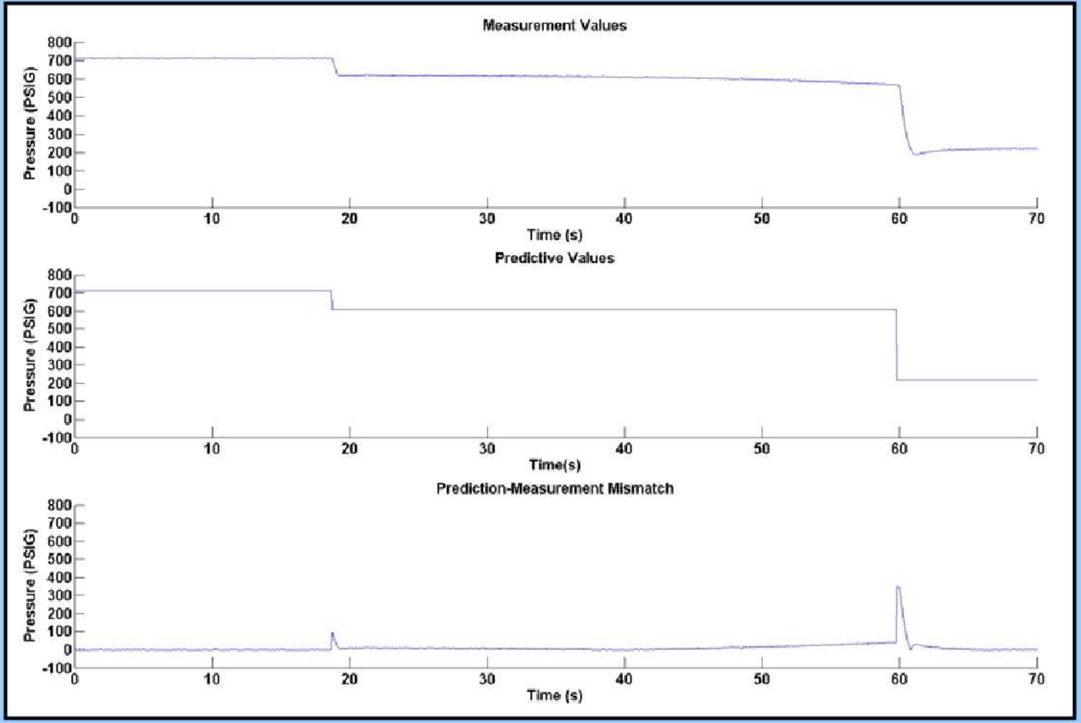
Model Coefficients

Sensor Data

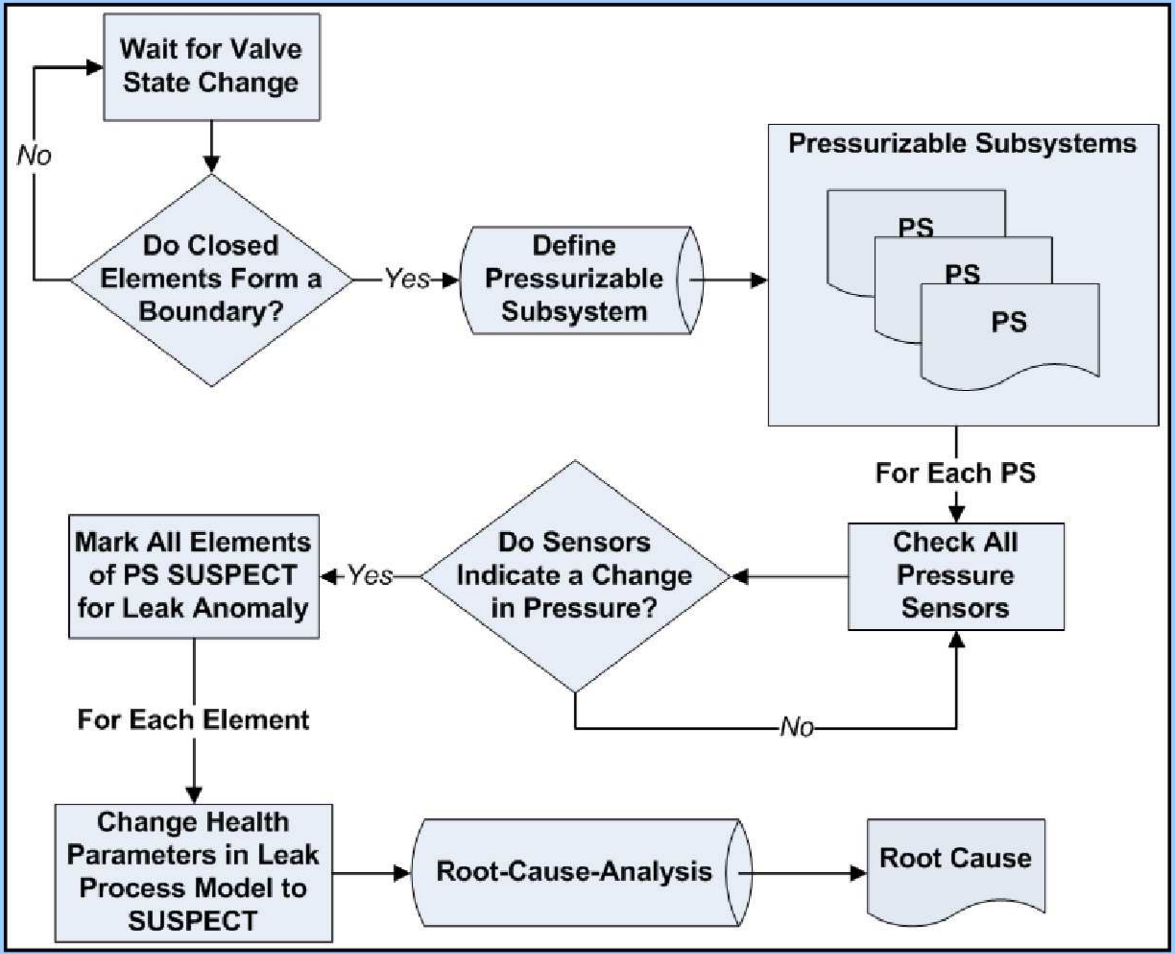
Predictive Model

Σ

Prediction-Measurement Mismatch



Checking for Pressure Leaks

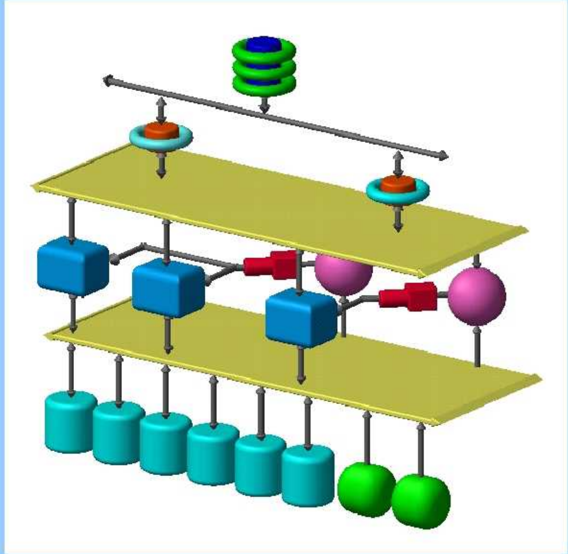


Electronic Datasheets

- 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