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Lifecycle Verification of a System of Systems

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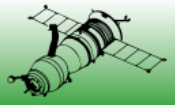
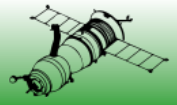



Outline

- PNNL SE tailoring process for asset health monitors
- HELLFIRE Health Monitor Unit (HMU): Progression from a system to a SoS
  - Revealed need for SoS thinking, esp. for verification
- SoS V-Models – existing and new
- Approaches to SoS verification
  - Configuration Management and Control
  - Lifecycle Simulation
- Simulating the HMU lifecycle to support SoS Verification
- Conclusions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Tailoring System Engineering for Rapid Deployment of Asset Monitors

Tailored Systems Engineering Framework for Asset Monitor Development

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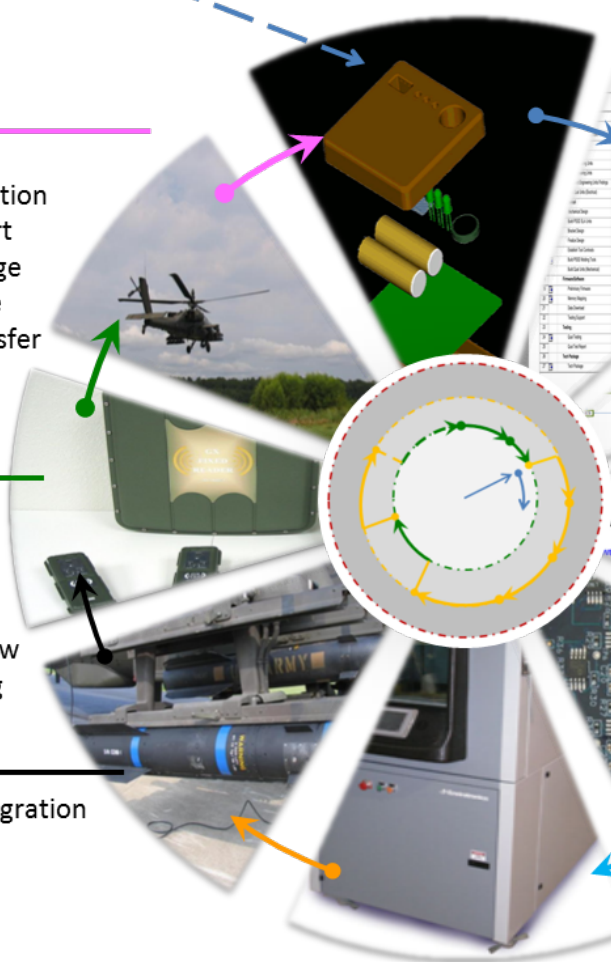

Needs Assessment/ Concept
- Alternate Needs Analysis
- Concept Development

Project Planning
- CONOPS
- Quality Plans
- Schedule
- Design for Manufacturing
- Risk Assessment

Requirements
- Environmental
- Performance
- Verification
- Quality
- Safety

Design
- Conceptual Design
- Preliminary Design
- Detailed Design

Fabrication
- Fabricate Engineering Units
  - Printed Circuit Boards
  - Mechanical Form Factor

Test

Integration
- System Integration
  - Firmware
  - Software
  - Hardware

Verification Validation
- Requirements Met
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Deployment
- Deploy System
- Low Rate Production
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- Tech Data Package
- Software Release
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- Reassess Needs

Assessing Project Risk and Complexity – Constructing a Risk Circle

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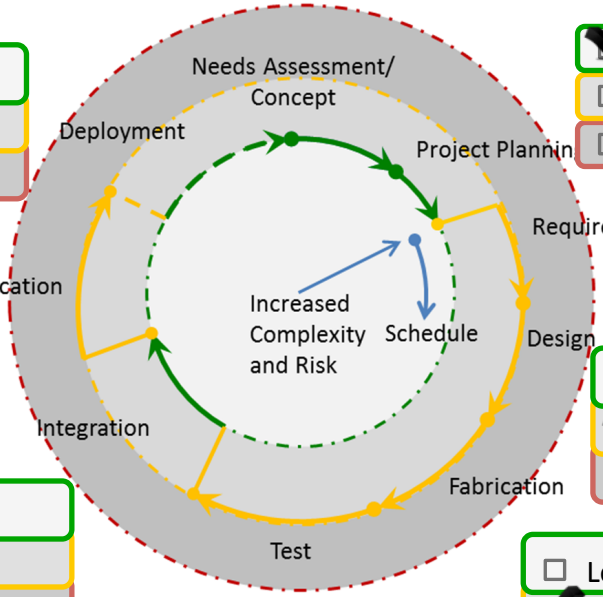
☑ Low	Concept Feasible
☐ Med	Unique Application
☐ High	Need Undefined

☑ Low	No Deployment
☐ Med	Low Quantity
☐ High	Multi unit/ Multi Phase

☐ Low	Low Test Complexity
☑ Med	Environmental Exposures
☐ High	Multi Vendor/ Multi Environment

☑ Low	Low Component Count
☐ Med	Multi Process/Vendor
☐ High	Rapid Schedule

☐ Low	Standard Testing
☑ Med	Develop Test Plans
☐ High	Complex Test and Planning



☑ Low	Standard PMP
☐ Med	Modified PMP
☐ High	Unique PMP

☐ Low	Defined
☑ Med	Vague/Unclear
☐ High	Undefined/Difficult

☐ Low	Simple
☑ Med	Moderate Complexity
☐ High	Complex

☐ Low	Low Component Count
☑ Med	Multi Process/Vendor
☐ High	Rapid Schedule

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HELLFIRE missile health monitor: progression from a system to a SoS

Health Monitor Unit – Version 3

The HMU includes an accelerometer, sensors, microprocessor, batteries, pushbutton, and status display

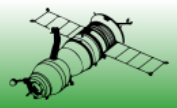
HELLFIRE Missile

- *Produced 1974–present*
- *Launched from multiple platforms (Kiowa, Apache, UAV)*
- *Evolving missions can result in extensive captive carry*
- *Logistical complexities make manual logging difficult*

Hellfire Missile Health Monitor Unit Version Development

Feature	V1
Sensor, Measurement Parameters	Vibration Duration Temperature
Download Connector	Internal Depot Download Only
Mode	Standalone System

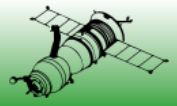
2006	2007	2008	2009	2010	2011	2012	2013


Hellfire Missile Health Monitor Unit Version Development

Feature	V1	V2
Sensor, Measurement Parameters	Vibration Duration Temperature	Vibration Duration Helicopter Detection Temperature
Download Connector	Internal Depot Download Only	Internal Depot Download Only
Mode	Standalone System	Standalone System

2006	2007	2008	2009	2010	2011	2012	2013



Hellfire Missile Health Monitor Unit Version Development

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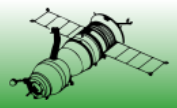
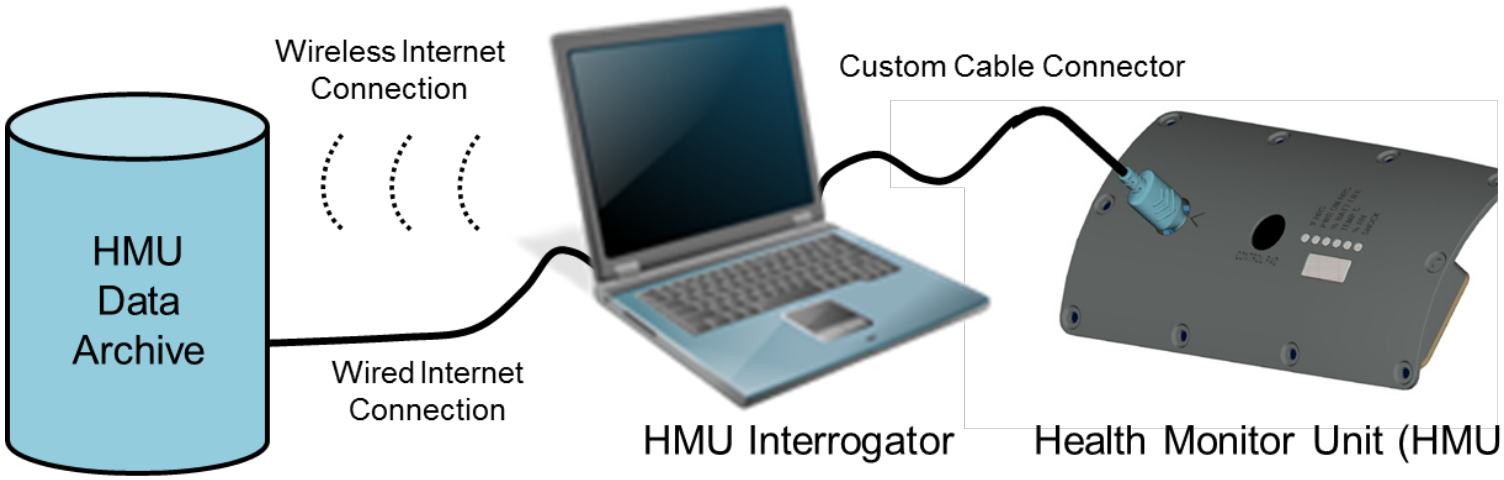
Feature	V1	V2	V3
Sensor, Measurement Parameters	Vibration Duration Temperature	Vibration Duration Helicopter Detection Temperature	Enhanced Helicopter Detection 3d Vibration Character Temperature 3d Mechanical Shock Relative Humidity
Download Connector	Internal Depot Download Only	Internal Depot Download Only	External Download Anywhere
Mode	Standalone System	Standalone System	Part of SoS

2006	2007	2008	2009	2010	2011	2012	2013

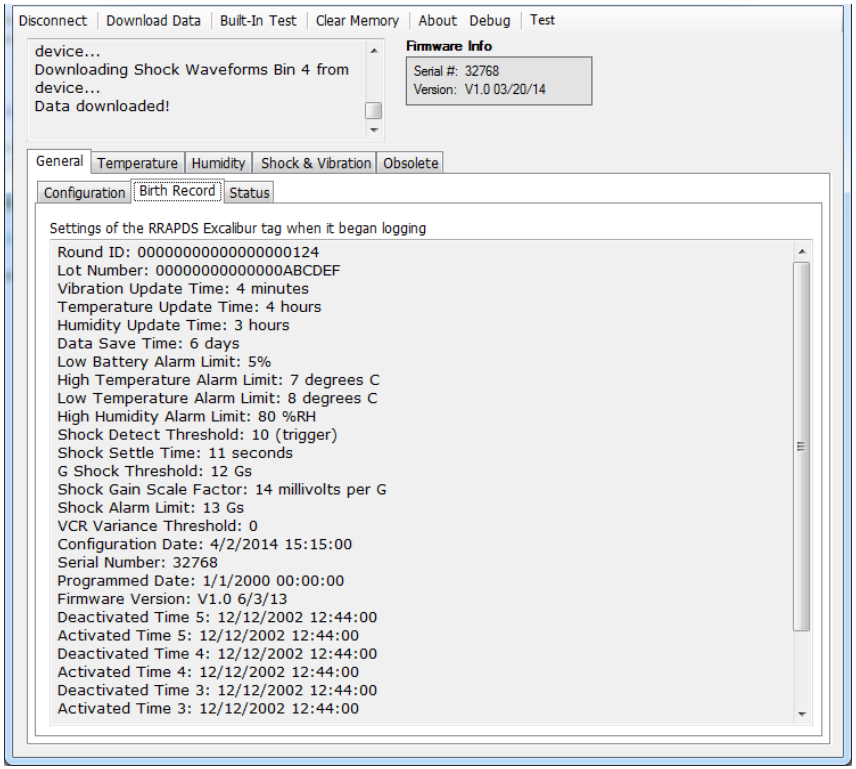



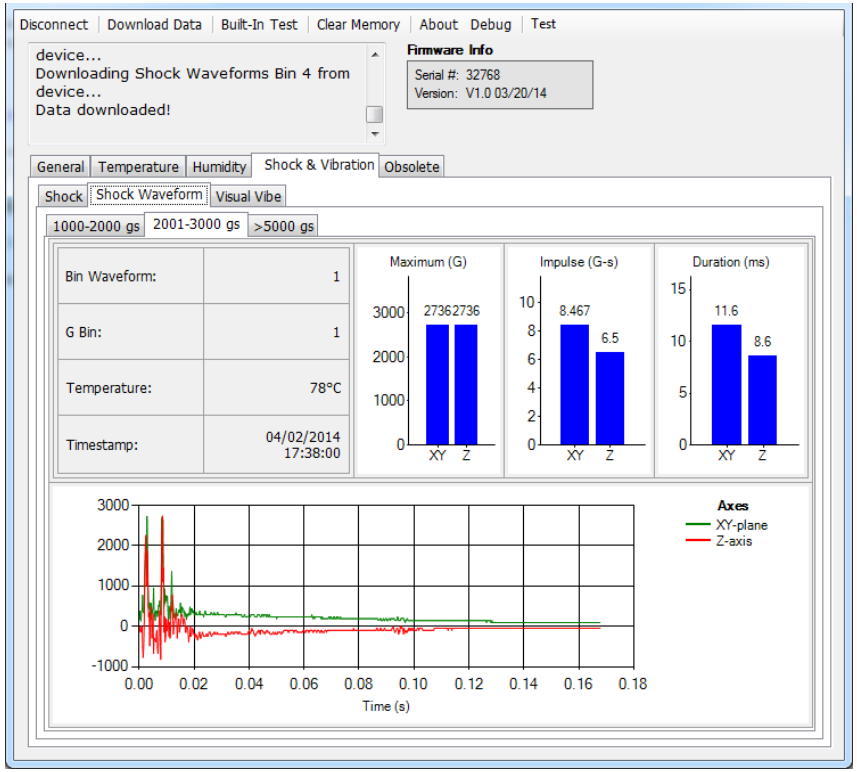

HELLFIRE Health Monitoring SoS Concept



- Due to the large number of HMU's in the field, AMRDEC identified the need for a centralized data archive and fieldable Interrogator
- The Interrogator has a graphical user interface (GUI) for visualization and stores data in the Munitions Historical Program (MHP) database
- The Interrogator was developed by Brockwell Technologies, Inc.

Screenshots of Interrogator





Verification Requirements

- The HMU team needed to implement SoS verification requirements late in the project
  - Verification would require several HMUs with identical data storage
    - Multiple teams
    - Multi platform (table, PC, laptop)
  - Each HMU needed to have data representative of ~ 5 years of usage
  - Needed to exercise all alarm features
- Developing a data upload capability was deemed too complicated
  - Alarm status was modified in real-time
  - Late stage firmware modifications could introduce secondary issues

Need for SoS Verification not Considered

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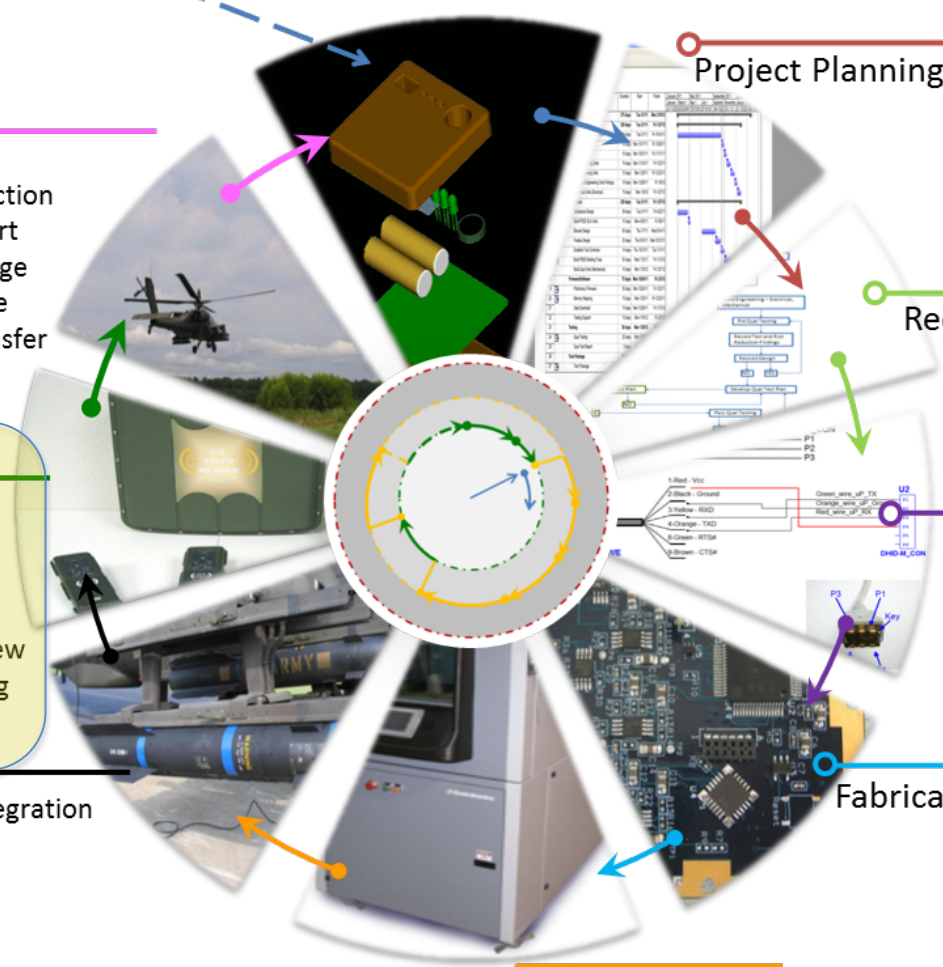

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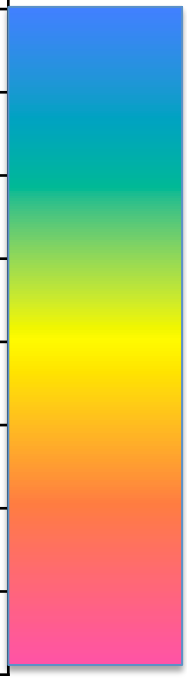
Characteristics of a System of Systems

- Proposed criteria, traits, and challenges that are intrinsic to SoS have been proposed
- Maier's Criteria
  - Operational independence of elements
  - Managerial independence of elements
  - Evolutionary development
  - Emergent behavior
  - Geographical distribution of elements
- Keating and Katina 2011
  - Interoperability, complementarity, and holism
- INCOSE handbook lists challenges that involve SoS
  - Asynchronous life cycles of individual systems within a SoS
  - Complexity
  - Fuzzy boundaries

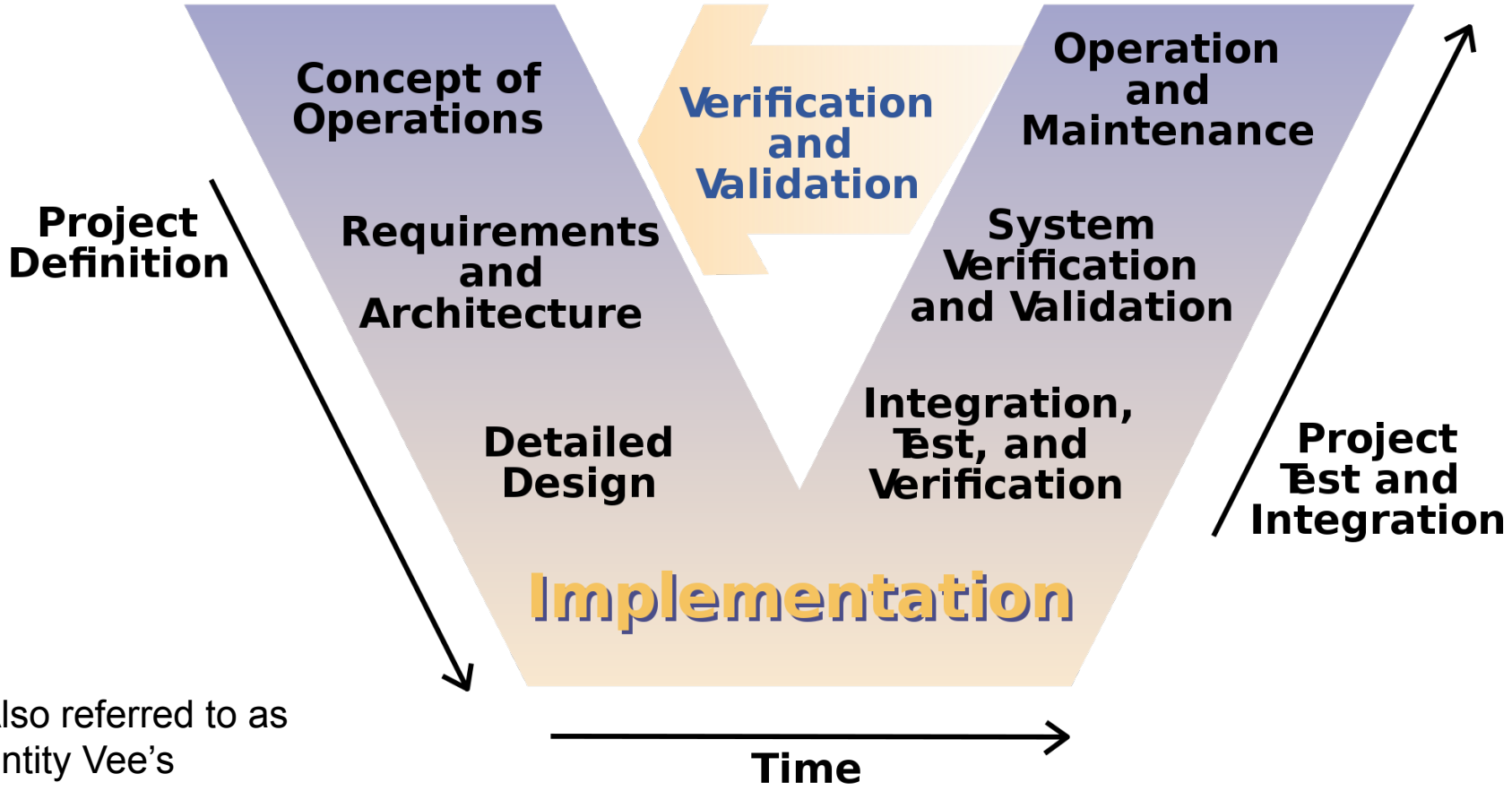
Health Monitoring System SoS traits
HMU + Interrogator

SoS Trait	Degree
Fuzzy Boundaries	Low
Emergent Behavior	Low
Operational Independence	Medium
Organizational Independence	Medium
Geographical distribution	High
Interoperability	High
Complementarity	High
Holism	High



V-Models for System of Systems

The V-Model of the Systems Engineering Process



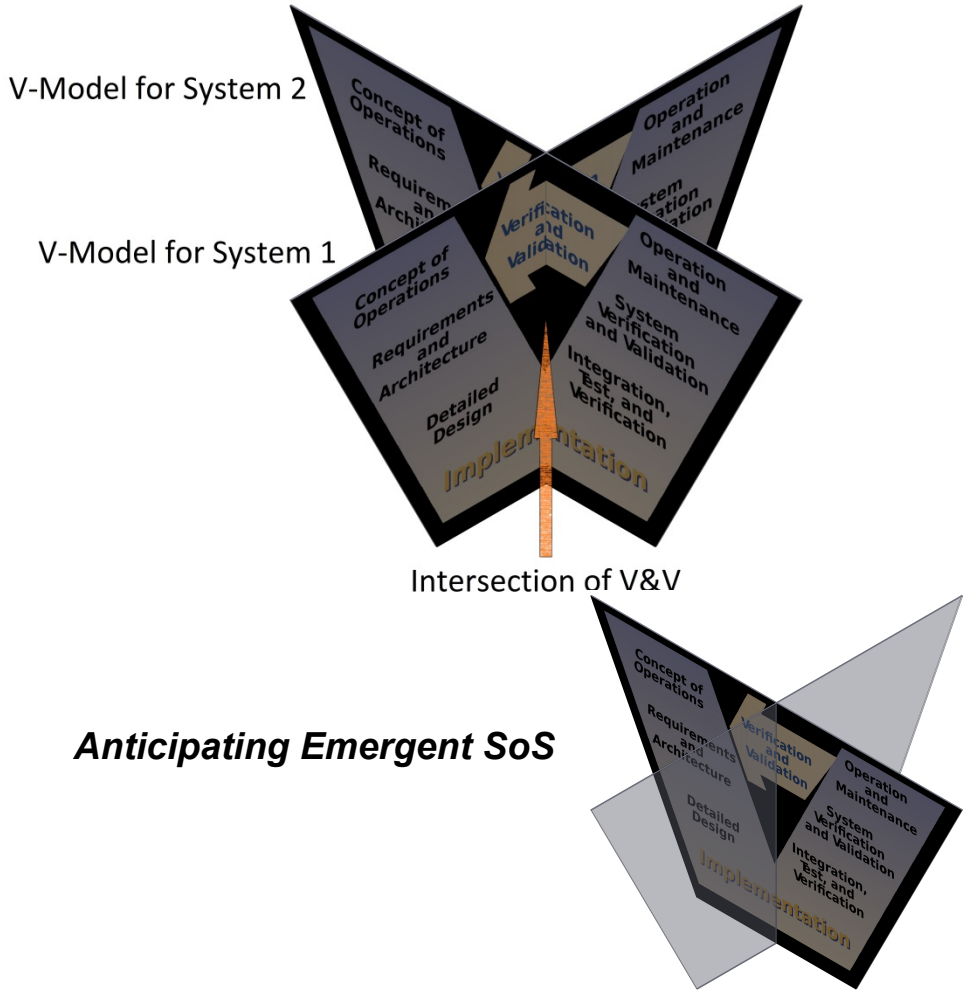
Also referred to as Entity Vee's

System of 2 Systems (So2S) Examples

Tablet and Toy Drone (Amazon)

Tablet and Autonomous Data Logger (LMS SCADAS XS)

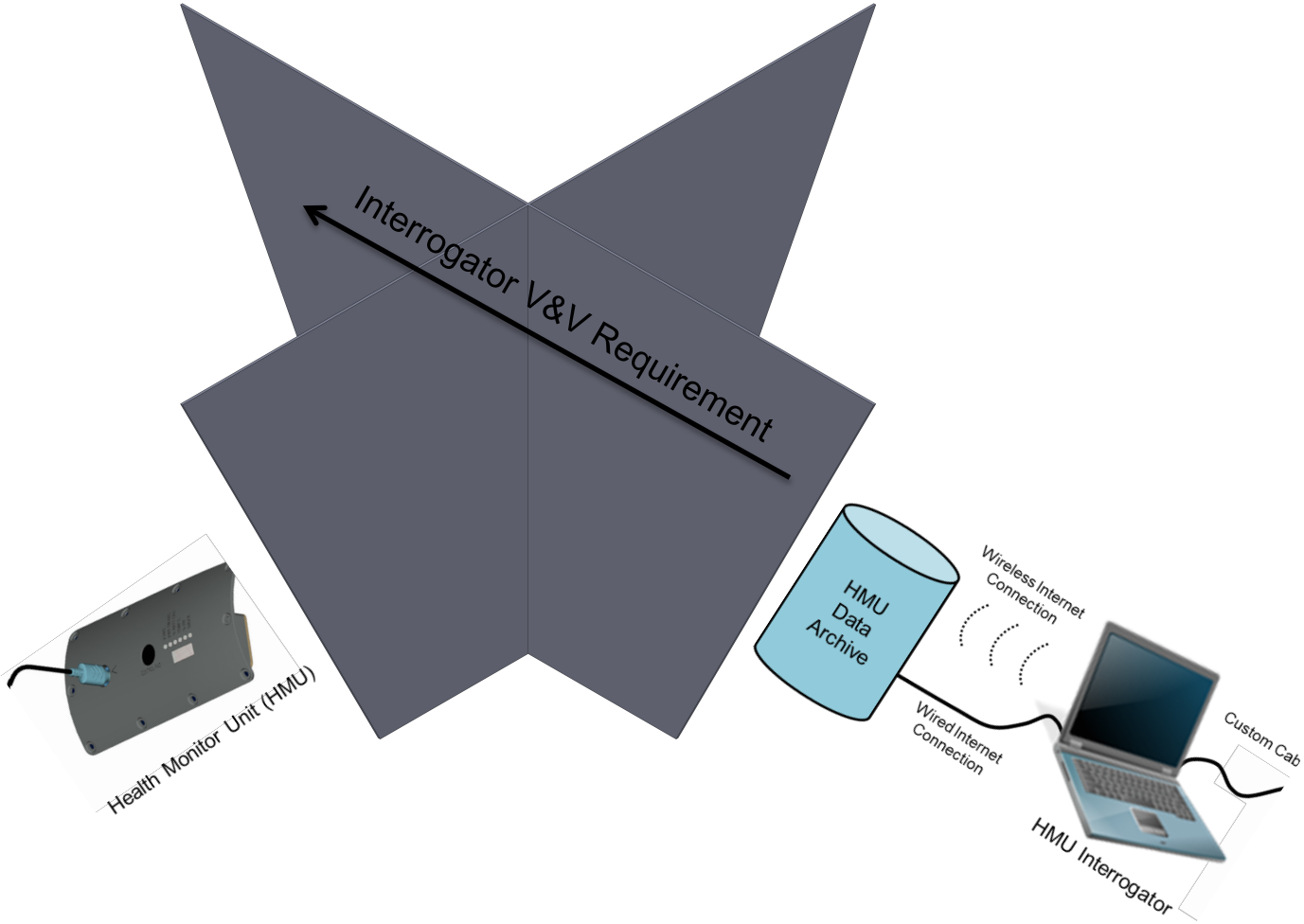
Intersecting V-Model for Modeling So2S



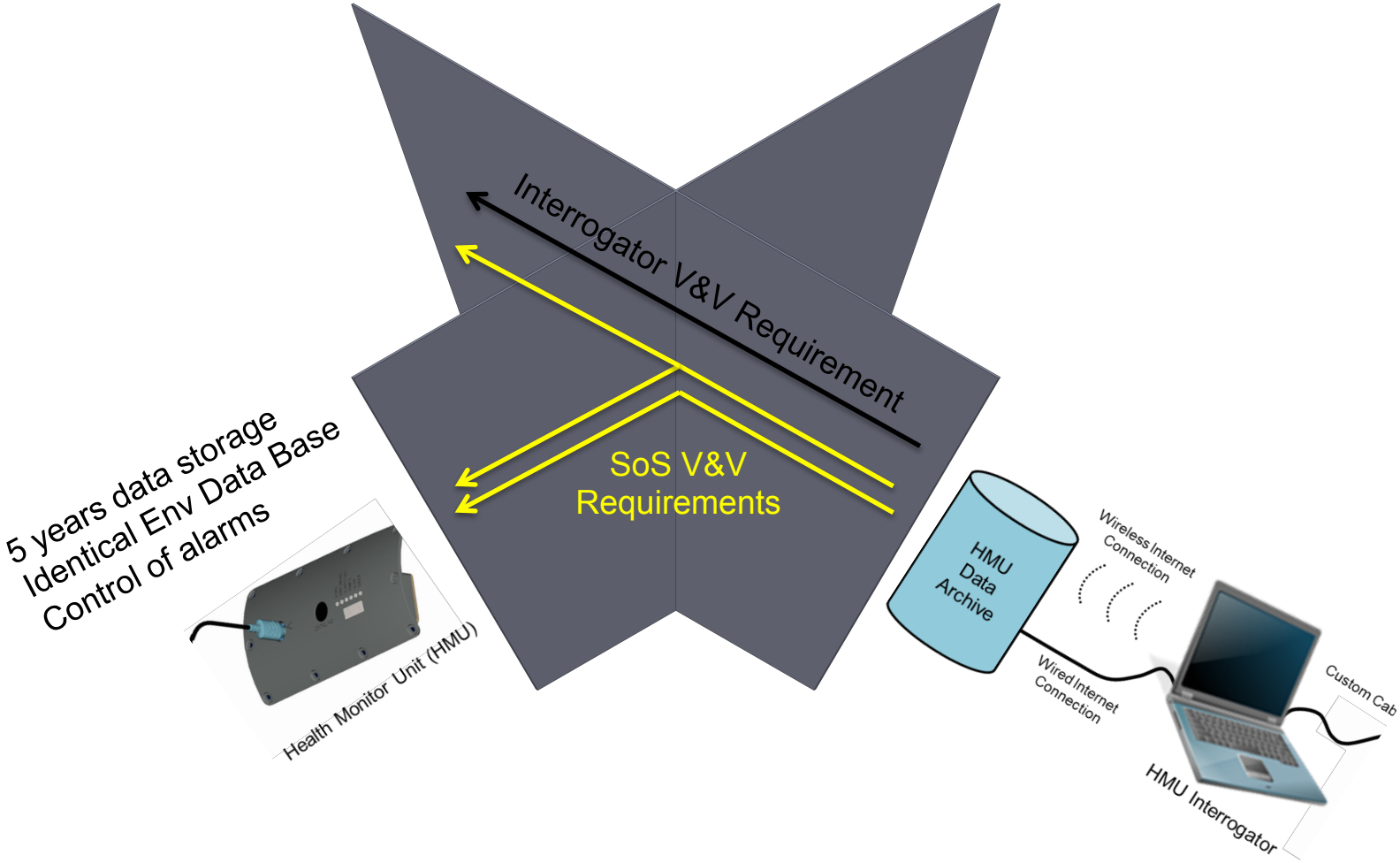
Anticipating Emergent SoS

- Intersecting V-Model communicates the need to flow So2S V&V requirements to system level plans
- Adaptable to emergent SoS
- Enable SoS thinking earlier in the process

HMU + Common Interrogator



HMU + Common Interrogator



Approaches to System of System Verification

SoS Verification Challenges

- ***System-level*** verification is intended to check that the system satisfies a set of requirements
- The verification of a ***SoS*** is more difficult:
  - Multiple organizations are involved
  - Requires integration with legacy systems
  - Separate development processes, funding cycles, schedules, and lifecycles

SoS Verification Concepts

- Configuration Management
  - Freezing the configuration of one system facilitates repeating failures and testing solutions
  - For electrical systems, increasing the number of system configurations that are tested implies a ***high degree of control*** over data content
- Integrated Master Schedule Development
  - Timing the completion of integration and verification two systems is challenging
  - Development teams need preliminary versions of the "other system"

SoS Verification Concepts

- Accelerated Verification through Lifecycle Simulation
  - Actual lifecycle exposure may be expensive, time consuming, or involve personnel risk
  - Allows multiple configurations to be tested sequentially
  - Challenges
    - complex or random operational scenarios
    - multiyear product lifecycle
    - order of events may affect outcome
    - system operation involving human interaction
    - environmental exposure may generate system responses (e.g. alarms)
- Test System Design
  - Accelerated environmental test systems
  - Dedicated verification features must be built into individual systems

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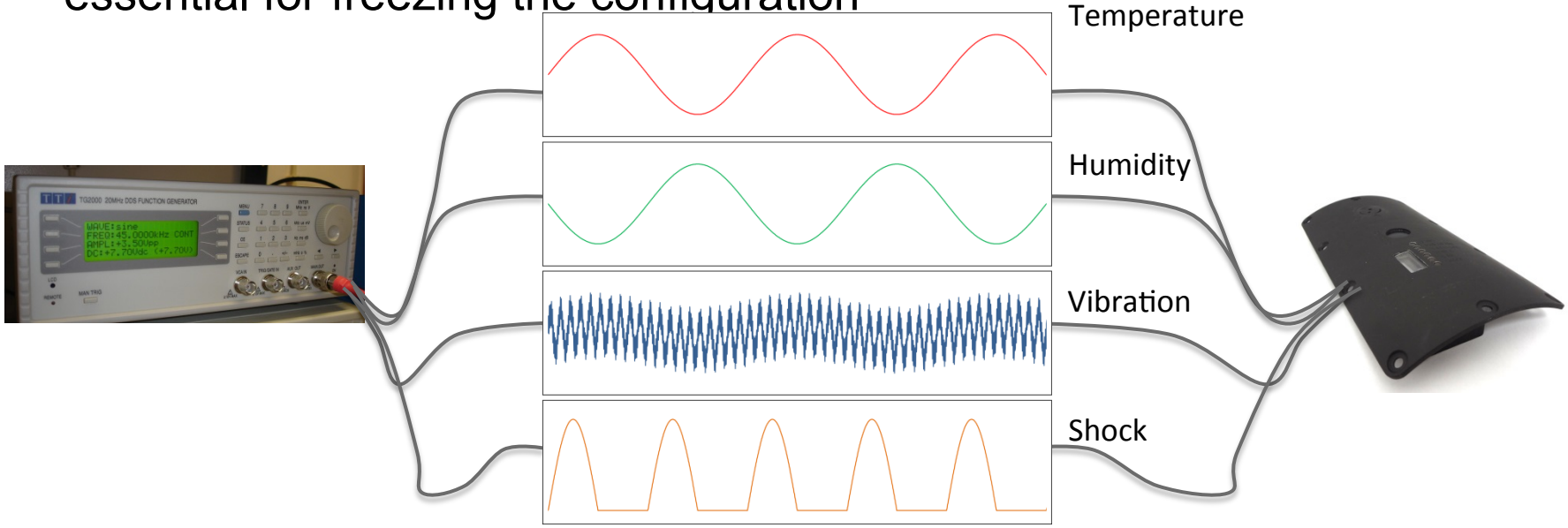
Verifying an Asset Health Monitoring System of Systems

Hardware Approach to Lifecycle Simulation

- Sensor inputs were hardwired to an external function generator to simulate
  - a diurnal temperature and humidity cycle
  - randomly occurring vibration and shock
- Changes to accelerated the clock cycle and sensor update time were implemented
- Using this system, five years of data could be uploaded into the HMUs in approximately 3 days.
- The ability to suspend and then restart data collection was identified as essential for freezing the configuration



Pros and Cons of Hardware LC Simulation

- Pros
  - Ability to test the alarm and data summary functions of the HMU during the So2S verification
  - Can implement late in development
- Cons
  - A/D conversion and timestamps created unit to unit variability
  - Used nonstandard firmware
  - Test duration could not be shortened further
  - Hardware needed to be modified

Conclusions

Conclusions

- SoS verification enablers:
  - *Verification features*
  - *LC simulation*
  - *Digital upload*
  - *Automated test systems*
- The So2S Intersecting V model communicates the need to address SoS verification requirements and augments our SE framework for standalone systems