Enabling Enterprise Systems
Thinking requires an Effective
SPDM Foundation

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VP Analysis Solutions | Aras

SPDM in the Enterprise Digital Thread
We design, build, test, simulate & maintain complex Connected Systems.

To understand/manage complex system behavior, the Reductionist design approach alone is not working.

Enter, Systems Thinking…
Systems Thinking vs Reductionist Design?

Achieving a balance between holism and reductionism
**System**

An arrangement of interacting parts or elements that together exhibit behavior or meaning that the individual constituents do not, organized to achieve one or more stated purposes.

**Requirements**

The stated purposes that a System must achieve. *All actions must be driven by Requirements.*

**Systems Thinking**

Understand and analyze system behavior and interactions holistically.

Capture and exploit Regularity/Patterns.

Capture and exploit Emergent system behavior – *the sum behaves differently than the parts.*

*[...a sensibility for the subtle interconnectedness that gives systems their unique character (Senge, 2006).]*

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The interaction between elements is the "key" system concept (D. Hitchins, 2009).

The focus on interactions and **holism** is a push-back against the perceived **reductionist** focus on parts and provides recognition that in **complex** systems, the interactions among parts is at least as important as the parts themselves (SEBoK, 2019).

*Thinking in Systems, Donna H. Meadows*

*SEBoK: Systems Engineering Body of Knowledge (sebokwiki.org)*
Systems Terms – in a Word

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Systems Thinking
understand

MBSE
represent

System Architecture
organize

Systems Engineering
intervene/design

Credits
Dave Long, Vitech
Pawel Chadzynski, Aras
Future Risks
without
enabling
Pervasive Systems
Thinking

Risks compounded by:
System Complexity & Emergent Behavior
Multiple Disciplines not in alignment

Risks
- Loss of Life
- Catastrophic Failures
- Missed Opportunities
- Liability
- Regulatory Actions
- Operational Shutdowns
- Delays / Missed Deadlines
- Cost Overruns

Ramifications
- Non-Optimal Products
- Inaccurate Conclusions
- Wrong Design Simulated

Design Quality Problems
Pervasive Systems Thinking: Challenges

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- Small pool of Systems Thinkers
  - Not all systems engineers are truly systems thinkers
  - Most engineers are not trained in systems engineering

- Ingrained practices
  - Focus on reductionist organizations and practices
  - *Why should an expert finite element analyst have to worry about emergent system behavior?*

- Disconnected multidisciplinary processes
  - Disciplines handled separately; brought together in an ad hoc manner and by physical testing

- Experts and data in silos
  - Blind men and elephant analogy; understanding of holistic/emergent system behavior is lost
  - Data are not managed and accessible across the enterprise; incomplete enterprise-level data

- Multiple/Incompatible tools
  - Each tool speaks its own language; no encompassing standards
  - Multiple tools from multiple vendors

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**Challenges compounded by Multidisciplinary Products and Use of Machine Learning and AI in Design**
Requirements-Driven Everything!

Are we designing the correct product?
Are we building the correct product?
Can we trace Requirements to all cross-discipline artifacts

Requirements-Driven Platform Approach
- Connect all engineering data and processes using Requirements-Driven enterprise Digital Thread
- Enable change impact analysis across disciplines
- Enable closed loop V&V of Requirements

Requirements-Driven everything enables Systems Thinking
Interdisciplinary Collaboration with Systems Models

When systems models sit at the center of designs, they become the connective tissue.

The Digital Thread runs through them.

Seamless Integration
Systems Modeling to 3-D Simulation
Need for Simulation Increasing Rapidly

Materials Advancements & Additive

Verification & Validation

Design Space Exploration
Future: More & More Simulations across the Lifecycle

MBSE / System Models

Connected & Autonomous

Digital Twin

Model refrigeration cycles based on first principles

Model complex cooling cycles

Source: modelon
Silos: Unable to Achieve Business of Engineering Strategies

Disconnected from Processes
Highly Diverse & Increasing
Separate & Complicated to Manage

Fed:

- CFD
- Composites
- Thermal
- ESD
- EMI
- Embedded Software / Firmware
- Co-simulation
- 0D / 1D
- FEA
- vibro-acoustics
- plastic flow
- metal forming
- casting
- nonlinear analysis
- chips & circuits
- Optics
- Materials characterization
- wiring & bonding
- vibro-acoustics
- plastic flow
- metal forming
- casting
Simulation Management: Challenges

- Large number of tools
  - Mixed-fidelity / Multi-physics modeling (from systems models to 3-D models)
  - Multi-disciplinary modeling (including mechanical, software, electronics)
  - Large number of tools from multiple vendors

- Data models (tool file formats) are all different
  - Each tool speaks its own language
  - Simulation processes usually use multiple tools

- Simulation Processes are manual and only run by experts in silos
  - Non-experts do not have access to simulation
  - Large number of product variants and autonomous testing requires full automation

- Simulation data not connected to other engineering (PLM) data
  - Tools from all vendors, all physics and all levels of fidelity must be integrated
  - Results from all tools should be available to the enterprise for decision-making

Risks compounded by Multidisciplinary Products &
Use of Machine Learning and AI in Design
Simulation On-Demand from Concept to Operation

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- **Concept of Operations**
- **Verify & Validate**
- **Operation & Maintenance**
- **Define**
- **System Architecture & behavior**
- **Detailed domain design**
- **Verify, Validate, Deploy**
- **Digital Thread**
  - Traceability
  - Support Iterative-Development Systems Models (Agile, Spiral…)

**System Exploration**
- System Optimization
- Emergent Behavior

Enable Systems Thinking

“Right-Fidelity” simulation available on-demand
Effective SPDM Should Enable

- Experts & Engineers
  - Deliver better/timely requirements-driven simulation coverage
  - Stay in sync with design / variant changes
  - Eliminate redundant administrative tasks

- Analyze Variations Quickly and Automatically
  - Rapidly conduct analysis on product variations, options and design changes
  - Enable “right-fidelity” simulation throughout the lifecycle
  - Fully-Automate repeatable tool chain processes

- Digital Thread
  - Across Concept Engineering, Detailed Design, Simulation & Test
  - From Requirements through entire Lifecycle
What’s Missing in SPDM – a Systems-Centric View

- Complete representation of the Product: A Systems-Centric view
  - System intent & System requirements
  - System Architecture & System Parameters
  - Multiple component representations
  - System constraints & Operating conditions
  - Performance metrics
  - Product variants/configurations

- Tool-agnostic data & processes
  - Commercial, in-house custom, etc.
  - “Lights-out” automation at any level of fidelity

- Robust automation across design changes and product family variants

Black-Box, File-Based Vendor/Tool-Specific

Systems-Centric, Template-Driven Simulation Management
source: ge
Simulation in an Integrated, Open, Extensible Platform

- Simulation integrated with all core PLM services
  - Configuration, ECO, and Lifecycle processes
  - Visual Collaboration
  - Configurator
  - Branch/Merge
  - Graph Navigation

- Open unified data model and APIs
  - Consistency for all users/implementations
  - Supports simulation data and processes
  - Custom extensions (data model, process, applications)
  - Connectors for commercial and in-house tools

Tool-Agnostic, Open Product Innovation Platform
1. Get the data right
   - Create and manage an engineering abstraction layer that is mostly tool-independent

2. Fully-Automate repeatable simulation processes
   - Simulation templates must be robust across significant design changes and across the entire product family, at the required level of fidelity
   - Auto-generate the simulation models

3. Connect simulation data to the product architecture
   - Simulation must be requirements-driven and systems-centric
Simulation Framework Architecture

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- Secure User Access
  - Web Client
  - Workstation Client

- Scripting & Process Definition
  - Scripting & Process Modeler

- Process Execution
  - Process Engine

- High Performance
  - Open APIs

- Remote Execution
  - Remote Job Engine

- Scalable Back End
  - Unified Data Model

- Persistent & Transient Data
  - Temp Files
  - File Vaults
  - Metadata Repository

- External Tools
  - CAD / CAE / Math / In-House Systems Modelling
  - Tool Connectors & Open APIs
  - Tool
  - Tool
  - Tool
  - Tool
  - Tool
  - Tool
  - Tool
  - Tool
  - Tool
  - Tool
  - Tool
  - Tool
  - HPC Nodes
  - HPC Nodes
Mixed-Fidelity models (systems to 3-D)
Multi-physics models
Multidisciplinary models (incl., software, electronics)
*Automation of assembly model generation, including connections*

**Tool-Agnostic Unified Product Data Model**

- **Modeling Engine**
  - Tool-Specific Data Model
  - Simulation Data Model (tool-independent)
  - Product Data Model

**PLM Platform Server**

- **Tool Connectors & Open APIs**

**Scalable Back End**

**Unified Data Model**

**Requirements-Driven, Systems-Centric, Template-Enabled Simulation Management**

**External Tools**
- CAD / CAE / Math / In-House Systems Modelling
- HPC Nodes

**Internal Tools**
- [Tool]
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Tool-Agnostic Unified Product Data Model

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Component reps.
Discrete reps. (e.g., mesh)
Engineering reps. (e.g., joints, welds)
Abstract groups
Environments (tool-, physics-specific)
Simulation Templates
Simulation material data
...

Requirements
Operating conditions
System architecture
eBOM / MBOM
CAD
Material data
Software
...

Unified Data Model

Numerical abstractions
Numerical properties
Solver parameters
Solver model templates
...

<5%
Tool-Specific Data Model

>95%
Simulation Data Model (tool-independent)

Product Data Model

PLM Platform Server

Tool Connectors & Open APIs

External Tools
CAD / CAE / Math / In-House Systems Modelling

Tool
Tool
Tool
Tool
Tool
Tool
Tool
Tool
Tool
Tool

HPC Nodes
HPC Nodes
Aras Platform – Connectors

Open architecture encourages integration with other enterprise systems and tools.

- MBSE
- Simulation
- MCAD PDM
- ECAD PDM
- ALM
- ERP
- MES
- IOT

Clients

Applications

Platform Services

Modeling Engine

Connectors
Simulation Automation – Templates & Connectors

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Aras Comet SPDM
Parametric, Multi-Fidelity, Multi-Source, Multi-Discipline

Unified Data Model & Templates
Connectors to External Tools

Product Representations

Analysis Models
(Auto-Generated)

Optimization Tools

- CAD Models
- Mesh Models
- Systems Models

- PLM
- Teamcenter
- Modelica
- MATLAB
- Code V
- Zemax
- OpticStudio
- Romax
- Isight
- ANSA Mesher
- ABAQUS
- MSC Nastran
- LS-DYNA
- ANSYS
- NX NASTRAN
- NX EXPLICIT
- ADAMS
- MBD Tools
- Home Grown

Simulation Automation – Templates & Connectors

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Simulation Automation – Templates & Connectors

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- Home Grown
Foundations of Effective Simulation Mgmt

- Open & extensible **Unified Data Model**
  - Across all physics, levels of model fidelity and disciplines
  - Simulation data captured mostly independent of the underlying tools
  - Vendor- & tool-agnostic
  - Support for any required standards through input/output Connectors

- Open & extensible **Connector Architecture**
  - Cover in-house tools & data
  - Enable commercial tools covering all required physics and levels of fidelity
  - Tight integration between parametric CAD & parametric mixed-fidelity CAE models

- **Robust Automation** across design changes & configuration variants
  - Simulation rules not based on CAD, instead product engineering / system architecture

- **Integral to mainstream processes across the lifecycle – Digital Thread**
  - Connected to Requirements, System Architecture and variant eBOMs
Systems Thinking is required, alongside the Reductionist approach

Requirements-Driven Systems Models are the connective tissue of the enterprise Digital Thread for multidisciplinary products

Simulation is essential and the need is growing exponentially
  - Current silo'ed & manual simulation is not adequate

Effective SPDM within the enterprise Digital Thread is required

Effective SPDM encourages/enables pervasive Systems Thinking
Aras is actively engaging in proof of concept initiatives for open reference architecture development. Please share your use cases & best practices:

MBSE / Simulation Management / Test Management

To collaborate/contribute your MBSE & Simulation Management use cases, contact:

Malcolm Panthaki | Aras
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Customers who use Aras Comet SPDM…
Customer Use Case #1

Rapid, High-Fidelity, Validated Analysis of Flight Hardware

The Aerospace Corp.
Aerospace Corp: Understanding HVAC Test Data

Distribution of temperatures across L13-16

Rigid body motions and wavefront errors introduced to individual lens components

Structural node displacements across L13-16 corresponding to temperature distribution

Wavefront error impact to entire visible camera
Integrated Optics Process With Thermal Controls Loop

Thermal & Structural Meshing

Thermal Controls Loop Using MATLAB

Structural & Optics Analysis – Focus correction loop
MBSE is highly effective for the design of complex systems by multidisciplinary teams.

Product quality is maintained or improved while reducing resource (cost, schedule) requirements by substantial margins (2X to 4x) by streamlining and improving the interfaces between discipline contributors.

Additional benefits include:

- Improved collaboration between discipline experts at Aerospace
- Early discovery of problems/conflicts that lead to expensive rework or mission-critical failures
- Cost-effective development of new space system concept designs
- High fidelity system engineering of space systems early in the product development cycle
- Excellent system engineering training vehicle for young engineers
- Reduces overdesign of space systems with consequent cost reduction
- Applicable throughout the product acquisition cycle

The Aerospace Corporation is currently on the leading edge of applying MBSE methods to the design of Electro-Optical sensors due to the use of Concurrent Engineering practices and the use of the Comet automation platform.
Customer Use Case #2

Understanding a Performance Issue in a Complex Laser System using automated Mixed-Fidelity Modeling

Air Force Research Labs.
Example: Beam Spread due to the MATRIX ASE
Results
AFRL: Project Benefits

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- Automate Mixed-Fidelity Modeling:
  Ability to perform systems level analysis using a combination of a custom systems analysis tool and 3-D FE COTS tools

- Selectively use high-fidelity models in a limited set of components – spend more computational power exactly where it is most required

- Rapidly validate complex multi-physics models against test results

- Reduce cycle time per iteration from weeks to hours while increasing accuracy and consistency

- Run large numbers of simulations automatically, looking for a better design
American Axle

- Market advantage based on engineering delivery of new technology systems at cost
- Enable consistent & accurate data for traceability
- Create repeatable processes for global scalability
- Each program: 50-100 configurations, each requiring 100’s to 1000’s of simulation runs

Solution Results

- Average 75% time reduction for analysis set up & report generation
- Improved product quality & reliability through greater simulation coverage
- Attained better reuse and repeatability of simulation processes

Tools & Solvers

- NX CAD
- Simulia/Abaqus
- NX/Nastran
- Romax
- Excel
- Mathematica
NASA Langley Research Center

- Electro-Optical sensor systems for satellite data collection
- Instruments highly sensitive to solar thermal effects
- Previously each analysis iteration took 2-4 weeks

Solution Results

- Structural-Thermal-Optical-Performance Analysis (STOP) with single repeatable process
- Ability to quickly conduct trade studies over many concepts for high level of design confidence
- Analysis iteration now takes < 1 day
- Engineers are introduced to “Systems Thinking” when using the Concurrent Engineering development process

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GKN Driveline

- Bending Frequency influenced by many design variables
- Libraries of templates and design architectures
- Create repeatable processes for global scalability across all engineering teams

Solution Results

- Democratize process for all engineers using Web GUIs
- Non-experts investigate design iterations rapidly before the experts are involved
- Automation drives process refinement/improvement, resulting in accuracy and consistency globally
- Improved product quality & reliability through greater simulation coverage
Magna Cosma

- Configuration and barrier crash analyses of bumper systems
- Manual process results in 6-8 hours per iteration
- CAD design change coordination issues resulted in errors, added costs and reliability impact

Solution Results

- Enabled repeatable parameter studies for better design decisions and traceability
- Process definition improved product quality across global organization
- Model assembly and report generation reduced from avg. 6-8 hrs to 15 minutes / iteration
Thank You

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