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Digital Twin via Integration of CAD and Simulation Models

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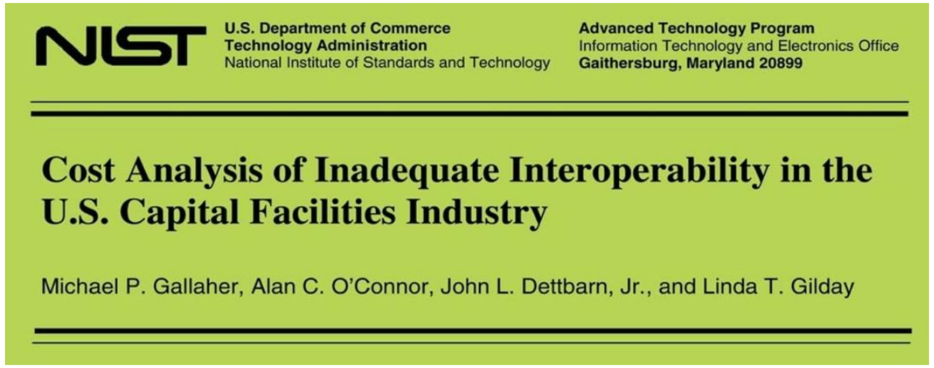
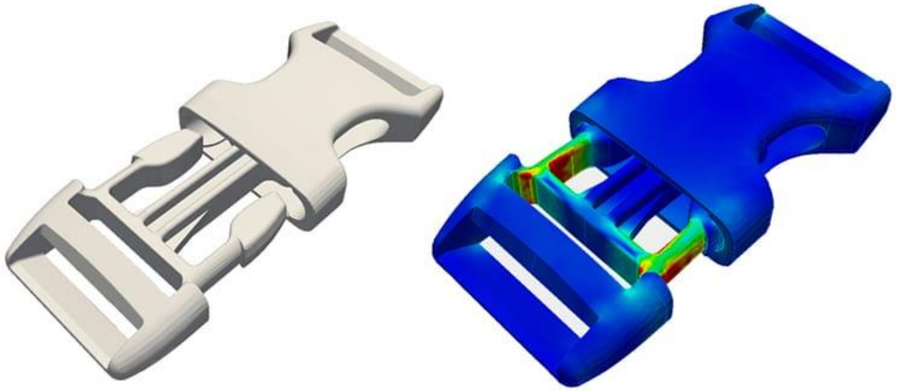
Focus, Need, and Industrial Relevance

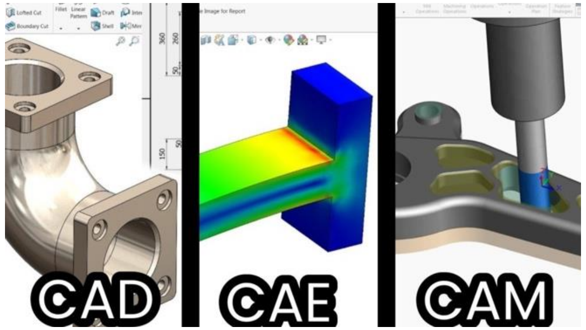

U.S. Department of Commerce
Technology Administration
National Institute of Standards and Technology

Advanced Technology Program
Information Technology and Electronics Office
Gaithersburg, Maryland 20899

Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry

Michael P. Gallaher, Alan C. O'Connor, John L. Dettbarn, Jr., and Linda T. Gilday





- NIST estimate: Improper interoperability of industrial data (CAD/CAM/CAE/PDM, etc.) costs approximately $15.8 billion per year [GCR, NIST. 2004]

- Studies show: 97.06% reduction in manual inputs and 63.92% reduction in analysis time per CAD model [Chun, 2025]

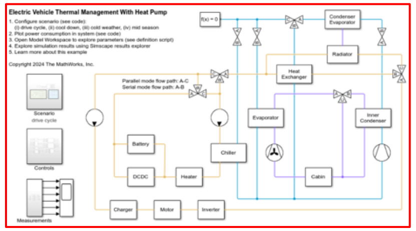
- Integrated CAD/CAE/CAM workflows enable: 40% fewer design errors, ≥30% shorter design-to-production cycles, 20%+ lower material costs, and 15% reduced labor costs [Skygens report, 2004]

Project Goals

- Develop an automated framework to convert CAD assemblies into executable, multi-domain digital twin models.
- Enable rapid generation of control-oriented simulation models for system-level analysis and optimization.
- Reduce design cycle time and increase scalability of digital twin development across complex engineering systems.

CAD update by Gen AI

Performance Simulation



Simulation Model Update

Objectives

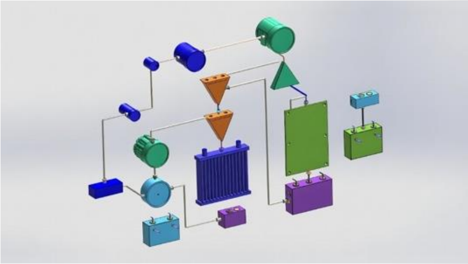
- Extract topology, connectivity, and physical properties from CAD assemblies using automated parsing and machine-learning–assisted classification.
- Develop a generalized intermediate representation (IR) that captures system-level abstraction across mechanical, thermal, electrical, and fluid domains.
- Automatically synthesize executable Simulink/Simscape models from the IR.
- Validate generated digital twins through subsystem case studies and demonstrate reduced modeling time and improved scalability.

Pilot Test Setup for Data Collection and Rotating Machine Configuration

Approach / Research Methods (1)

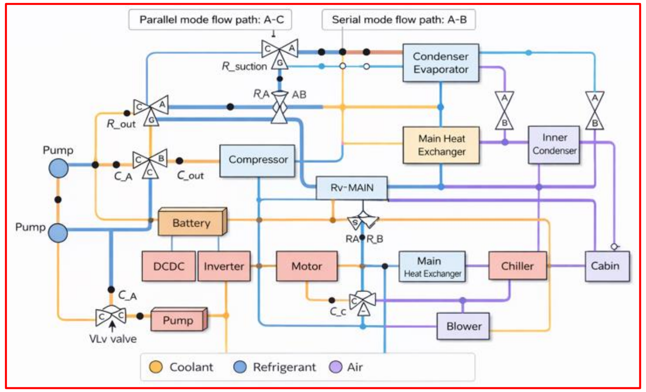
1. CAD Parsing and System Intent Extraction
   - Analyze CAD assemblies to identify components, ports, and interconnections.
   - Classify system components using rule-based and machine-learning methods.
   - Generate system topology with component types and confidence levels.

Vehicle CAD model



Thermal System Topology

- 2. Intermediate Representation Development
   - Convert CAD geometry into a multi-domain intermediate thermal-fluid-mechanical representation.
   - Model connectivity, boundary conditions, and lumped/distributed abstractions.
   - Establish a standardized schema for scalable system abstraction.



Example Intermediate Representation for Thermal Management System

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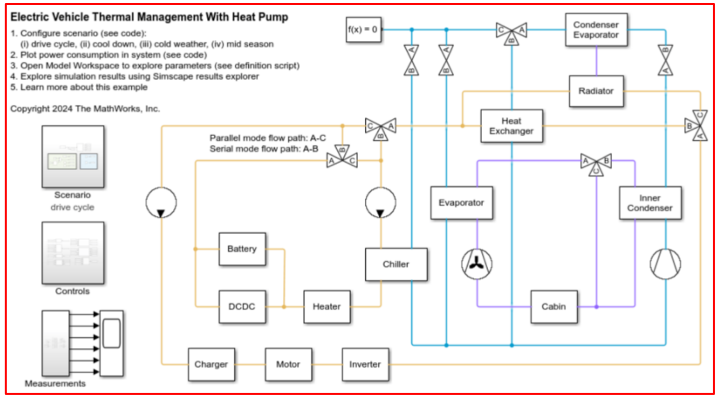
Approach / Research Methods (2)

3. Automatic Model Synthesis
   - Map the intermediate representation to Simulink/Simscape libraries.
   - Automatically generate blocks, parameters, and network connections.
   - Integrate supervisory control and sensor interfaces for digital twin readiness.

4. Validation and Digital Twin Deployment
   - Compare synthesized models against manually developed benchmarks.
   - Evaluate computational efficiency and scalability.
   - Demonstrate subsystem digital twins (e.g., powertrain, thermal management, suspension).



Simulink/Simscape Model

Outcomes / Deliverables

- An automated CAD-to-simulation digital twin generation framework.
- A standardized intermediate representation schema for multi-domain system abstraction.
- Executable Simulink/Simscape models automatically synthesized from CAD assemblies.
- Validated digital twin case studies demonstrating reduced model development time and improved design iteration efficiency.
- Software toolkit and technical documentation for industrial deployment.

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Expected Impacts

- By enabling automated conversion of CAD assemblies into executable simulation models, the proposed framework will significantly reduce model development time, accelerate design iteration, and improve early-stage system validation across mechanical, thermal, electrical, and fluid domains.
- The integration of geometry-based design data with control-oriented simulation models will enhance system-level optimization, reduce reliance on physical prototyping, and support more informed engineering decisions throughout the product lifecycle.
- The project will advance scalable digital twin deployment, strengthening model-based engineering practices, improving industrial competitiveness, and supporting the transition toward more intelligent, data-driven, and sustainable manufacturing systems.

Project Administration

Budget

Item	Year 1	Year 2	Total
Salaries and Stipends			
Faculty – H. Yoon	3,000	3,000	6,000
Faculty – C. Chen	3,000	3,000	6,000
Graduate Research Assistant	31,200	31,200	62,400
Fringe Benefits			0
Faculty and Staff (32%)	1,920	1,920	3,840
Student Research Assistants	1,664	1,664	3,328
Other Direct Costs			
Supplies, Software, and Equipment			
Travel	3,416	3,416	6,832
Total Direct Costs	44,200	44,200	88,400
Indirect Costs (10% Request)	4,420	4,420	8,840
Items Not Charged F&A			
GRA Tuition	11,380	11,380	22,760
Budget Totals	**$60,000**	**$60,000**	**120,000**

Duration: 24 Months

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8

- Q1. System setup and sensor data collection
- Q2. Sensor data preprocessing
- Q3. Prediction model development using deep learning
- Q4. Deep learning model training
- Q5. Refinement of model inference
- Q6. Edge deployment of the prediction model
- Q7. Integration with industrial control networks
- Q8. Performance validation

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Questions?

Selected References

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- O'Donnell, J. and Yoon, H.S., 2020. Determination of time-to-failure for automotive system components using machine learning. *Journal of Computing and Information Science in Engineering*, *20*(6), p.061003.
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