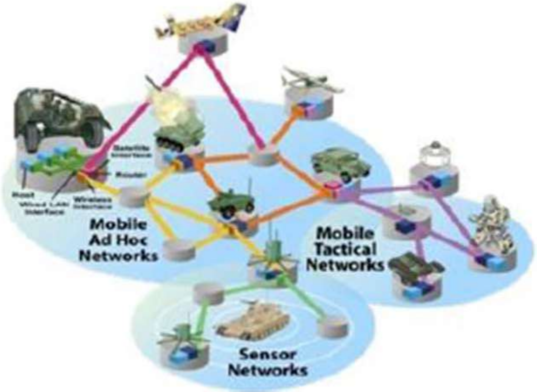
Component Based Networking: Network MBSE for MANET

The Challenge & Need:
Design DoD and Commercial MANET Adaptive to Dynamic Mission Requirements



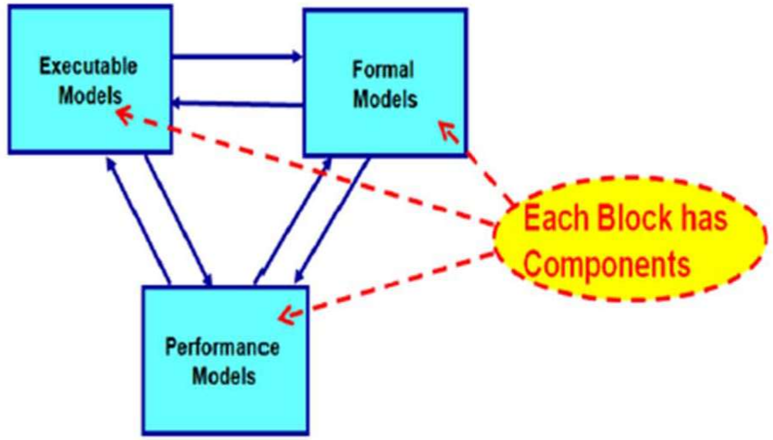
Dynamic Interconnection and Interoperability

- Broadband wireless nets capable for **multiple dynamic interface** points
- **Any node** can serve as **interface/gateway**

Fig.1: Intelligent Wireless Multi-Nets

Fig.2: Component Based Networking

Component-Based Network Synthesis



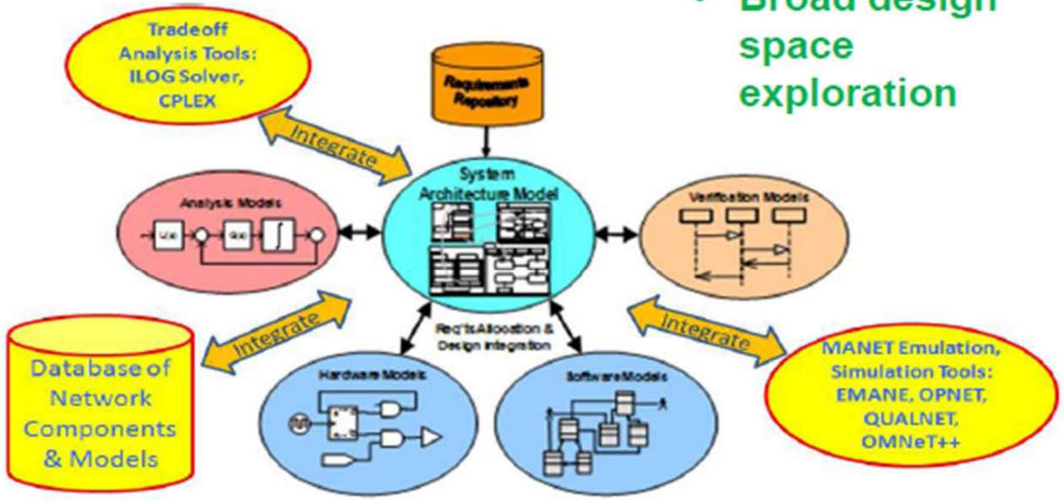


Fig. 3: Network MBSE Toolset : integrating **SysML** Architecture Model with DB of network models, emulation-simulation models, tradeoff tools

BENEFITS

- Reduced MANET cost and fielding time
- Modularity and re-use
- Increased agility in designing, modifying and fielding new MANET
- Broad design space exploration

Components for Routing Protocols

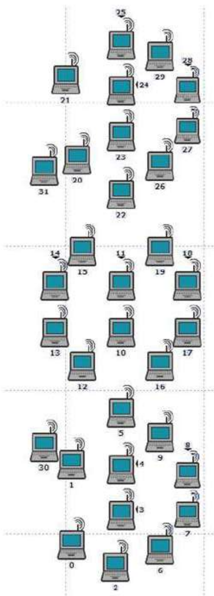
- Neighborhood Discovery Component (NDC)
  - Status of nodes that are close to me (2-hop neighborhood)
- Selector of Topology Information to Disseminate Component (STIDC)
  - What information should be broadcasted in the network
- Topology Information Dissemination Component (TDC)
  - How the information is shared
- Route Selection Component
  - Path selection Criteria

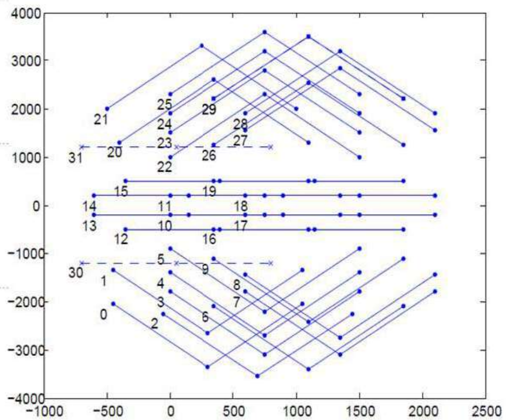
Challenges

- Most local pruning algorithms proposed **do not guarantee QoS optimal paths** for routing.
  - In most cases, they **only guarantee connectivity**

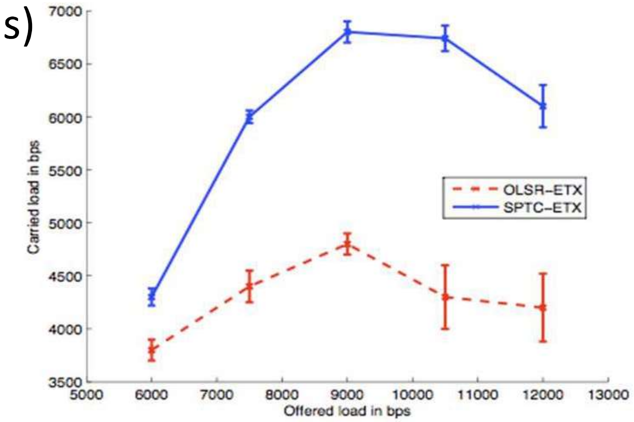
- Non-triviality for preserving QoS optimal paths in local pruning algorithms:
  - **Preserving global properties from only local observations**

3 Platoon Mobility Scenario





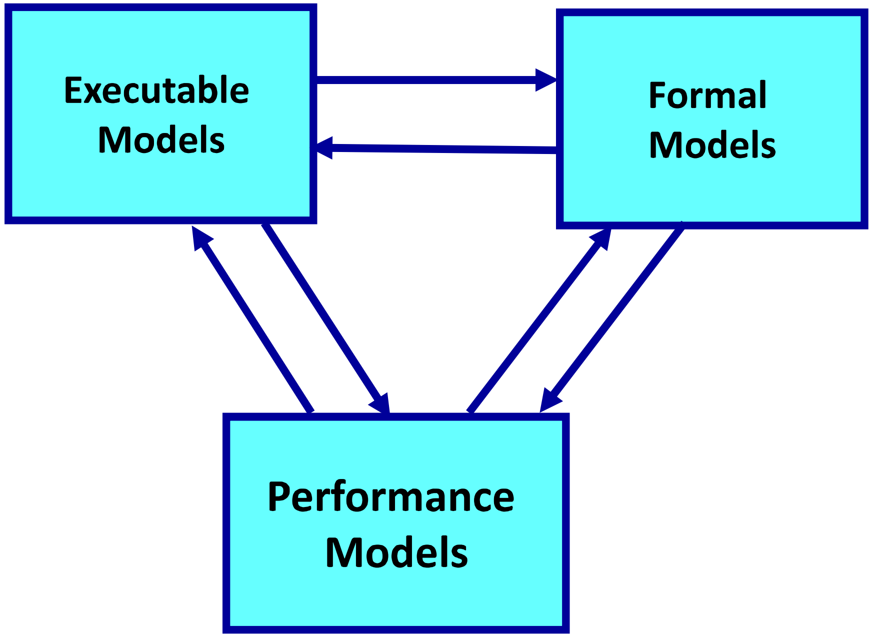
Long connection from 20 to 0 (platoon heads)



	OLSR-ETX	SPTC-ETX
Saturation CL	~ 2 Mbps	~ 2 Mbps
TC message rate	923 kbps	890 kbps

Type	Connection	Offered-load
Intra-platoon	(1,3),(2,9),(4,6),(7,5),(20,29), (14,17),(16,11),(17,18),(19,12), (21,22),(23,27),(23,28)	12 kpbs
Inter-platoon	(1,18) (20,11),(20,0) (10,1),(21,10)	2.4 kbps 6 kbps 12 kbps

Component-base Networks and Composable Security



Studying compositionality is necessary!

Universally Composable Security of Network Protocols:

- Network with many agents running autonomously.
- Agents execute in mostly asynchronous manner, concurrenty several protocols many times. Protocols may or may have not been jointly designed, may or not be all secure or secure to same degree.

Key question addressed :

- **Under what conditions can the composition of these protocols be provably secure?**
- **Investigate time and resource requirements for achieving this**

Universally Composable Security (UCS)

Results todate (Canetti, Lindell, …) :

- When there is a clear majority of well behaving nodes (i.e.2/3) **almost any functionality is secure under UCS**
- When there is no clear majority then UCS is **impossible** to achieve unless there are pre-conditions – typically some short of trust mechanism
- Introducing **special structure in the network** (e.g. overlay structure, small subset of absolutely trusted nodes) helps substantially in establishing UCS, even without preconditions
- **Many applications:** military networks, health care networks, sensor networks, SCADA and energy cyber networks
- **The challenge and the hope: Use "tamper proof hardware" (physical layer schemes, TPM etc.) even on a small subset of nodes to provably (validation) establish UCS – role of fingerprints and physical layer techniques.**
- **Establish it and demonstrate it?**

Latest: Adaptive Component-Based MANET Security

- **Components of MANET Routing Protocols**
- Neighborhood Discovery Component (NDC)
  - Status of nodes that are close to me (2-hop neighborhood)
- Selector of Topology Information to Disseminate Component (STIDC)
  - What information should be broadcasted in the network
- Topology Information Dissemination Component (TDC)
  - How the information is shared
- Route Selection Component
  - Path selection Criteria

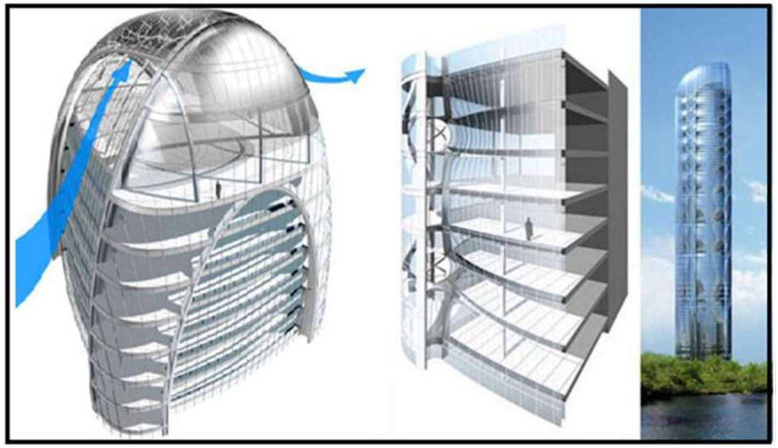
- **Cross-layer – MAC and Routing**
- **Detect attacks – mitigation strategies – adaptively change protocol component parameters and structure**
- **Distributed trust an integral part**
- **Treat it as a Feedback Control System!**
- **Part of the DARPA WND program**

Buildings as Cyber-Physical Systems

- **Research focus:** Platform-Based Design for Building-Integrated Energy Systems.

Pearl River Tower Complex

Green Technology Tower –– Architectural Proposal for Chicago



NET-zero Energy

NIST Net Zero Energy Residential Test Facility

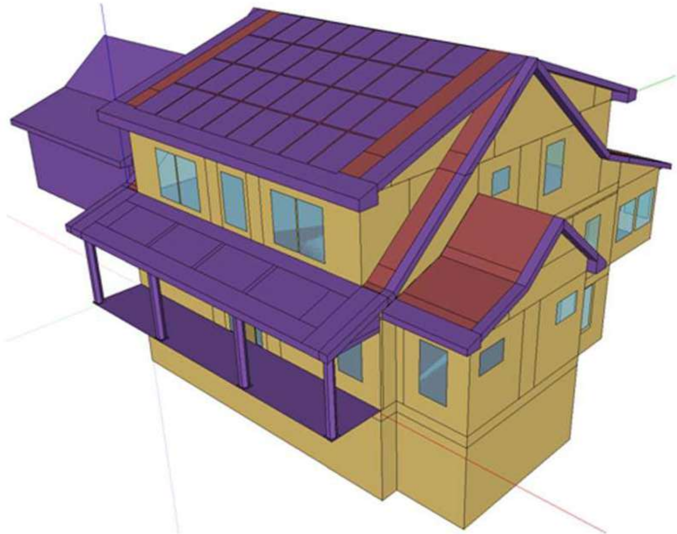
Courtesy J. Kneifel (2012)

CURRENT CAPABILITIES AND SOFTWARE

EnergyPlus

- Developed in 2001 by DOE and LBNL, currently v8.1
- Whole Building Energy Simulator – Weather, HVAC, Electrical, Thermal, Shading, Renewables, Water, Green Roof
- Steady state simulation down to 1 minute time intervals
- Reporting on built-in, component or system level properties.
  - Reports can vary in frequency: Annual, Monthly, Daily, Timestep
- Includes EML for HVAC controls (see MLE+)

EnergyPlus



EnergyPlus - Pros

- Highly detailed models for realistic as-builts
- Captures many of the complex physical interactions that outside and within a building
- Active and wide community and support

EnergyPlus – Cons

- Models can have long development time and steep learning curve

Courtesy EnergyPlus, J. Kneifel (2012)

CURRENT CAPABILITIES AND SOFTWARE

BEopt – Building Energy Optimization

- Developed by NREL
- Software that couples with EnergyPlus (and DOE2) that acts as an optimized simulation controller and provides easy analytic capabilities
- Extends functionality of EnergyPlus

BEopt – Pros

- Decreases time per simulation by simplifying scope of energy model
- Uses sequential search algorithm to reduce number of necessary simulations
- Lists discrete options for parameters
- Includes model dependencies between parameters
- Finds optimal designs for Bi-Objective Optimization of Life Cycle Cost vs Energy Savings

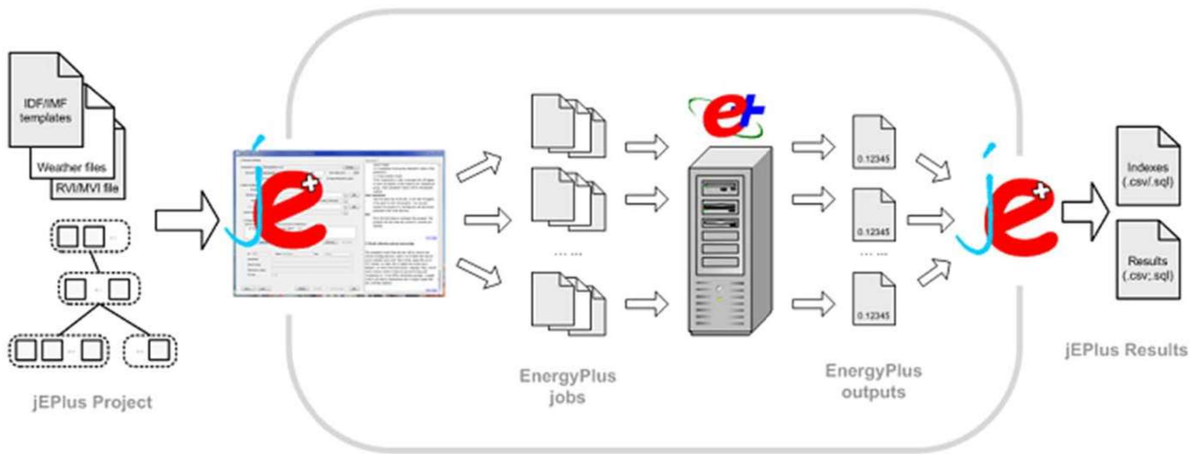
CURRENT CAPABILITIES AND SOFTWARE

jEPlus

- Developed by Yi Zhang and Ivan Korolija at De Montfort University, UK
- Java wrapper for EnergyPlus that simplifies parametric analysis
- Extends functionality of EnergyPlus

jEPlus– Pros

- Greatly enhances parametric analysis across all platforms
- Parametric tagging system makes it much easier to code for large state spaces



Courtesy Y. Zhang

MULTI-OBJECTIVE OPTIMIZATION

Problem Formulation

Design Parameters	Description	Constraint	Initial	Unit
x_1	Exterior Wall Insulation (R-Value)	$19 \leq x_1 \leq 44$	$x_1 = 19$	$\frac{\text{ft}^2 \cdot {}^\circ\text{F} \cdot \text{hr}}{\text{Btu}}$
x_2	Roof Insulation (R-Value)	$50 \leq x_2 \leq 75$	$x_2 = 50$	$\frac{\text{ft}^2 \cdot {}^\circ\text{F} \cdot \text{hr}}{\text{Btu}}$
x_3	Window (U-Value)	$0.2 \leq x_3 \leq 0.35$	$x_3 = 0.35$	$\frac{\text{Btu}}{\text{ft}^2 \cdot {}^\circ\text{F} \cdot \text{hr}}$
x_4	Window (SHGC)	$0.25 \leq x_4 \leq 0.35$	$x_4 = 0.35$	Unit-less
x_5	Infiltration (ACH)	$0.6 \leq x_5 \leq 3$	$x_5 = 3$	ACH
x_6	HRV/Ventilation (% Energy Recovered)	$0\% \leq x_6 \leq 85\%$	$x_6 = 0\%$	%
x_7	Lighting (% Efficient Lighting)	$75\% \leq x_7 \leq 100\%$	$x_7 = 75\%$	%
x_8	PV (Capacity)	$0 \leq x_8 \leq 10240$	$x_8 = 0$	W

MULTI-OBJECTIVE OPTIMIZATION

Initial Cost Objective Function

Minimize

$$IC = \sum (IC_{Wall} + IC_{Roof} + IC_{Win} + IC_{Inf} + IC_{Vent} + IC_{Light} + IC_{PV}$$

where

$$\begin{aligned}
IC_{Wall} &= A_{Wall}\,(.0666\,(x_1 - 19) + 0.7) \\
IC_{Roof} &= A_{Roof}\,(0.1\,(x_2 - 49) + 2.5) \\
IC_{Win} &= A_{Win}\,(456.2 - 2633\,x_3 - 216.6\,x_4 + 3863\,x_3^2 + 942\,x_3\,x_4 \\
IC_{Inf} &= \frac{V_{room}}{8}\,(0.52\,x_5^{-0.7462}) \\
IC_{Vent} &= 42(8.571\,x_6^2 + 0.8571\,x_6) + 1300 \\
IC_{Light} &= 0.2237\,(1281 - (-2676\,x_7 + 3288)) \\
IC_{PV} &= 2.6\,x_8;
\end{aligned}$$

MULTI-OBJECTIVE OPTIMIZATION

Energy Use Objective Function

Minimize

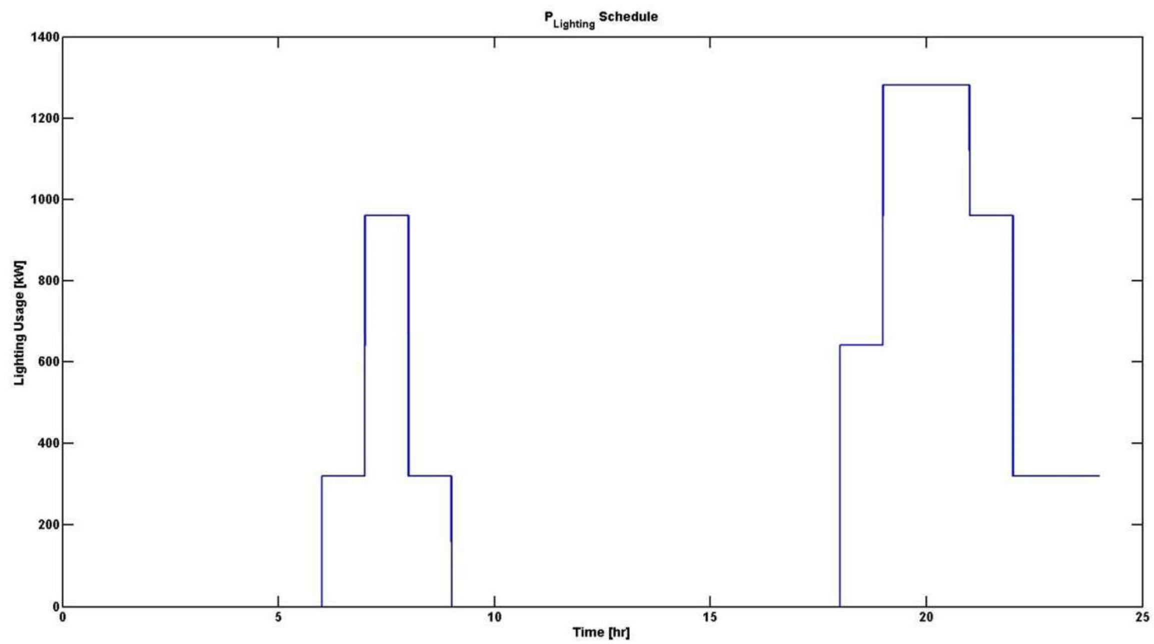
$$EU = \sum_{t=0}^{24} \frac{(P_{PV}(t) + P_{Lighting}(t) + \beta_t P^{op}_{HVAC})}{60000}$$

β_t is the On/Off factor for the HVAC unit at timestep t
$P^{op}_{HVAC} = 1000$

MULTI-OBJECTIVE OPTIMIZATION

Energy Use Objective Function

$$P_{Lighting}(t) = \begin{cases} 0 & \text{for } 0 \leq t < 6 \ \& \ 8 \leq t < 18 \\ (0.25)(-2676\, x_7 + 3288), & \text{for } 6 \leq t < 7 \ \& \ 22 \leq t \leq 24 \\ (0.5)(-2676\, x_7 + 3288), & \text{for } 18 \leq t < 19 \\ (0.75)(-2676\, x_7 + 3288), & \text{for } 7 \leq t < 8 \ \& \ 21 \leq t < 22 \\ (-2676\, x_7 + 3288), & \text{for } 19 \leq t < 21 \end{cases}$$



MULTI-OBJECTIVE OPTIMIZATION

Operational Cost Objective Function

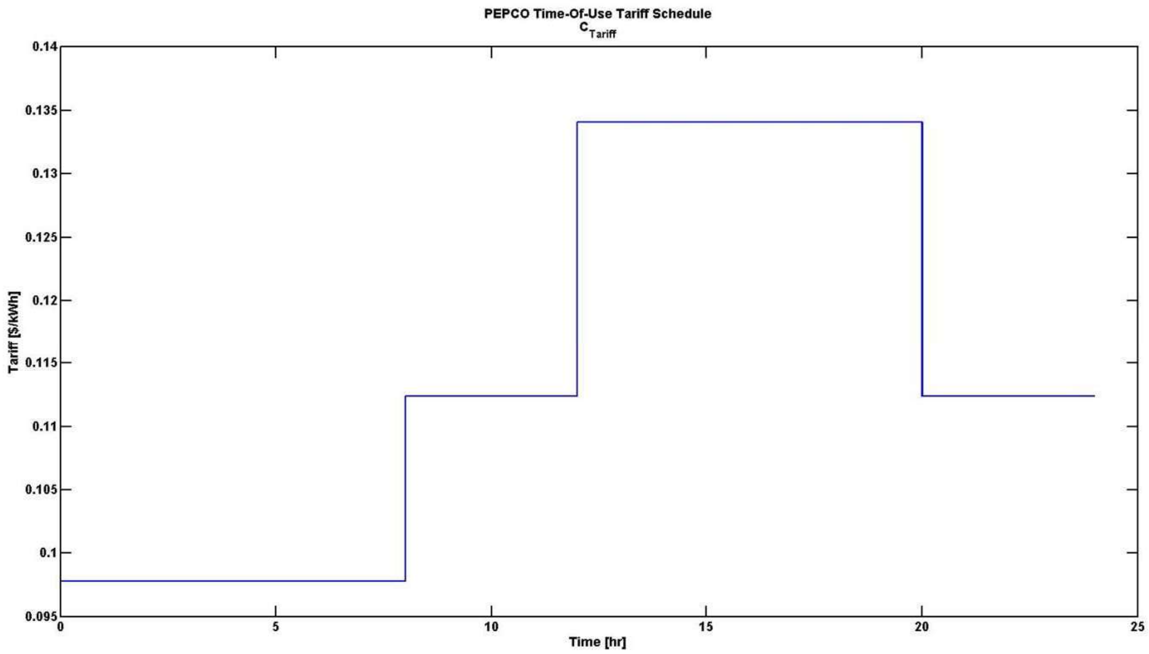
Minimize

$$OC = \sum_{t=0}^{24} \frac{C_{tariff}(t)[P_{PV}(t) + P_{Lighting}(t) + \beta_t P_{HVAC}^{op}]}{60000}$$

MULTI-OBJECTIVE OPTIMIZATION

Operational Cost Objective Function

$$C_{tariff}(t) = \begin{cases} 0.0978, & \text{for } 0 \leq t < 8 \\ 0.1124, & \text{for } 8 \leq t < 12 \ \& \ 20 \leq t \leq 24 \\ 0.1341, & \text{for } 12 \leq t < 20 \end{cases}$$



MULTI-OBJECTIVE OPTIMIZATION

User Comfort Objective Function

Maximize

$$UC = \sum_{t=0}^{24} \gamma_t$$

where

$$\gamma = \begin{cases} 1, & \text{for } T_{room,t} < T_{thresh} \\ 0, & \text{for } T_{room,t} \geq T_{thresh} \end{cases}$$

Home Performance Objective Function

Minimize

$$HP = \sum_{t=0}^{24} \beta_t$$

MULTI-OBJECTIVE OPTIMIZATION

Heat Transfer Equations

$$T_{room}[t] = \frac{Q_{net,t-1}}{C_p \cdot \rho \cdot V_{room}} + T_{room}[t-1]$$

$$C_p = 0.24\ \frac{\text{Btu}}{^\circ\text{F} \cdot \text{lb}_\text{m}}$$

$$\rho = 0.075\ \frac{\text{lb}_\text{m}}{\text{ft}^2}$$

$$V_{room} = 12800\ \text{ft}^3$$

MULTI-OBJECTIVE OPTIMIZATION

Simulation

Next Iteration

Design Parameters:

x1 - Exterior Wall Insulation [R] = **30.00**

x2 - Roof Insulation [R] = 50.00

x3 - Window U-Value [U] = 0.35

x4 - Window SHGC [SHGC] = 0.35

x5 - Infiltration [ACH] = 3.00

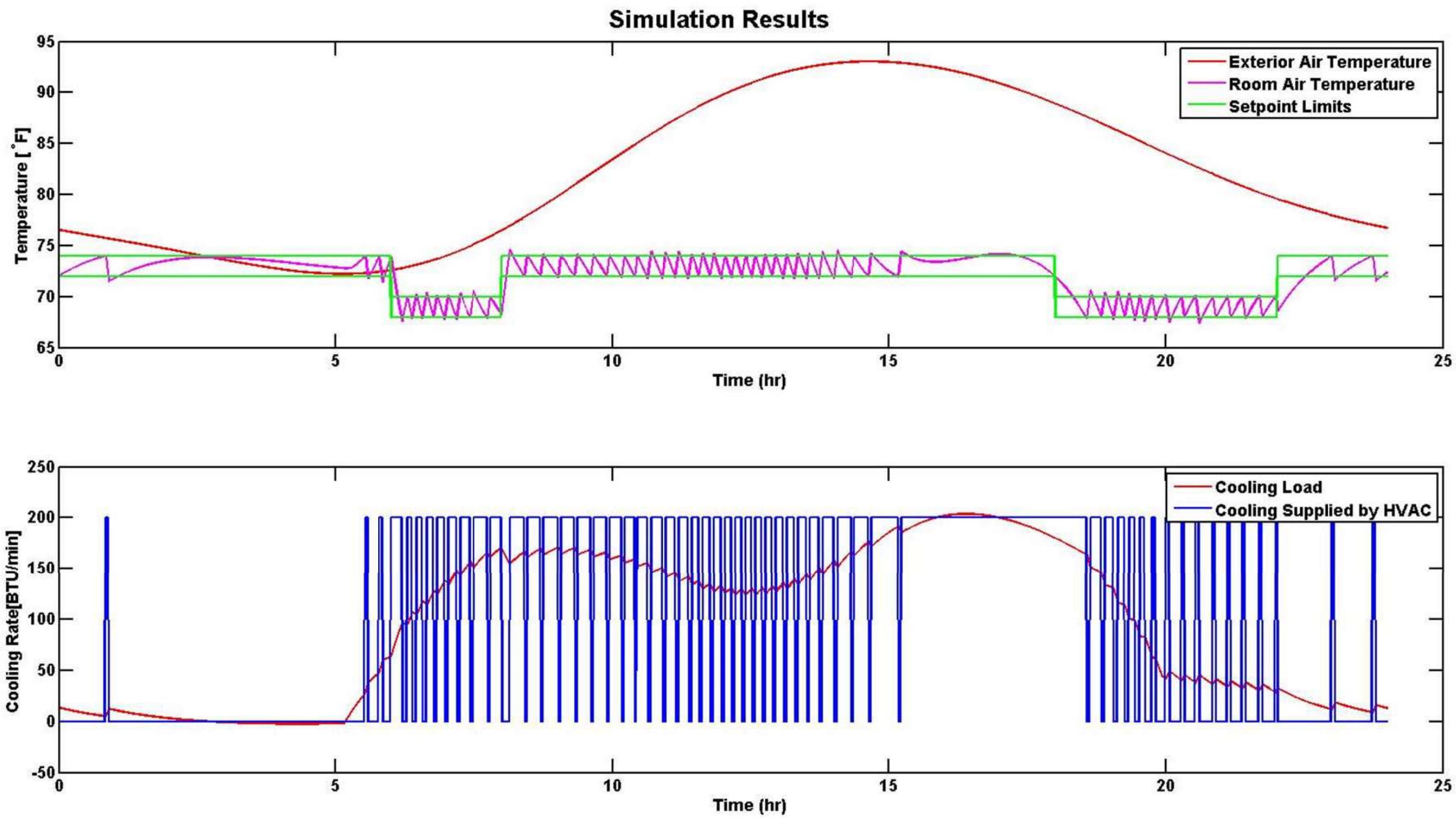
x6 - HRV/Ventilation [% Energy Recovered] = 0.00

x7 - Lighting [% Efficient Lighting] = 0.75

x8 - PV [Watt] = 0

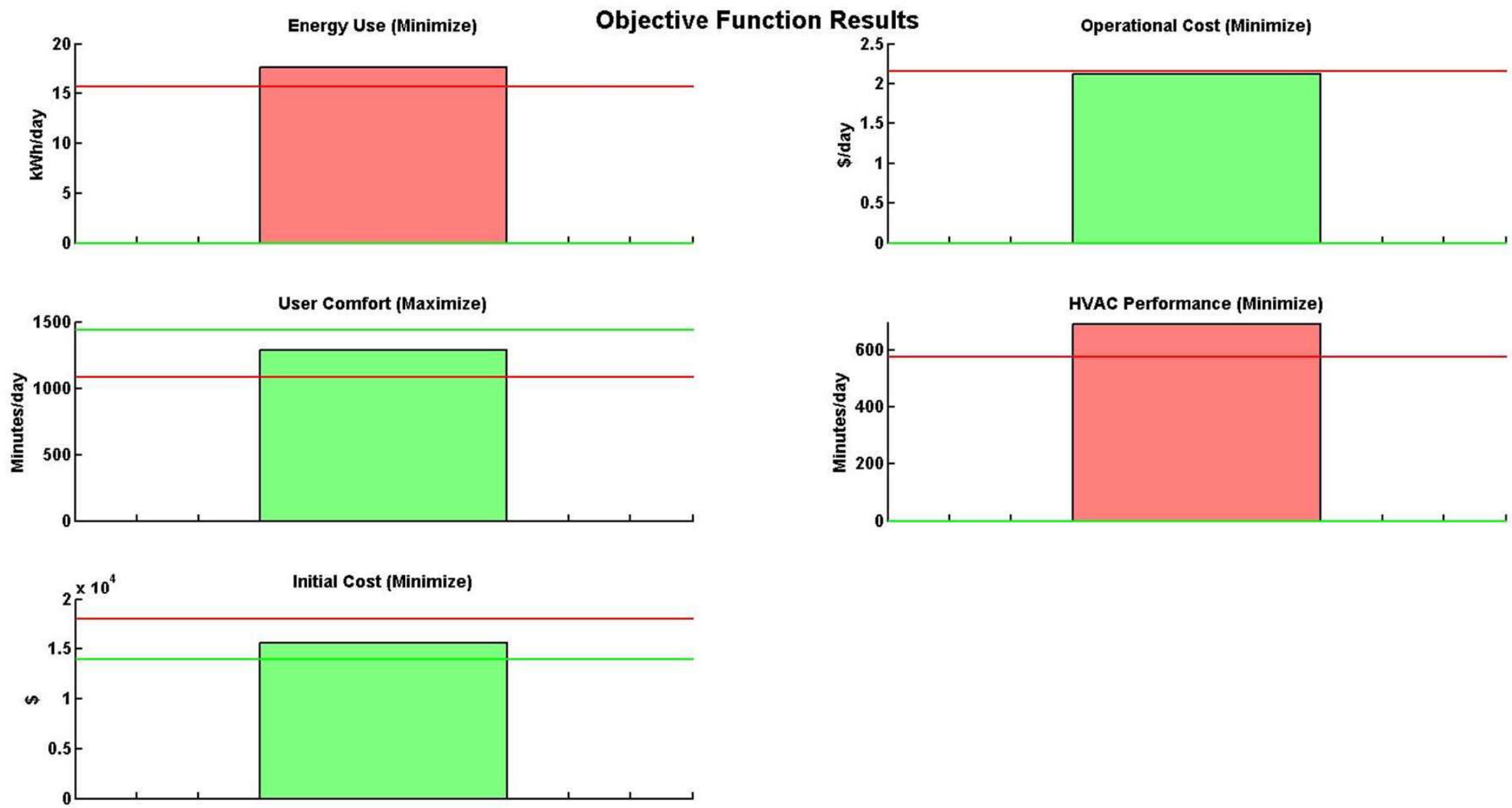
MULTI-OBJECTIVE OPTIMIZATION

Simulation



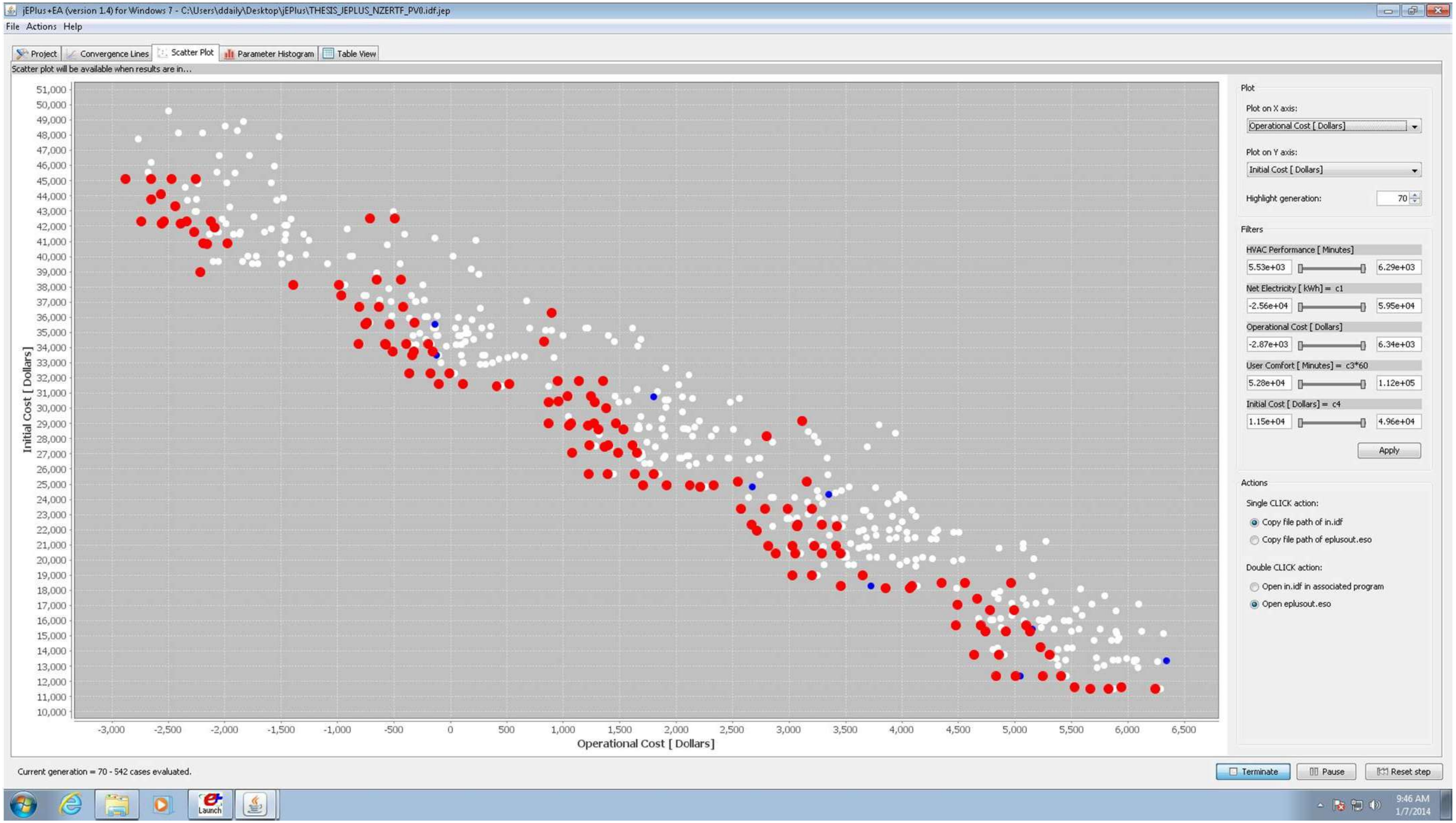
MULTI-OBJECTIVE OPTIMIZATION

Simulation



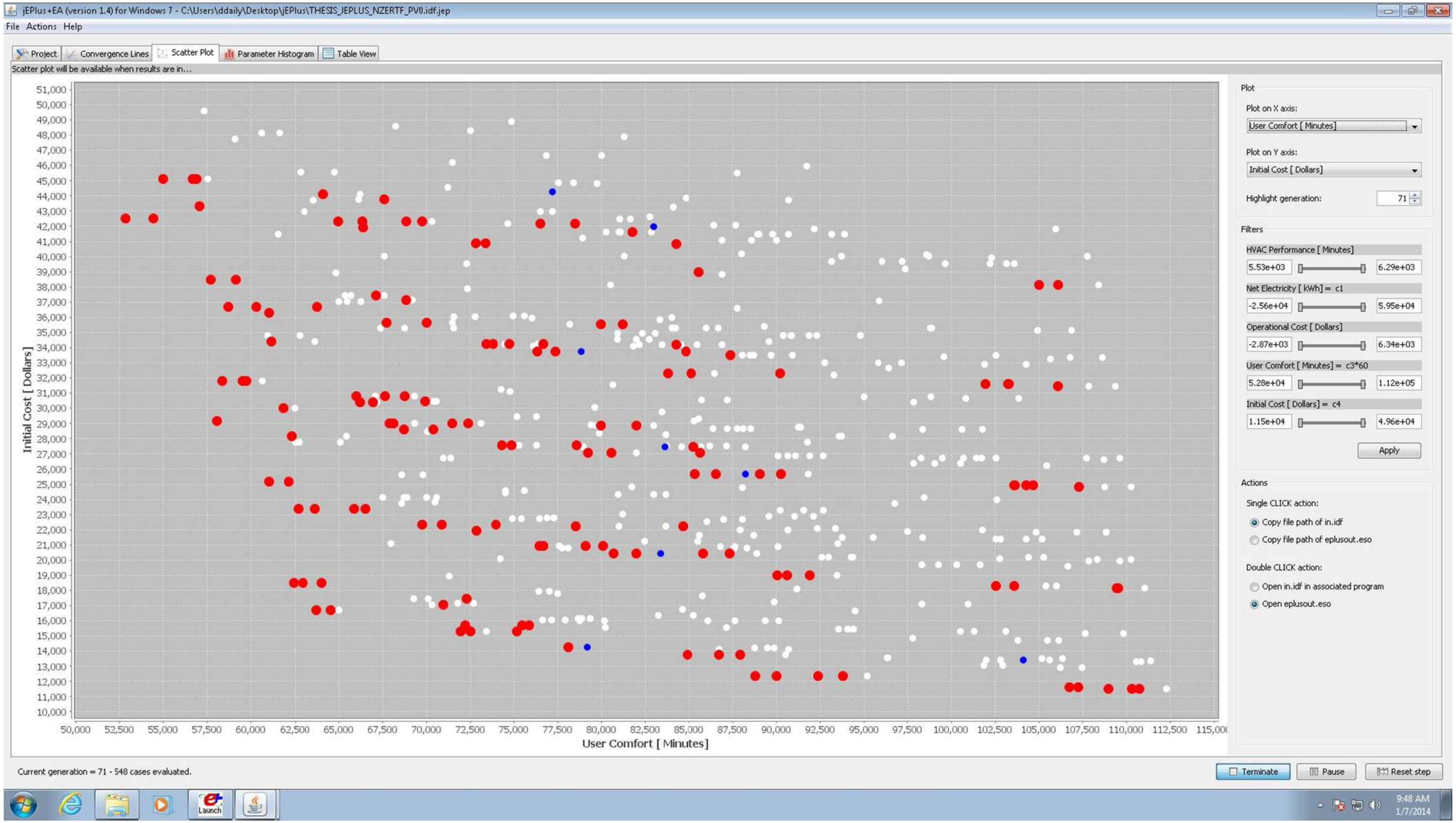
JEPLUS+EA OPTIMIZATION

Simulation



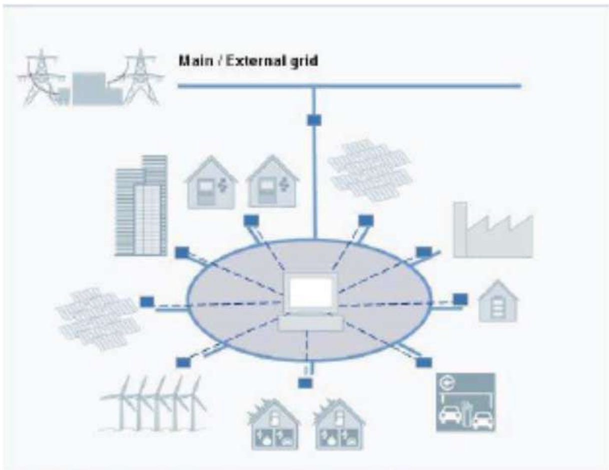
JEPLUS+EA OPTIMIZATION

Simulation



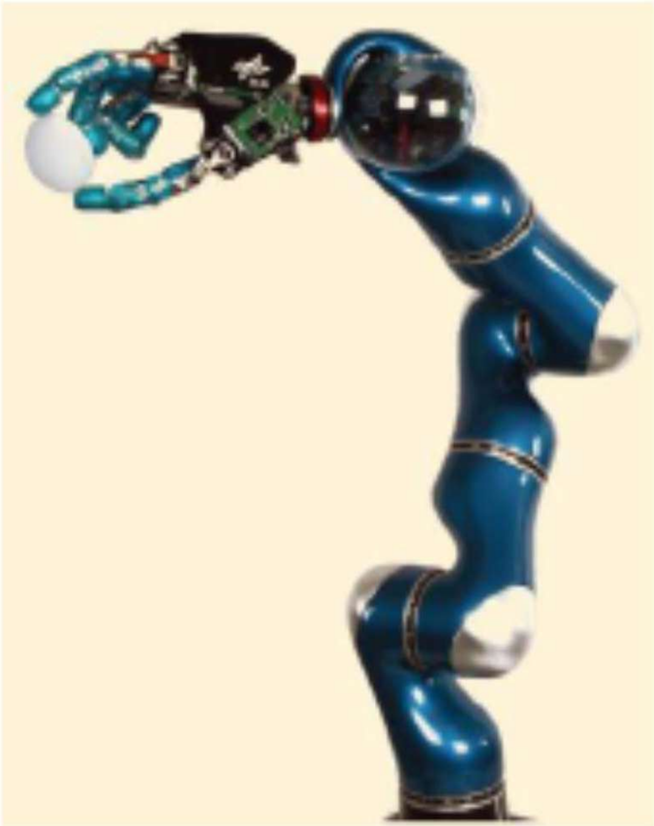
Integrating Siemens PLM Tools for MBSE in Energy Efficiency

- **Teamcenter, 4GD, NX CAD, PLM elements like Cost**



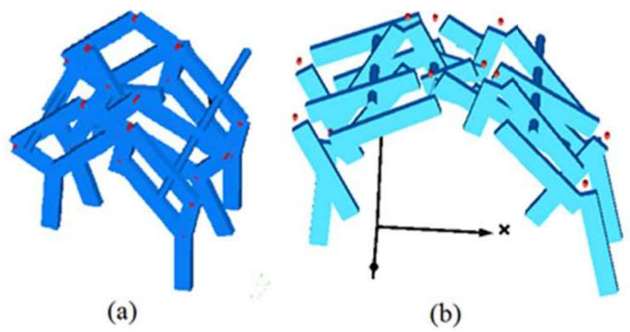
- Smart-grids at various scales from a few houses to neighborhoods to regions
- Retrofit design of existing houses for improved energy efficiency
- Zero or positive energy houses by design
- Partitions and design elements (4GD)
- Manufacturing (read Construction) process management
- Collaborative design and requirements management (Teamcenter)
- Linking Teamcenter, NX CAD, 4GD, with our MBSE framework suite; especially with our advanced tradeoff and design space exploration tools

MBSE for Robotic Arms and Grippers



- Transcend areas of application: from space to micro robotics
- Include material selection in design
- Include energy sources, resilience, reliability, cost
- Include validation-verification and testing
- Use integrated SysML and Modelica environment
- Link it to tradeoff tools CPLEX and ILOG Solver
- Demonstrate reuse, traceability, change impact and management

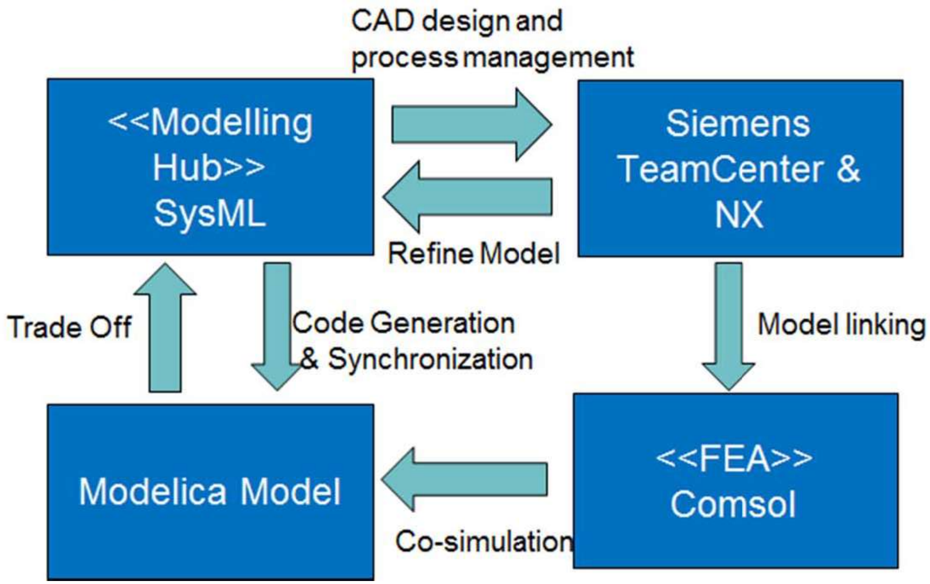
Application to Microrobotics



- Micro-robots design and manufacturing require control algorithm and physical layer (material and geometry) co-design.
- This insect-like robot is modeled in Modelica language using Differential Algebraic Equation.
- We are working on a Model-Based Systems Engineering approach to perform analysis, modeling and tradeoff for robotics and its material and control parameters.

Siemens Tools Utilization

- Design and analysis CAD model at the design phase
- Guide requirement to implementation from CAD design to physical simulation



Microrobot

Kinematics

- Coordinate transformations

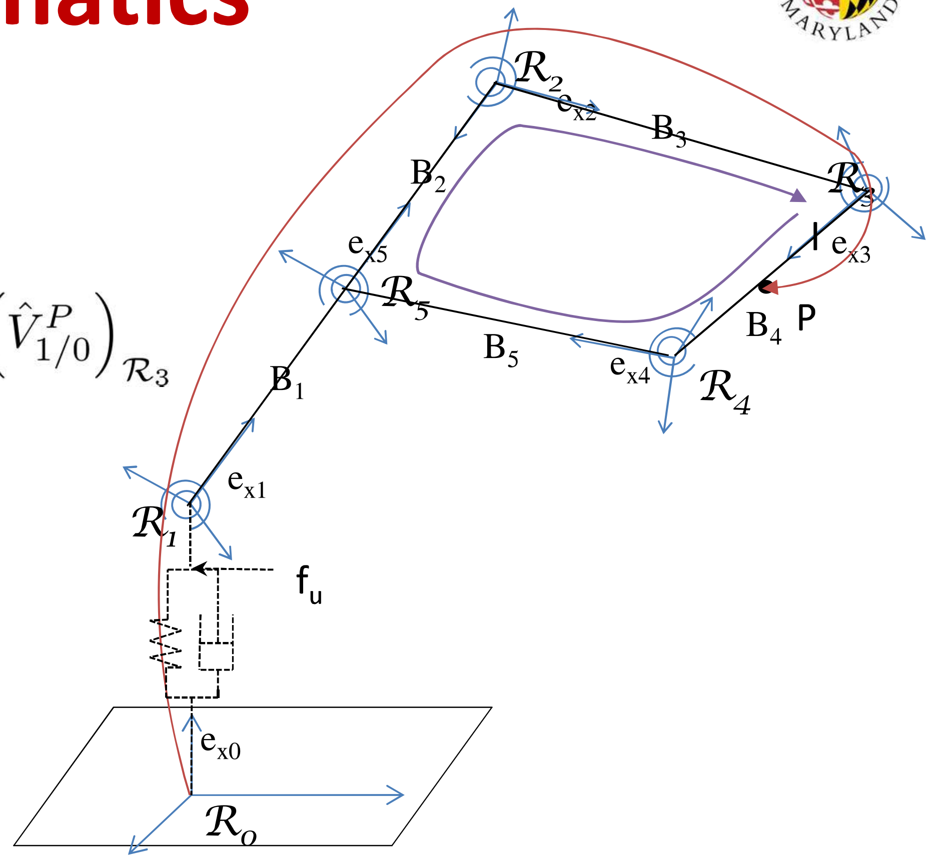
$$\left(\hat{V}^P_{3/0}\right)_{\mathcal{R}_3} = \left(\hat{V}^P_{3/2}\right)_{\mathcal{R}_3} + \left(\hat{V}^P_{2/1}\right)_{\mathcal{R}_3} + \left(\hat{V}^P_{1/0}\right)_{\mathcal{R}_3}$$

- Direct Kinematics

$$\left(\hat{V}^P_{3/2}\right)_{\mathcal{R}_3} = \begin{pmatrix} \dot{\theta}_3 e^3_z \\ l e^3_x \times \dot{\theta}_3 e^3_z \end{pmatrix}$$

$$\left(\hat{V}^P_{2/1}\right)_{\mathcal{R}_3} = \begin{pmatrix} \dot{\theta}_2 e^2_z \\ (l_2 e^2_x + l e^3_x) \times \dot{\theta}_2 e^2_z \end{pmatrix}$$

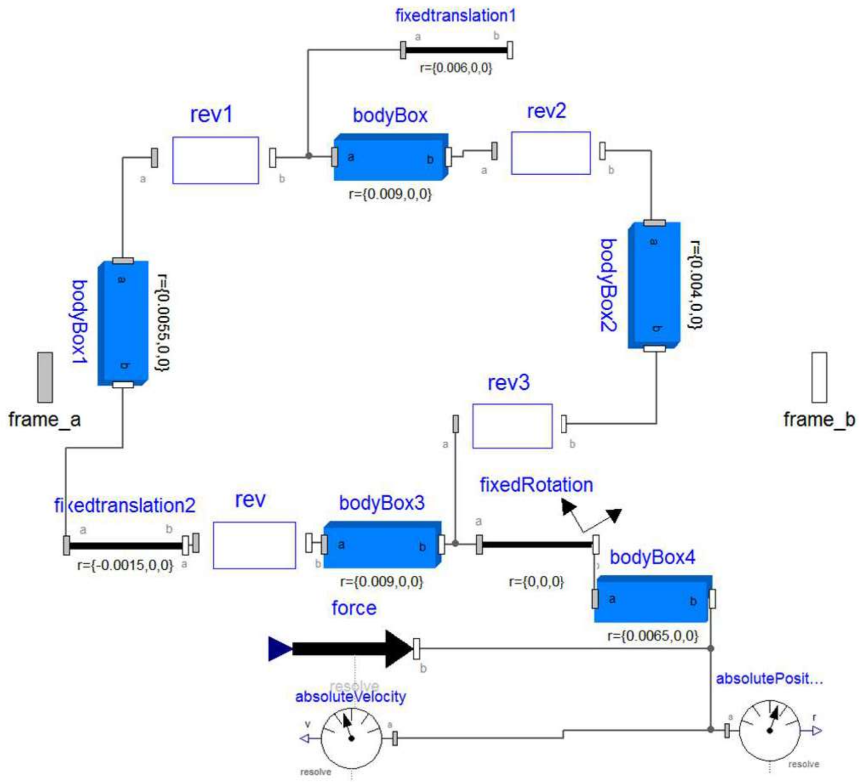
$$\left(\hat{V}^P_{1/0}\right)_{\mathcal{R}_3} = \begin{pmatrix} \dot{\theta}_1 e^1_z \\ (l_1 e^1_x + l_2 e^2_x + l e^3_x) \times \dot{\theta}_1 e^1_z \end{pmatrix}$$



Mechanical model of one single leg. One can express the motion of point P in terms of generalized coordinates and its derivatives using a coordinates transformation.

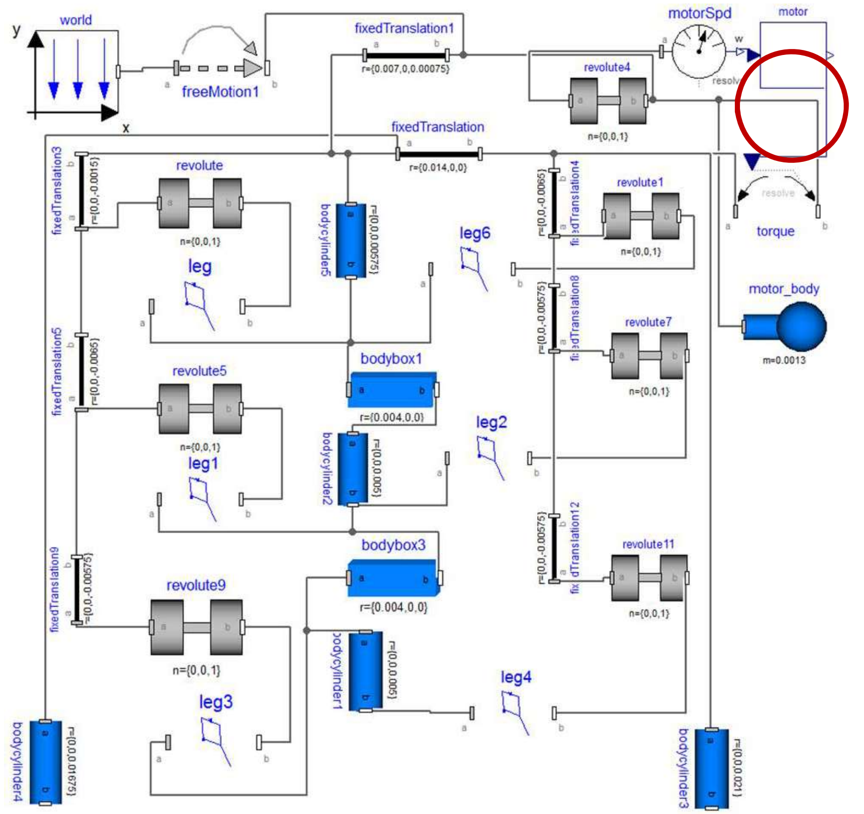
Modelica Model

- Leg Model



Structure of the leg model in Modelica block diagram. The joints rev, rev1, rev2 and rev3 are the joints with flexible material.

- Overall Model



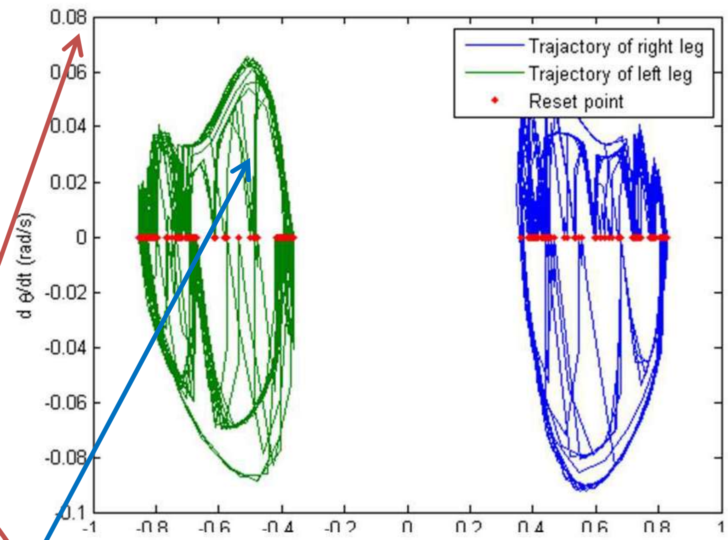
Simplified structure of the robot using the leg submodel. Highlighted submodel is an electrical motor model, includes a Pulse Width Modulation controller, which is the Cyber part of the robot.

Limit Cycle Analysis and Adding PWM

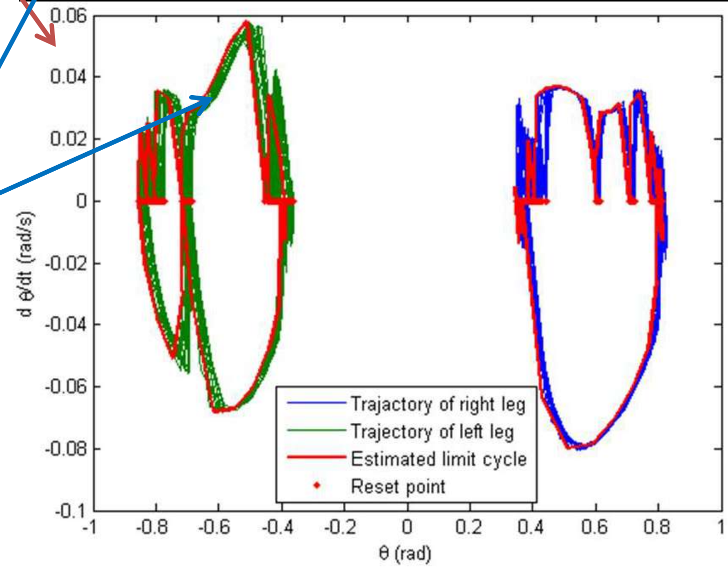
- New geometry alters the problem dramatically.
  - Although the new joint dimension should improve stability, it is hard to verify.
  - Howev[illegible] s used, t[illegible] able to[illegible] ne high te[illegible] joints, unless motor output is increased dramatically. So no comparison is given here.
  - By che[illegible] we find th[illegible] e helpfu[illegible] jumping behavior.

Note decreases in limit cycle size in derivative direction

Note changes in reset points of limit cycles

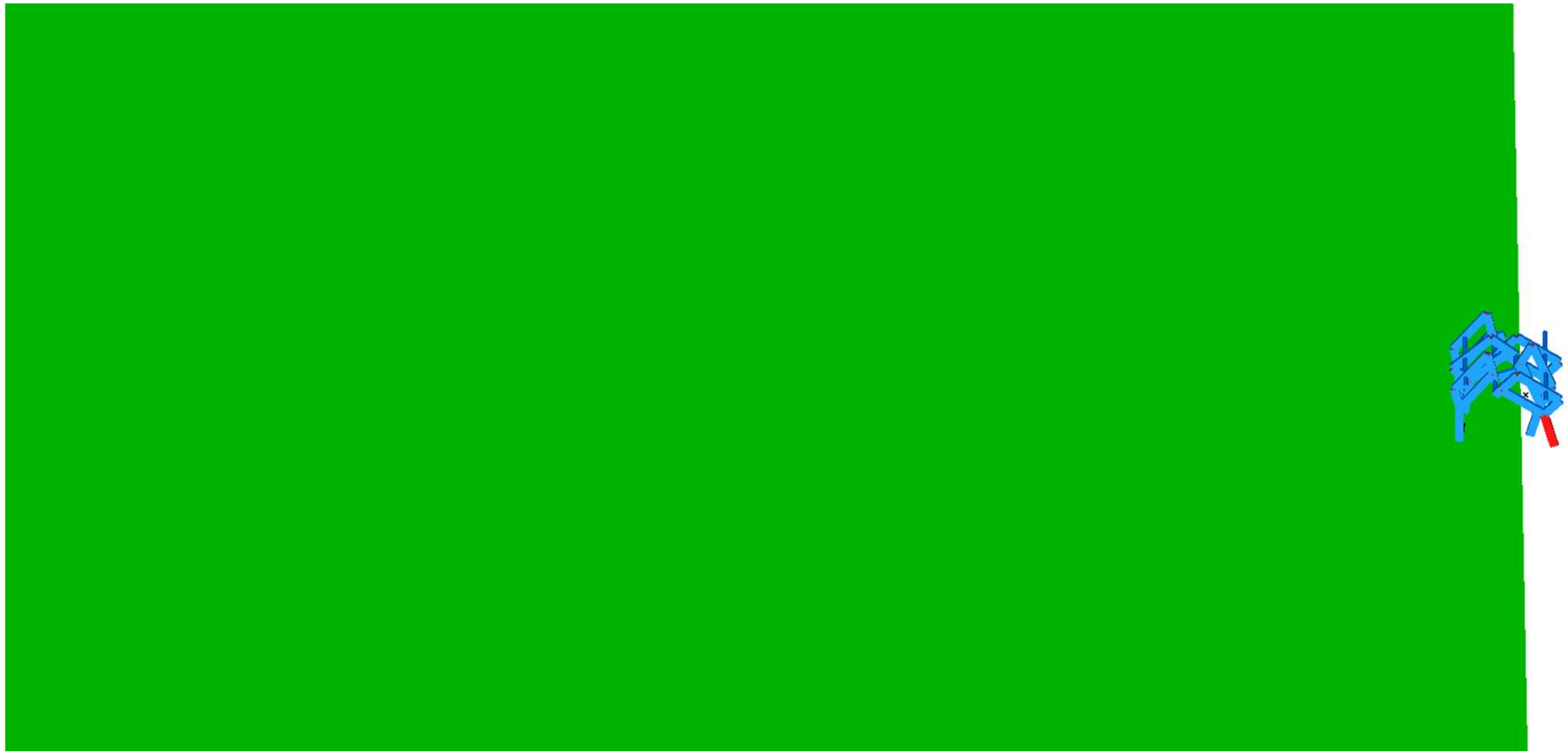


Before adding PWM

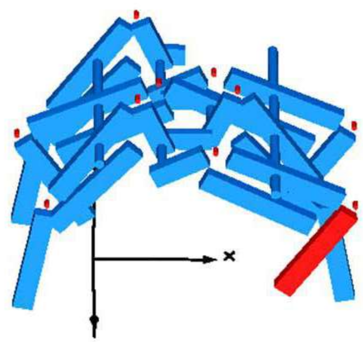


After adding PWM

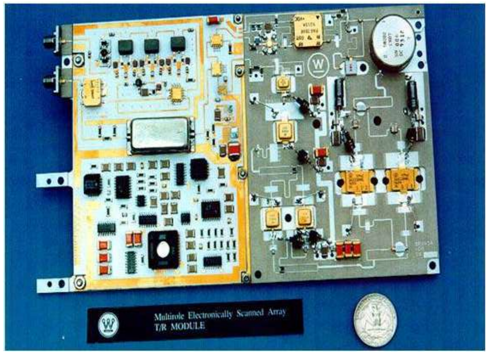
Animation of First Model



Second Model



Integrated Product and Process Design of T/R Modules



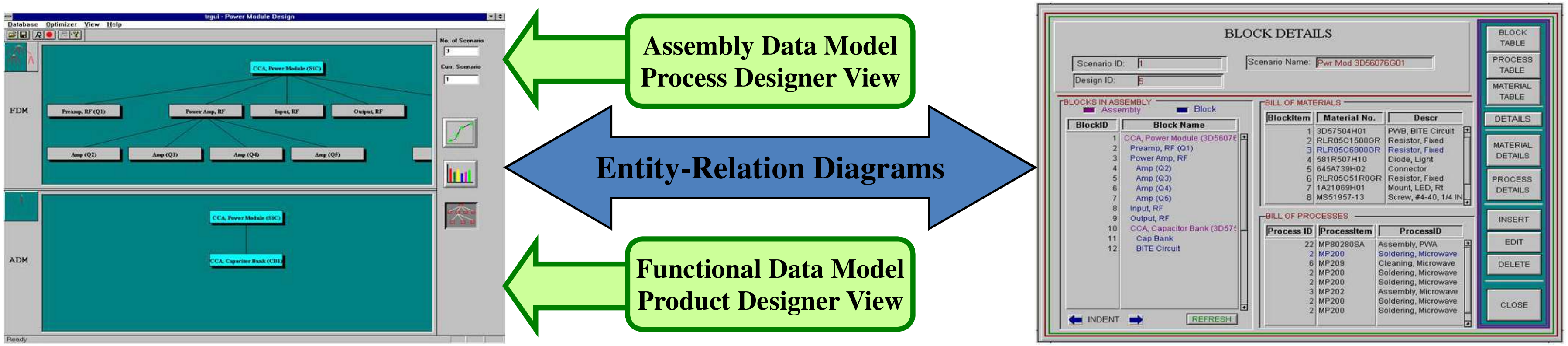
PROBLEM

Integrate Electronic and Mechanical Design
information interchange among tools used by designers

Identify alternative components
integration with part catalogs, corporate databases

Help generate and evaluate alternative designs
estimate cost, manufacturing time, reliability, etc.evaluate tradeoffs

Help generate process plans
process parameters, time estimates, etc.



SOLUTION

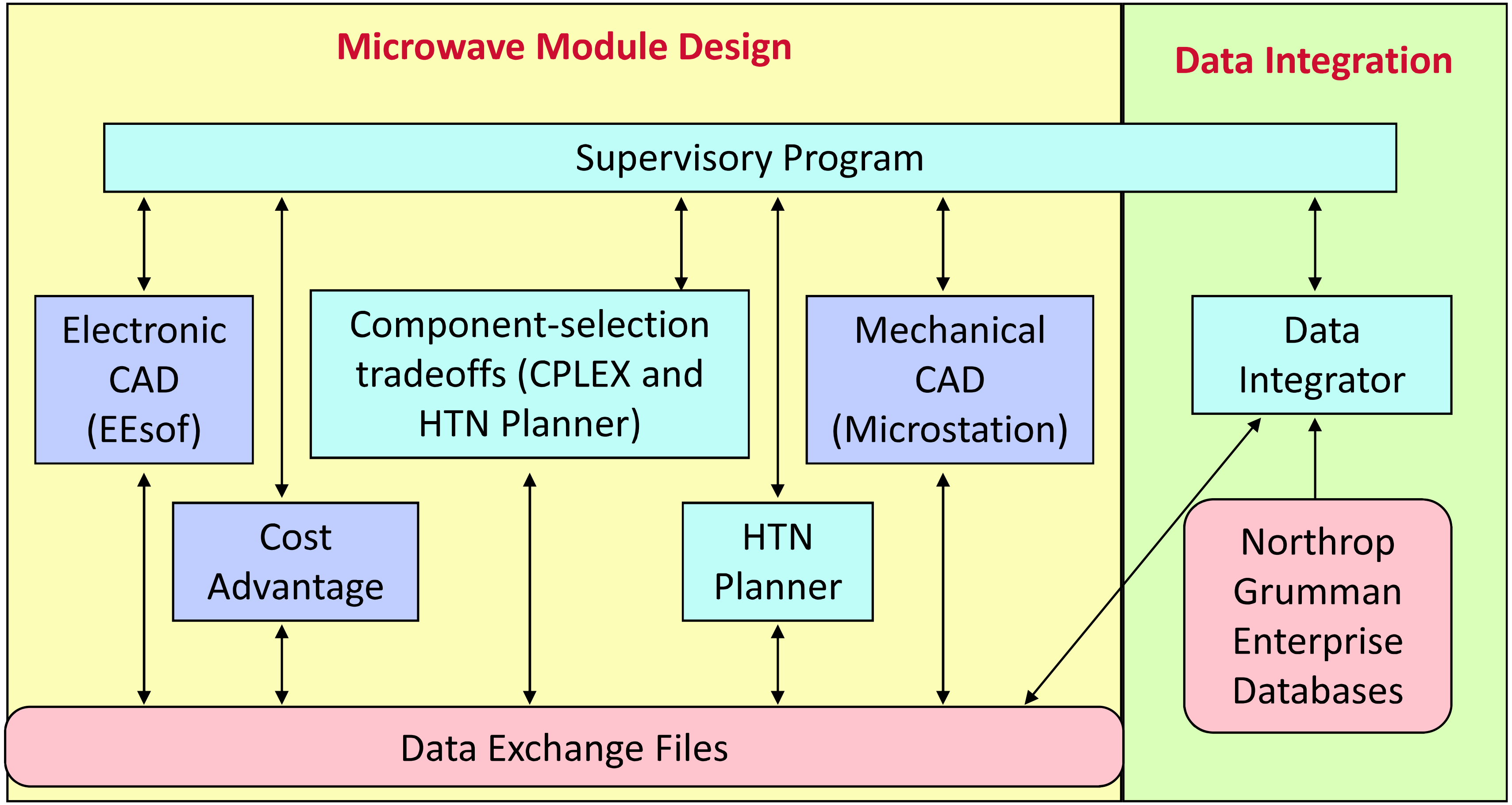
Object-Relational Databases and Middleware to integrate heterogeneous distributed data sources: **multi-vendor DB, text, data, CAD drawings, flat, relational, object DBs**

Entity-Relation Diagrams to provide multiple expert views of the data and integrate product and process design phases into a single system environment

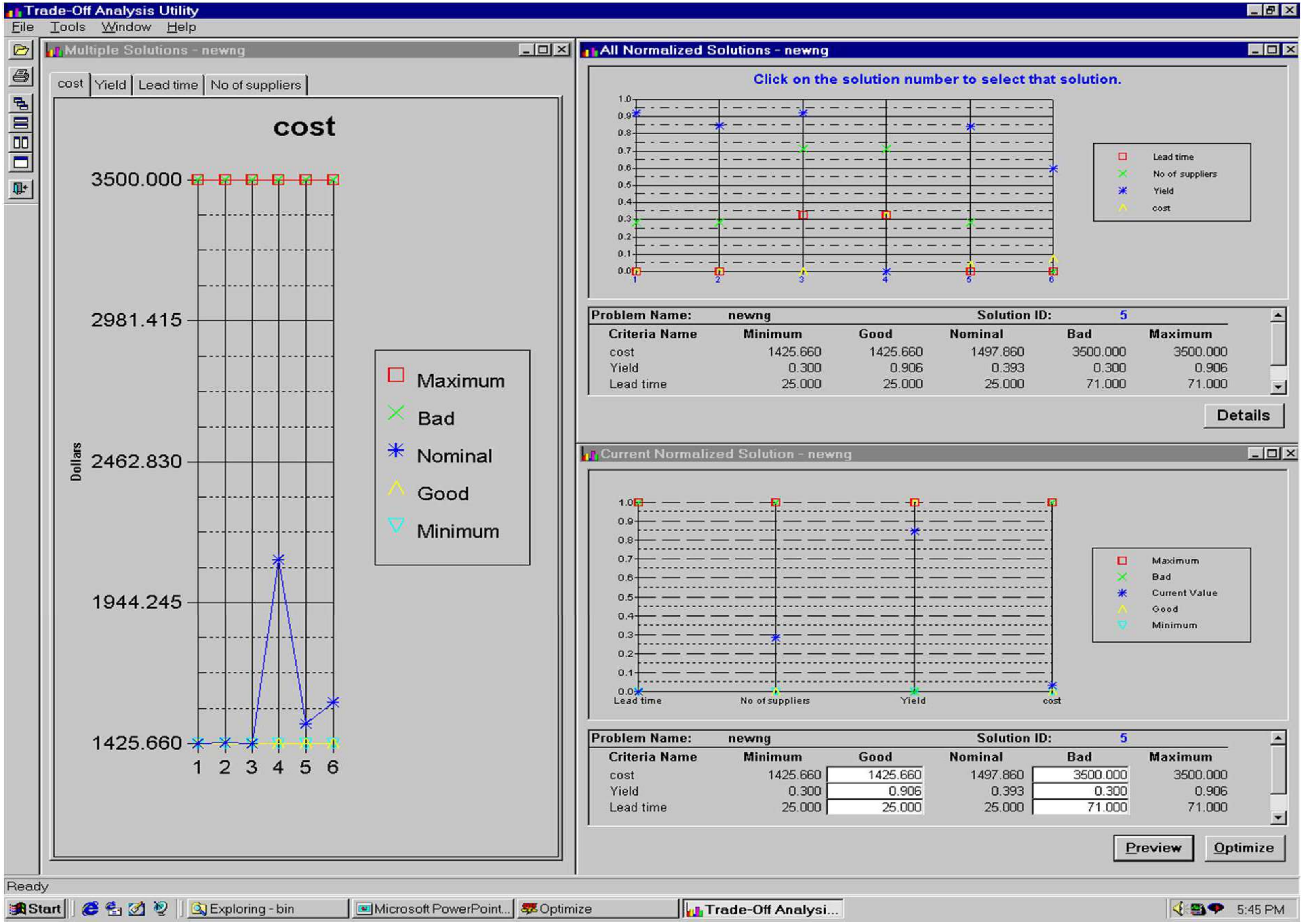
Hierarchical Task Network planning to explore alternate options at each level of the product: parts and material, processes, functions assemblies

Multicriteria Optimization for trade-offs: cost, quality, manufacturability, ...

IPPD System Architecture



Tradeoff Analysis via Multicriteria Optimization



Virtual Engineering Everywhere

Helping over 30 different teams and skills in the company work together

Linking over 40 different EE design representations throughout the entire development process

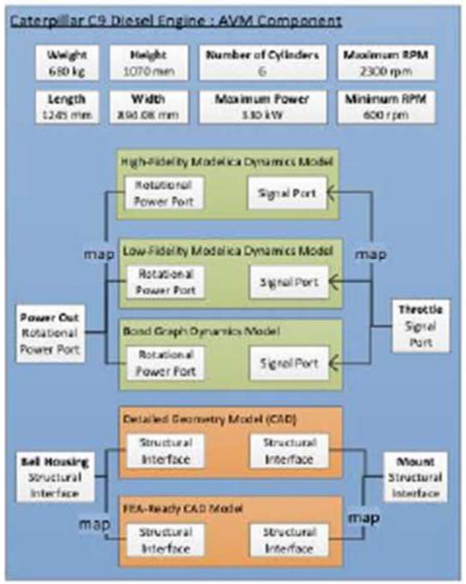
Ensuring that the EE design flow is integrated at the same level of quality and performance as the 3D CAD system

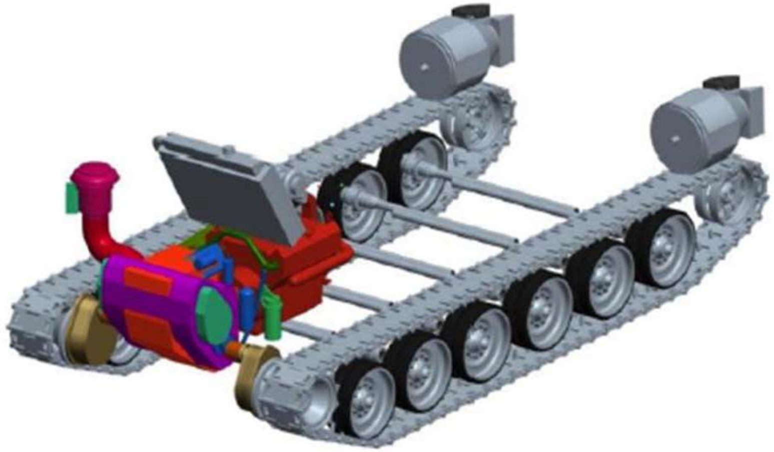
Model based design and executable specification in the OEM/supplier chain

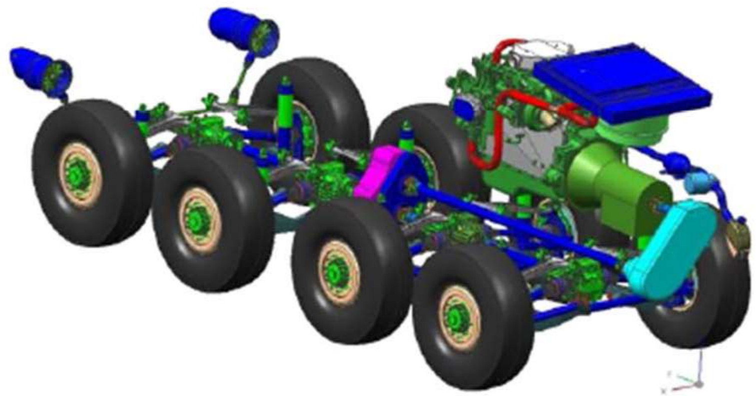
META – iFAB – AVM: Component Models

As of today:

- 131 component classes
- 469 component instances
- 43 parametric components
- 112 ITAR protected models
- 357 non-ITAR protected models





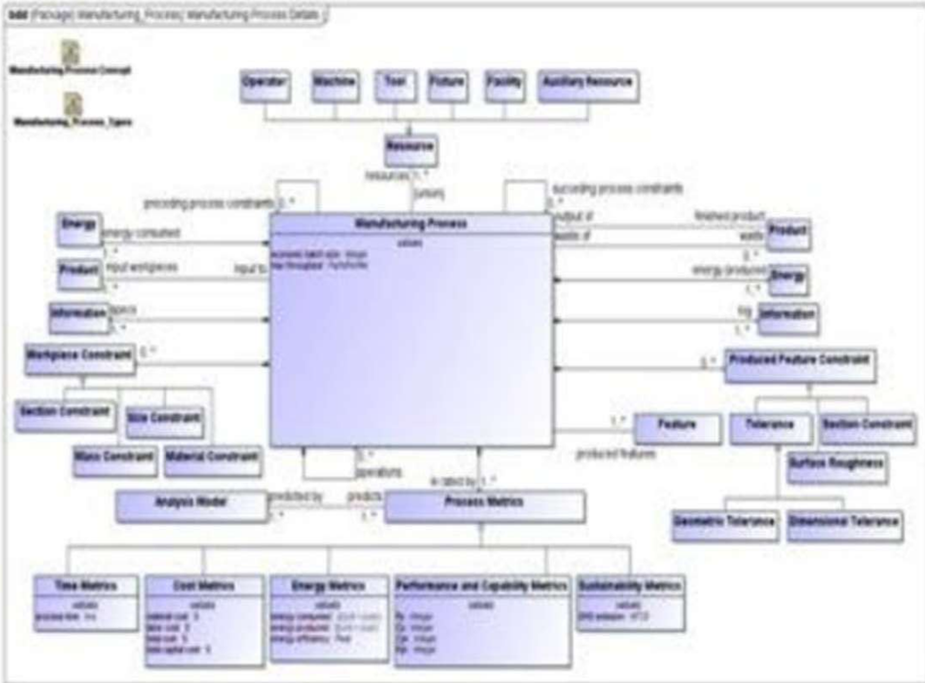


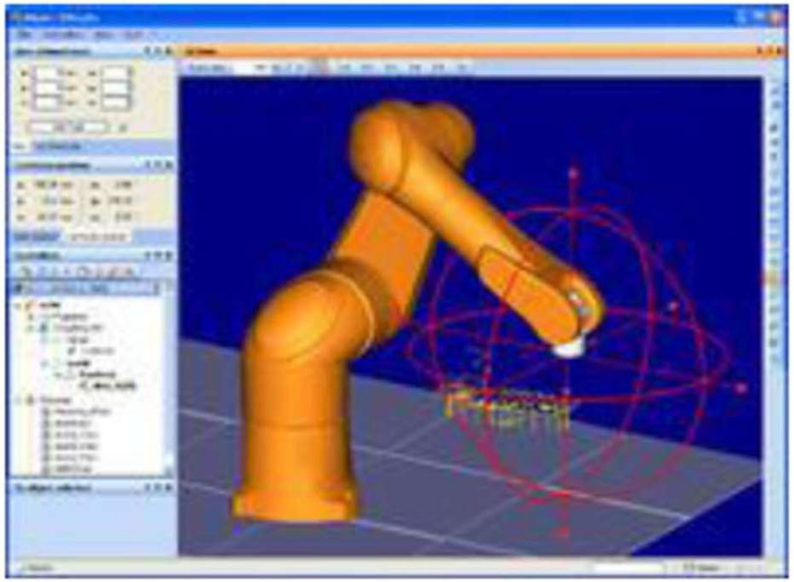
Source: Ricardo PLC

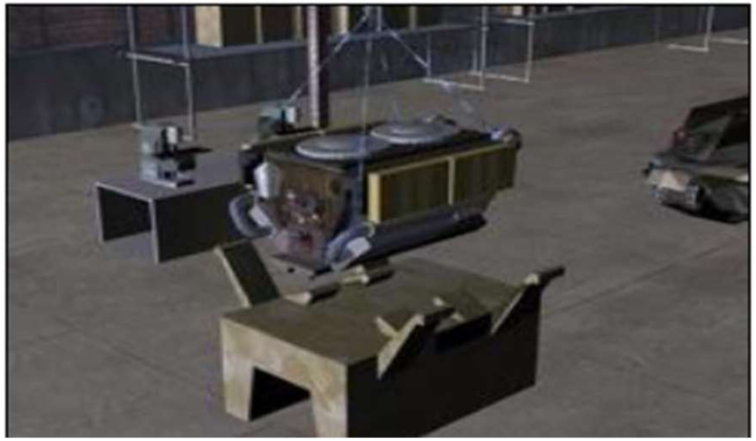
META – iFAB – AVM: Manufacturing Process Models Semantics Across Domains

As of today:

- 7 material shaping processes
- 19 general processes
- 231 machine instantiations
- 64 manual labor units
- 3,212 tools







Sources: Penn State ARL; GM Research