Adaptive Vehicle Make (AVM)

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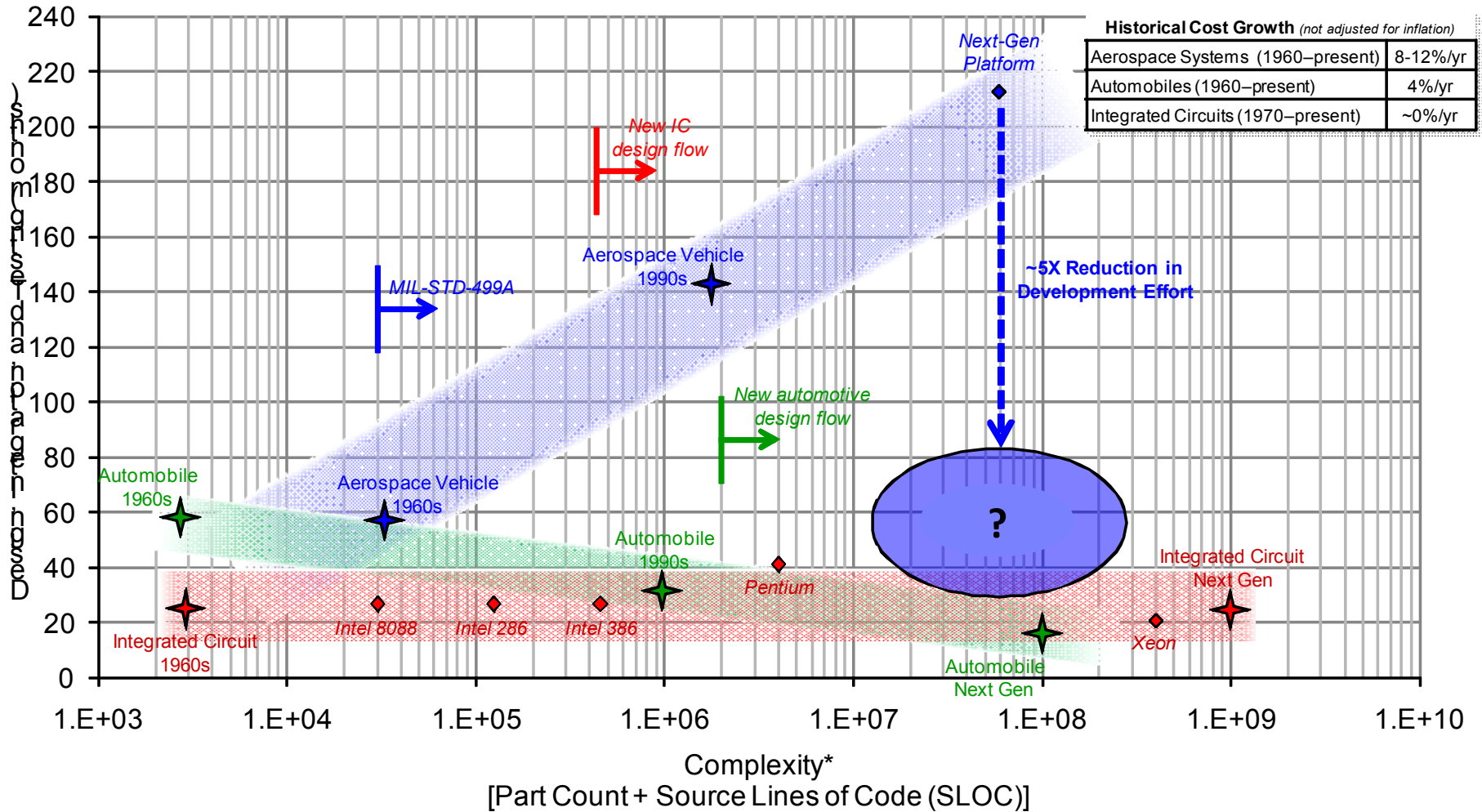
Tactical Technology Office

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MIL-STD-499A (1969) systems engineering process: as employed today

SWaP used as a proxy metric for cost, and dis-incentivizes abstraction in design

System decomposed based on arbitrary cleavage lines . . .

Conventional V&V techniques do not scale to highly complex or adaptable systems—with large or infinite numbers of possible states/configurations

Cost Optimization

System Functional Specification

Re-Design

System Layout

Verification & Validation

SWaP Optimization

Decomposition →

Integration →

Subsystem Design

Subsystem Testing

SWaP Optimization

Power

Data & Control

Thermal Mgmt

Component Design

Component Testing

Resulting architectures are fragile point designs

. . . and detailed design occurs within these functional stovepipes

Unmodeled and undesired interactions lead to emergent behaviors during integration

SWaP = Size, Weight, and Power
V&V = Verification & Validation

Desirable interactions (data, power, forces & torques)
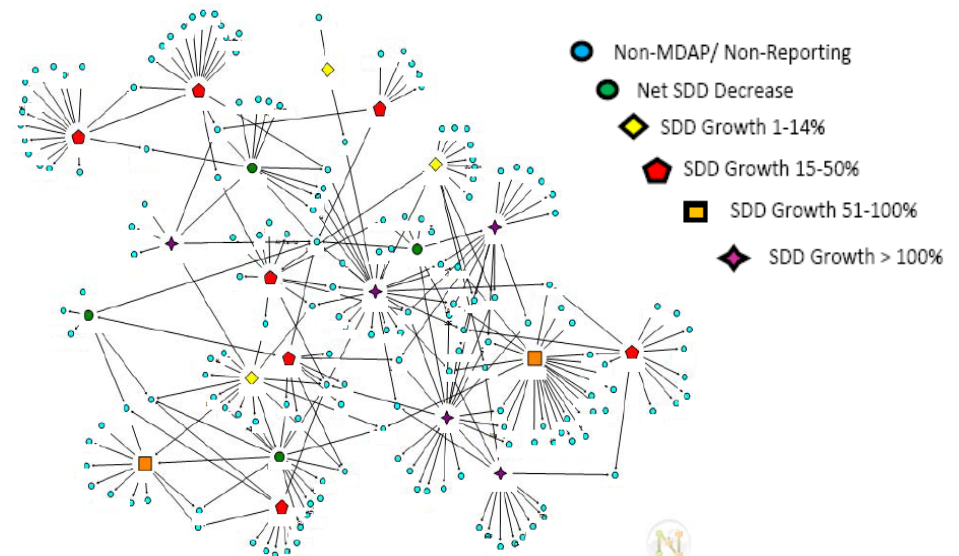*Undesirable interactions (thermal, vibrations, EMI)*

The technical problem is in the seams

Between stages of production →

Between people & organizations →
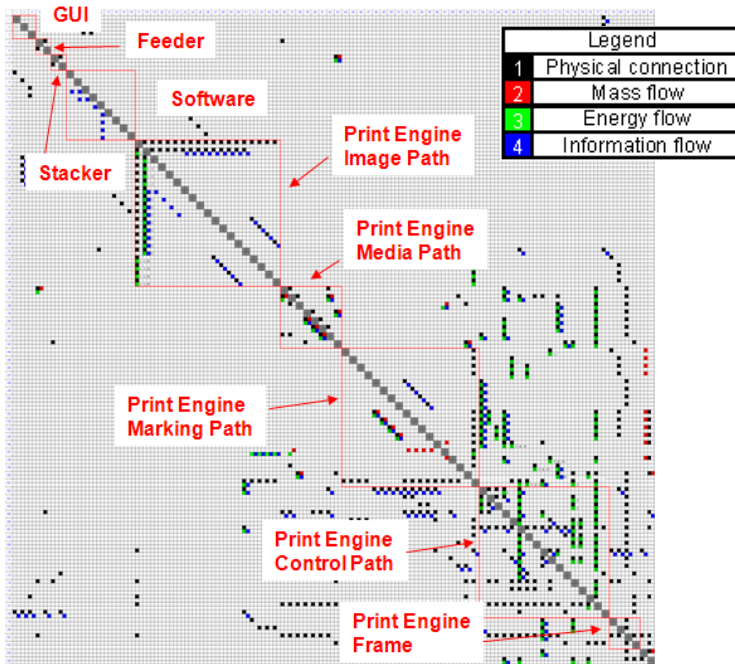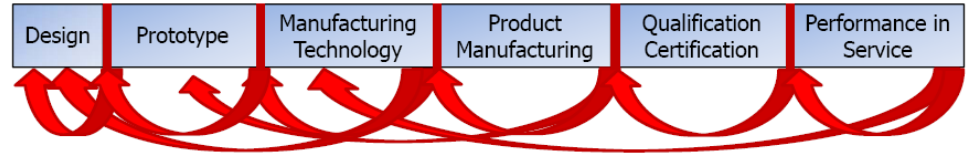
Source: MIT ESD (deWeck et al., 2008)

← Between system components

Source: DDR&E/SE (Flowe et al., 2009)

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Adaptive Vehicle Make vision

Shorten development times for complex defense systems [META]
- Raise level of abstraction in design of cyber-electromechanical systems
- Enable correct-by-construction designs through model-based verification
- Compose designs from component model library that characterizes the "seams"
- Rapid requirements trade-offs; optimize for complexity & adaptability, not SWaP

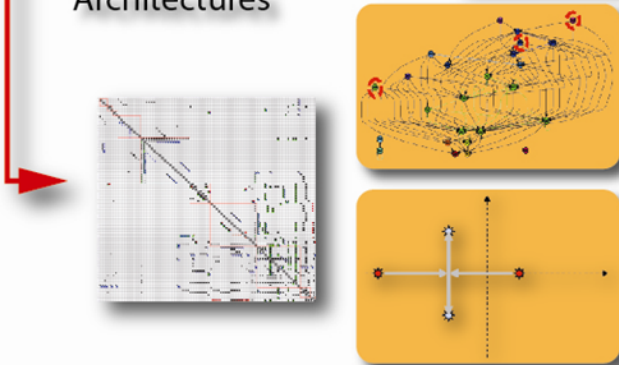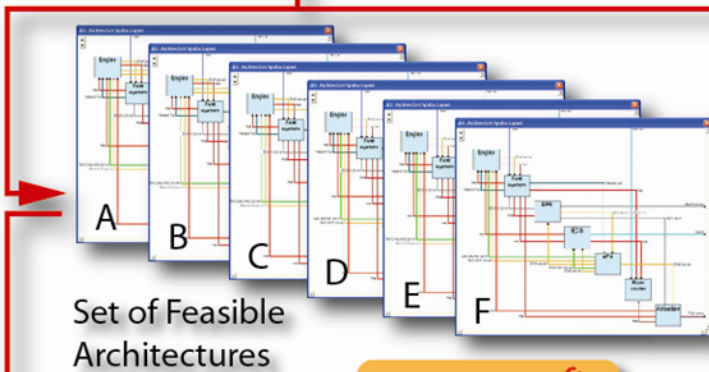**Shift product value chain toward high-value design activities [iFAB]**
- Bitstream-configurable foundry-like manufacturing capability for defense systems
- Rapid switch-over between designs with minimal learning curve
- "Mass customization" across product variants and families

Democratize design [FANG]
- Crowd-sourcing infrastructure to enable open-source development of cyber-electromechanical systems [vehicleforge.mil]
- Prize-based Adaptive Make Challenges culminating in an Infantry Fighting Vehicle for testing alongside a program of record [FANG]
- Motivate a new generation of designers and manufacturing innovators [MENTOR]

META

Formalized Design Language
Construction Rules · Semantic Definitions · Constraints
Mathematic Representation

System Requirements

Component Model Library

Complexity Assessment

$$c\,(\eta, A) = \sum_{i=1}^{n} \alpha_i + \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{\kappa=1}^{4} \beta_\kappa \alpha_{ij\kappa} + \gamma \left[\frac{\log(\eta)}{\log(7)}\right] E(A)$$

Cost vs. Complexity

Set of Feasible Architectures
A B C D E F

System Structure Assessment

Abstraction Based Design

Correct-By-Construction

STOCHASTIC FORMAL VERIFICATION
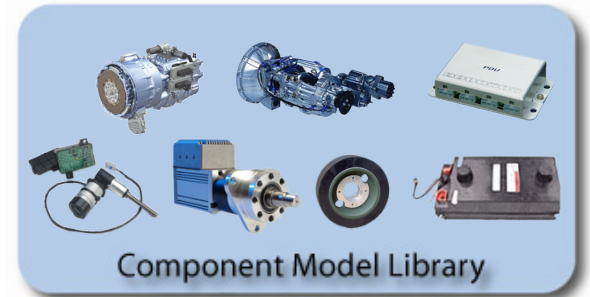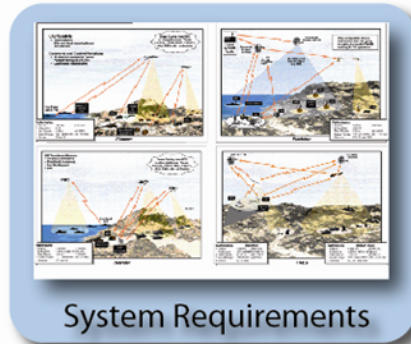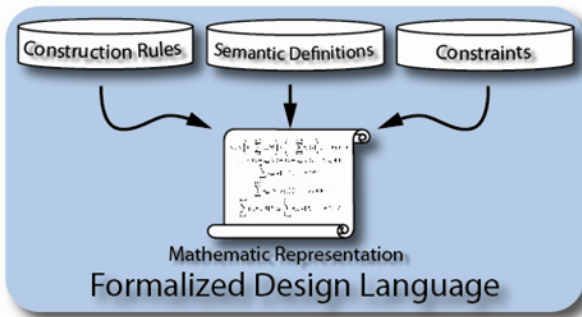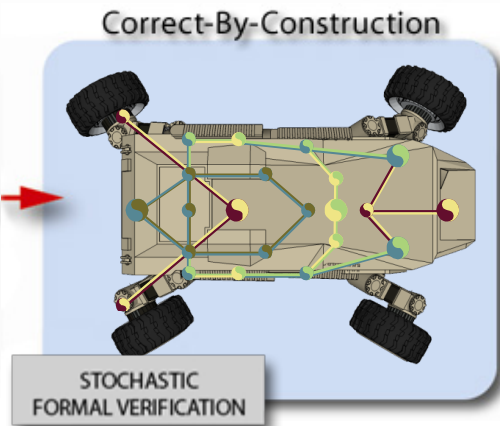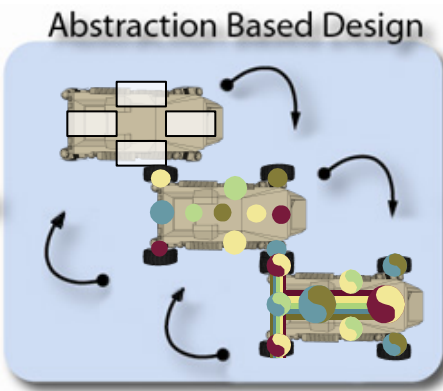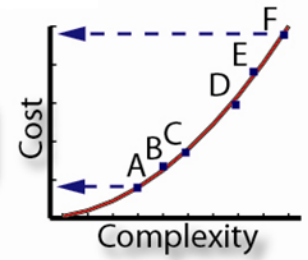
Notional iFAB foundry configuration

Paint & Finish

Additive/Subtractive Manufacturing

Welding

Sheet Metal Fabrication

Composites

Assumptions:
- 100k ft^2 total space.
- Need not be geographically co-located.
- All custom components in-sourced.
- All unmod COTS components out-sourced.

"Core Manufacturing Science" Insertion

- Drill & fill
- Wire bundles
- Robotic assembly

Fuels & Tribology

Tape Laying

Autoclave

CNC Brake

Harness Buildup

Laser Cutter

Automated Harness Loom

Electronics Fabrication

3D Printer

CNC Mill 5-Axis

Paint Booth

Welding Robots

Assembly

Fuel Cell Test Set

CNC CMM

6-Axis Robots

Swaging Press

Anodizing Tank

Articulating CMM

CNC Tube Bender

Machine Instructions (STEP-NC, OpenPDK)

Dynamometer

Logistics

iFAB Foundry Configuration

Tube Bending

Hydraulics & Pneumatics

QA / QC

Product Meta-Representation

Estimated Size of Component Model Library

Assembly	Unique Parts (upper limit)	Total Parts (lower limit)	Library Parts (unique x 5)
Drivetrain	3,000	8,000	15,000
Chassis/Armor	5,000	12,000	25,000
Other	7,500	10,000	37,500
Total	15,500	30,000	72,500

Note: Estimates are at the numbered part level. Cables and circuit boards counted as single part. Excludes variable mission equipment, software.

Elements of a Component Model

Physical attributes	Undesirable emissions
• size and shape • mass properties • elastodynamics	• thermal • electro-magnetic • vibrational
Interfaces	Performance
• data • power • mechanical	• blackbox model • failure modes

Fast, Adaptable Next-generation Ground vehicle (FANG)

Mobility/Drivetrain Challenge

SCOPE
- Vehicle drivetrain to meet IFV speed, efficiency, terrain, reliability objective
- Available model library to include:
  - Hybrid-electric systems
  - Novel ground interfaces

PARTICIPANT POOL
- Global

INCENTIVE
- Prize $1M for winning design
- Winner(s) judged based on multi-objective weighting function

DESIGN AGGREGATION
- Use of META metalanguage required
- Use of vehicleforge.mil optional

BUILD APPROACH
- iFAB foundry build for top design(s)

Chassis/Integrated Survivability Challenge

SCOPE
- Chassis and armor design to meet principal IFV-like survivability objectives
- Available model library to include:
  - Advanced armor concepts
  - Novel configs (monocoque, v-hulls)
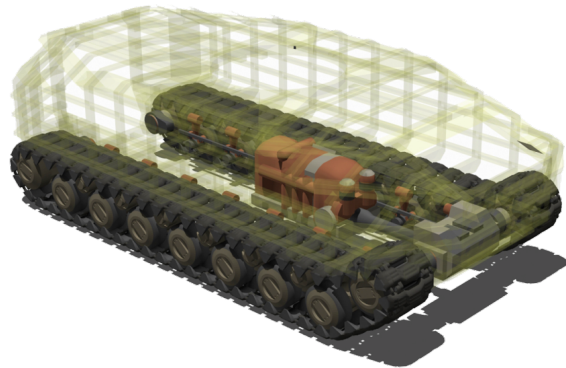
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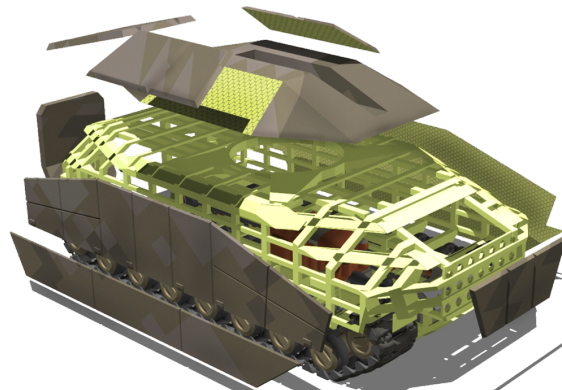
Total Platform Challenge

SCOPE
- Complete IFV based on core Army objectives and distilled requirements

PARTICIPANT POOL
- Global

INCENTIVE
- Prize $2M
- Winner judged based on satisfaction of constraints and multi-attribute preference function (i.e., entirely objective approach)

DESIGN AGGREGATION
- Use of META metalanguage required
- Use of vehicleforge.mil optional

BUILD APPROACH
- iFAB foundry build for top design(s)

Goal

- Experiment in crowd-sourced design
- Militarily-relevant application
- Existing (simple) commercial infrastructure

Approach

- Utilize existing social network of ~20,000 from Local Motors (increased by ~3,000)
- Crowd-source design of a combat support vehicle
- $10k in prizes
- Build in existing micro-factory

Results

- 159 final designs submitted
- 100 of "high caliber" according to DARPA Service Chiefs Fellows
- 4 week design period
- 14 week build period
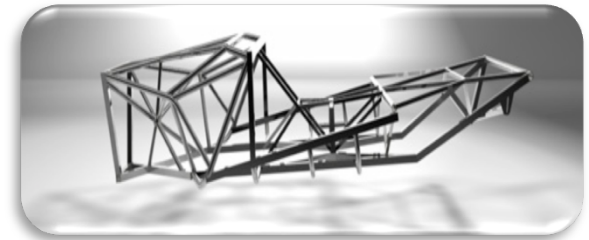
Goal

- Educate, motivate, and inspire a next-generation cadre of designers and manufacturing innovators

- Inculcate AVM-type design methods such that they become pervasive in subsequent generations of engineers

Approach

- Design collaboration using modern CAD tools and conventional social networking media

- Distributed manufacturing across networks of schools equipped with various digital manufacturing equipment

- Run competitive prize challenges for design and build of moderately complex systems (e.g. go-carts, mobile robots, small UAVs, etc.)

- Outreach Objectives:
  - 10 schools in CY12
  - 100 schools in CY13
  - 1,000 schools in CY14

- Participation by domestic and foreign schools

Picture credits: Robot image source - gorobotics.net; Los Gatos HS, CA; Loy Norris HS , MI; Stoney Creek HS, CA; Lakeridge HS, OR; New Smyrna Beach HS, FL; Longhill HS, West Sussex, UK; Brockton HS, MA

AVM portfolio schedule

CY09	CY10	CY11	CY12	CY13	CY14	CY15
	FY10	FY11	FY12	FY13	FY14	FY15

META
Tools & Metalanguage

META-X
Tools Maturation

C2M2L-1
Mobility Drivetrain Library

C2M2L-2
Chassis & Surv Library

C2M2L-3
Full IFV Model Library

iFAB
Tools & Model Library

iFAB
Configure, Build, and Operate Foundry

vehicleforge.mil
Crowd Source Design Infrastructure Development and Maintenance

XC2V
CS Pilot

FANG
Execute Adaptive Make Challenges

Mobility/Drivetrain Challenge — *Design* — *Fab* — *T&E*

Chassis/Integrated Survivability Challenge — *Design* — *Fab* — *T&E*

Total Platform Challenge — *Design* — *Fab* — *T&E*

Comparative Testing

USMC/US Army IFV Prototype

MENTOR
Distributed Manufacturing High School Outreach

SBIR Portfolio
Large-Scale Manufacturing in Quantities of One

Adaptive Vehicle Make performer community

META

Adventium Enterprises	Formal metalanguage capable of integrating models across multiple abstraction levels and perspectives
BAE Systems	Multi-abstraction-level design framework with simulation traces for certification
Boeing	Metrics suite to support multiple disciplines using rich corporate historical data
Dassault Systèmes	Extension of commercial CATIA/DELMIA PLM suite to enable formal verification
IBM Haifa Research Lab	Formal contract-based language to enable true multi-domain, platform-based design
MIT (Dr. Rhodes)	Epoch-based real-option theory to assess changeability costs in system designs
MIT (Prof. Wilcox)	Entropy-based sensitivity and variance-based allocation theories for early complexity assessment
Rockwell Collins	Pre-verified, reusable design patterns for hardware/software co-design
Smart Info Flow Tech (SIFT)	Unified probabilistic and non-probabilistic verification with counter-examples to guide design
SRI International	Verifying and guiding design across abstraction levels and domains using compositional framework
United Tech Research Ctr	Platform-based generation of design space of feasible architectures with metric-based selection
Vanderbilt Univ (Dr. Bapty)	Compositional cross-domain tool-chain analysis templates that support deep domain analysis
Vanderbilt Univ (Dr. Neema)	Rich model-based approaches developed for software and VLSI into the CPS world
Xerox PARC	Function-based framework for co-verification assessment and reasoning at early stages of design

iFAB

Boeing/General Motors	Manufacturing capability and process model library with describing foundry resources & human actors
Carnegie Mellon Univ	Distributed agents/process model approach for two-way interface between CAD and CAM systems
Intentional Software	Formal "meta meta" language to enable multi-domain co-design of artifact & manufacturing
Penn State ARL	Agent-based foundry configuration and trade space visualization
Univ of Delaware	Developing compositional cross-domain tool-chain analysis templates for composites manufacturing
Xerox PARC	Rapid construction and search of feasible manufacturability spaces and metrics for such spaces
Georgia Tech GTRC	Creating adaptable software libraries of manufacturing processes pertinent to the fabrication of electro-mechanical components and/or assemblies

vehicleforge.mil

GE Research/MIT*	Custom collaboration site linking to MIT DOME model repository and social network challenge platform
Georgia Tech GTRI*	Collaboration site based on open source distributed version control system; teamed with RedHat
Vanderbilt University*	Collaboration site derived from KForge software and information forge site platform
Univ of Pennsylvania*	Credentialing users and contributions utilizing reputation-based quantitative trust management