Simulation & Analysis Knowledge Council: Research and Planning Update

CIMdata KC Workshop: A CIMdata PLM Leadership Event

25 June 2014—Cincinnati, Ohio, USA

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Our Mission...

Strategic consulting for competitive advantage in global markets

CIMdata is the leading independent global strategic management consulting and research authority focused exclusively on the PLM market.

We are dedicated to maximizing our clients' ability to design and deliver innovative products and services through the application of PLM.

S&A Knowledge Council Lead

Professional background

- Dr. Keith Meintjes, Practice Manager for S&A
  - 29-years at GM included numerous positions of technical and strategic leadership
  - Developed CFD tools for combustion
  - Part of a team to apply simulation tools for powertrain product development
  - Engineering group manager for simulation at GM Powertrain
  - Responsible for GM's global strategy for high-performance computing
  - Champion of GM's CAE "Grand Challenge" initiative to improve simulation capability for all aspects of vehicle development
  - Was Research Director for Simulation at CPDA, acquired by CIMdata in 2011
  - Ph.D. thesis (Princeton) on fluid flow simulations with combustion

Simulation & Analysis Knowledge Council

A CIMdata Knowledge Council

- The Council focuses on physics-based simulation (CAE) to support the full product life cycle
  - An integrated environment (framework) provides tools to manage access to applications, data, and computing resources, including high performance computing
  - Assessments of end-user requirements and best practices from leading-edge companies, together with tools to measure organization capability and technology ROI provide a sound basis to drive measurable improvements
  - Simulation integrates with other elements of the PLM environment, including product geometry, test, and requirements
- The council is open to industrial and supplier participants, through corporate sponsorships or individual memberships

Simulation & Analysis Knowledge Council

A CIMdata Knowledge Council

- Simulation-driven decision support
  - Multi-discipline system models used up front enable and facilitate requirements decomposition for subsystems and components
  - Model-based strategies allow trade studies, collaboration and concurrent engineering across domains like mechanical design, electrical, software and controls
  - Embedded tools and vertical applications provide design guidance and real-time feedback on performance, cost and manufacturability
  - Detailed simulations are used for product and manufacturing validation and for verification of performance to requirements
- The Council is concerned with the effective use of simulation for product and manufacturing system development, not with technical features and functions of simulation applications

S&A Knowledge Council Deliverables – 2013

Setting the stage for future work

- US Workshop—1 May, Cincinnati, OH
  - Sold out event
  - Agenda speakers from industrial end-user companies
  - Discussion panel featured solution suppliers
- S&A track at PLM Road Map—9-10 Oct, Chicago, IL
- Papers and presentations on topics of concern to members
- Prototype readiness assessment applied for Simulation Data Management

S&A Council Workshop – Cincinnati 2013

Over 50 attendees from 36 organizations

CIMdata's Simulation & Analysis Council

Activities and research priorities driven by members

Recent Council priorities:

- Process automation for simulation
- Simulation data (and process) management
- The democratization of simulation
- Simulation analytics
- The rise of Systems Engineering for mechanical design
- Simulation Governance – managing simulation as a strategic competitive advantage

It's not just about simulation.
It's how you best do engineering.

CIMdata's Simulation & Analysis Council

Activities and research priorities driven by members

Ongoing concerns:

- Simulation data (and process) management – slow adoption by end users
- Leveraging the cloud
- Model-based strategies for collaboration and concurrent engineering
- Support for systems engineering
- Maturity models and capability assessments

Simulation Governance

Simulation Capability is a Strategic Competence

- Reliance on simulation brings new elements of risk
- How do we assure accuracy, reliability and quality?
- Simulation Governance is a strategy to manage and develop simulation capability at all levels:
  - Understanding by CxO executive leaders
  - Communication throughout the organization
  - Development of technical competence
  - Best practices, standard work, and quality assurance
  - Verification and validation
  - Integration in the product and manufacturing development processes
- Simulation is often not simply an analog of some other element of your PLM strategy

S&A Knowledge Council Deliverables - 2014

Moving the community forward

- S&A Governance- Maturity Model and readiness assessments
- European Workshop (with Systems Engineering Knowledge Council)—9 Apr, near Frankfurt, Germany
- US Workshop—25 June, GE Learning Centre, Cincinnati
- PLM Road Map content—2 October, Plymouth, MI
- Council-directed research agenda (ongoing)
- Member-specific research (limited hours)
- On-site member briefing / workshop
- Council-only publications (white papers, commentaries)

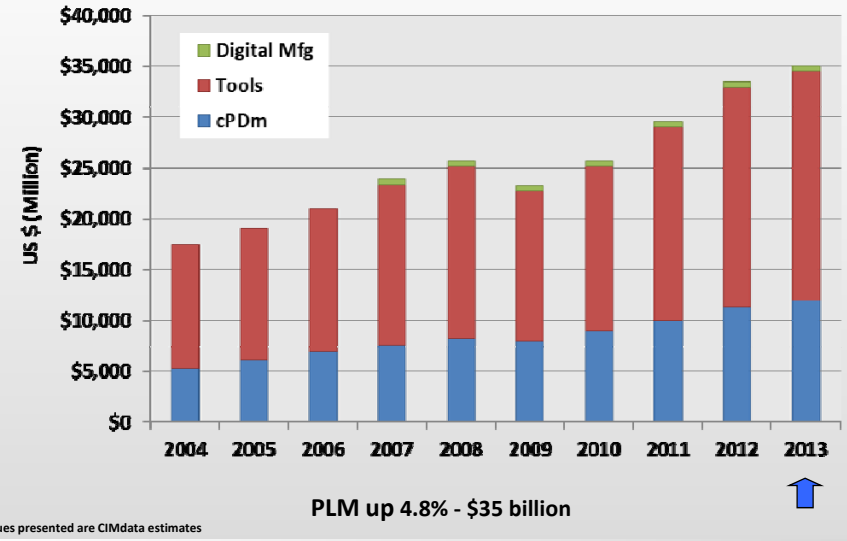
2013 Market Results

Mixed results by segment (US $ Millions)

Segment	2013 Revenues	YoY Growth
cPDm Comprehensive Technology Providers	$4,827	5.7%
cPDm-Focused Applications	$1,643	5.8%
Digital Manufacturing	$542	3.1%
SI/Reseller/VAR	$5,414	5.5%
Tools		
MCAD-Multi Discipline	$3,245	1.13%
MCAD-Design Focused	$2,569	0.12%
Non-bundled NC	$1,126	7.7%
Simulation & Analysis	$4,365	6.6%
Other Tools (e.g., ALM)	$1,087	7.8%
EDA	$6,960	6.5%
AEC	$3,267	3.2%
Total	$35,045	4.8%

PLM Market Investment

End-user spend increased during 2013



PLM up 4.8% - $35 billion

Revenues presented are CIMdata estimates

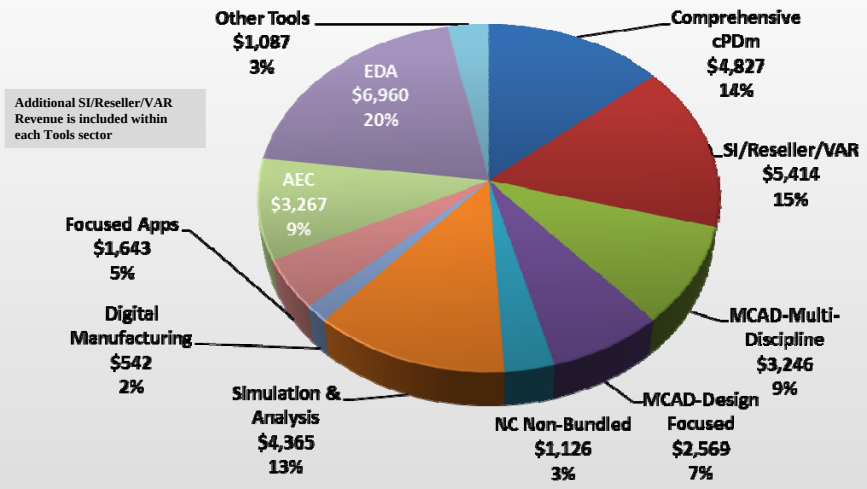
Market Forecasts

For 2014 (US$ Millions) and 5-year compound annual growth rate (CAGR)

Segment	2014 Estimate	5 Year CAGR
cPDm Comprehensive Technology Providers	$5,069	5.2%
cPDm-Focused Applications	$1,737	5.7%
Digital Manufacturing	$564	4.1%
SI/Reseller/VAR	$5,630	4.2%
Tools		
MCAD-Multi Discipline	$3,383	4.6%
MCAD-Design Focused	$2,698	5.1%
Non-bundled NC	$1,193	6.2%
Simulation & Analysis	$4,692	7.7%
Other Tools (e.g., ALM)	$1,174	8.3%
EDA	$7,430	7.0%
AEC	$3,398	8.3%
Total	$36,968	5.8%

PLM Investments by Segment

Distribution of PLM investments in 2013

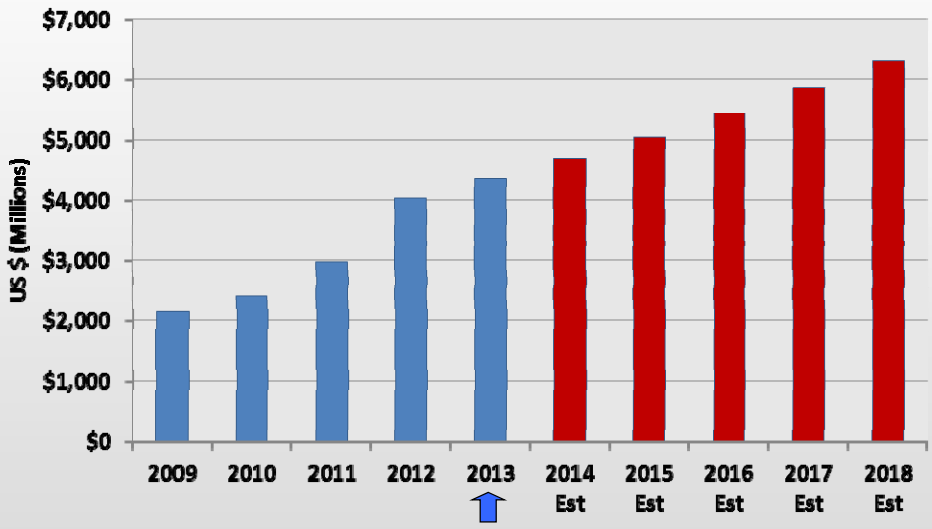


Revenues presented are CIMdata estimates

Estimates are US $ (Millions)

Simulation & Analysis – Investments

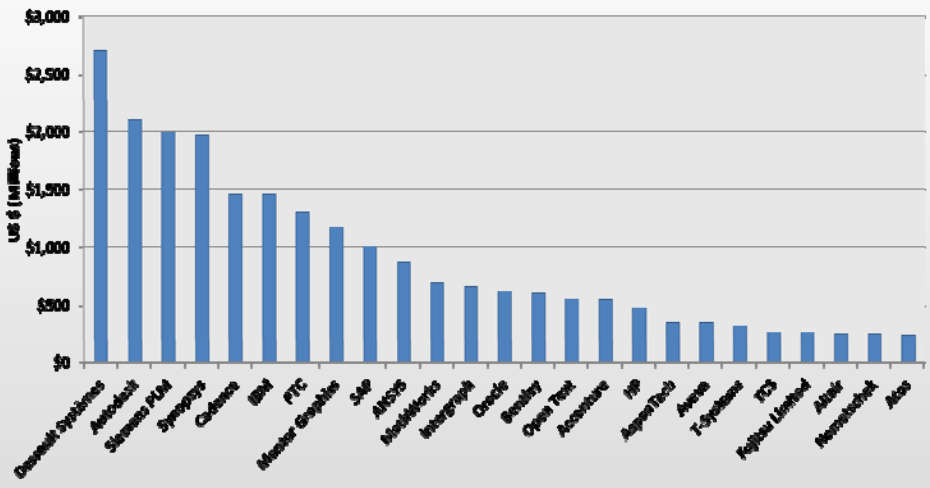
Software + services market history and forecast – Five year CAGR estimate = 7.7%



Revenues presented are CIMdata estimates

2013 Overall PLM Revenue Leaders

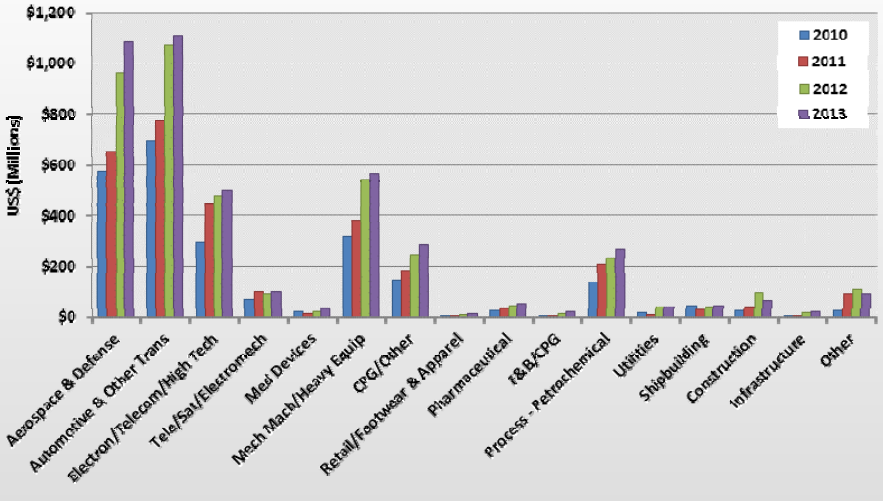
Many diverse companies generate PLM revenue



Revenues presented are CIMdata estimates

S&A Spend by Industry

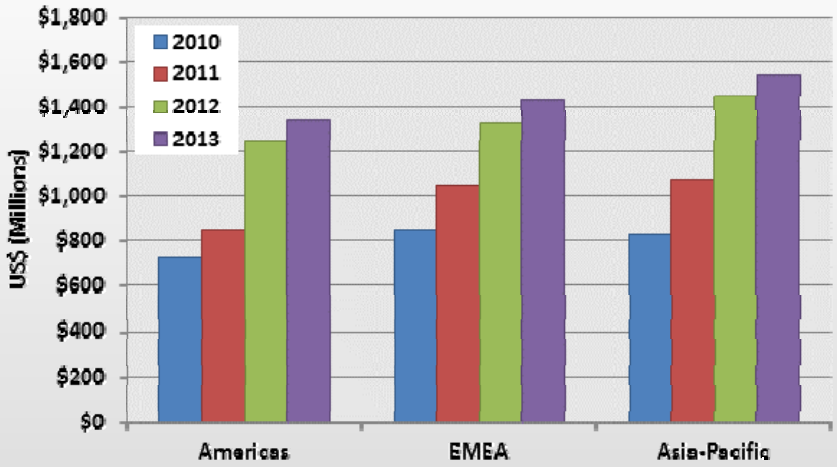
Historical data from 2010 to 2013



Revenues presented are CIMdata estimates

S&A Spend by Geographic Region

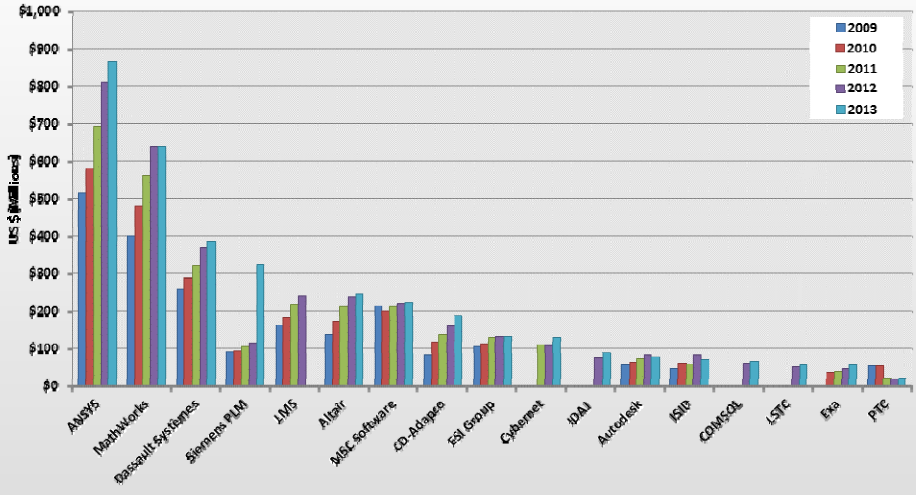
Historical data from 2010 to 2013



Revenues presented are CIMdata estimates

S&A Competitor Revenue Estimates

Historical data from 2009 to 2013

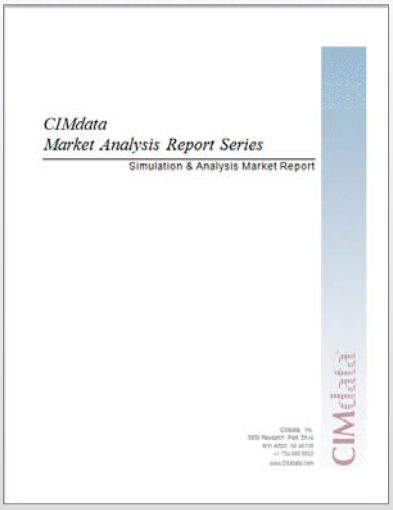


Note: For 2013, LMS is included in Siemens PLM

Revenues presented are CIMdata estimates

The S&A Market Analysis Report

More fully leverages PLM MAR data, adds S&A specific content



- Expanded coverage of S&A market
- Builds on "Market Overview" report published early in 2013
- MAR contains S&A market data
  - End user company size
  - Software and service delivery
  - By industry
  - By geography / country
- Added qualitative sections on Top 10 S&A competitors
- Table of contents: www.cimdata.com

Expanded Simulation & Analysis Coverage

Driven by market changes, increased emphasis on systems engineering

- Our analysis has contained simulation & analysis (S&A) for some time
- Was focused more on computer-aided engineering (CAE)
- Market changes demanded an expansion
- Mainstream PLM competitors expanding portfolios to meet their customers demands
- Systems engineering moving beyond just automotive and aerospace
- Published "S&A Market Analysis Report" in 2013
- Continue and expand publications in 2014 and beyond

The Rise of Simulation

A half-century of incredible advances

- It is now 50 years since 3D structural simulation was implemented on digital computers
- The capability for technical computing has doubled every 18 months over those 50 years
- The multiplying factor is about 10 billion – the number of seconds in three centuries
- Simulation now covers many physics disciplines, systems, and systems of systems
- Simulation capability now vastly exceeds that of physical testing for product development

Simulation is essential to meet product requirements (e.g., crash safety)

The Rise of PLM

From Computer-Aided Drafting to the entire product lifecycle management

- PLM is now about 30 years old
- PLM now covers a very wide range of product information over the entire lifecycle
- Companies have made huge financial and intellectual investments in their PLM strategies

The Circular Economy

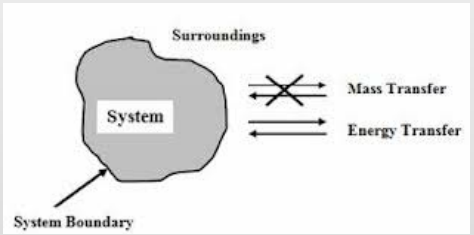
The product lifecycle, from cradle to cradle

- An evolution of concerns raised half a century ago by the Club of Rome ("The Limits to Growth")
- "Take, Make, Dispose" results in massive waste
- A lifecycle view of materials over multiple product cycles
- Reuse, repurpose, recycle (without degradation)
- Biological materials re-enter the biosphere
- New business models: Access over ownership
- Thermodynamics: A "Closed System" which allows energy, but not material flow across its boundaries

The Circular Economy – Implications

Concerns raised for simulation

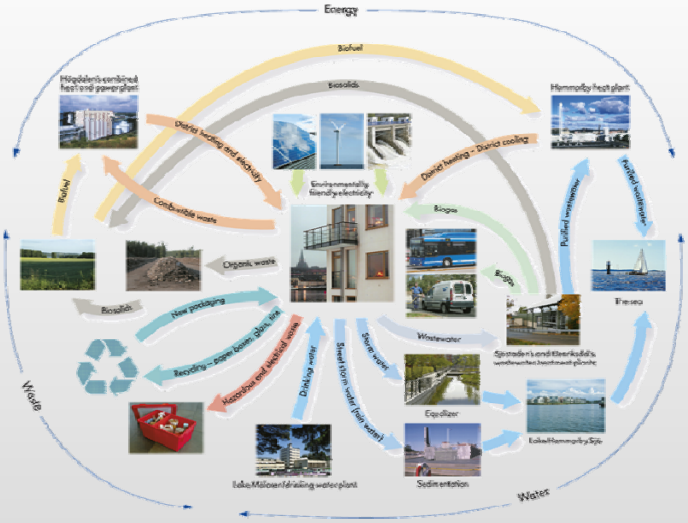
- Lifecycle view of a closed system (thermodynamics)
- Materials selection and engineering
- System simulation, including biological analogs
- Optimization
  - PIDO (Process Integration and Design Optimization)
  - Structural topology and shape optimization
  - Multi-discipline
  - Energy and thermal emphasis, including chemistry and electrical (batteries)



http://3.bp.blogspot.com/-cldc9KMHcP8/UDPFjsIyEMI/AAAAAAAADds/AySi0kH1Edk/s1600/image004.jpg

Picturing the Circular Economy

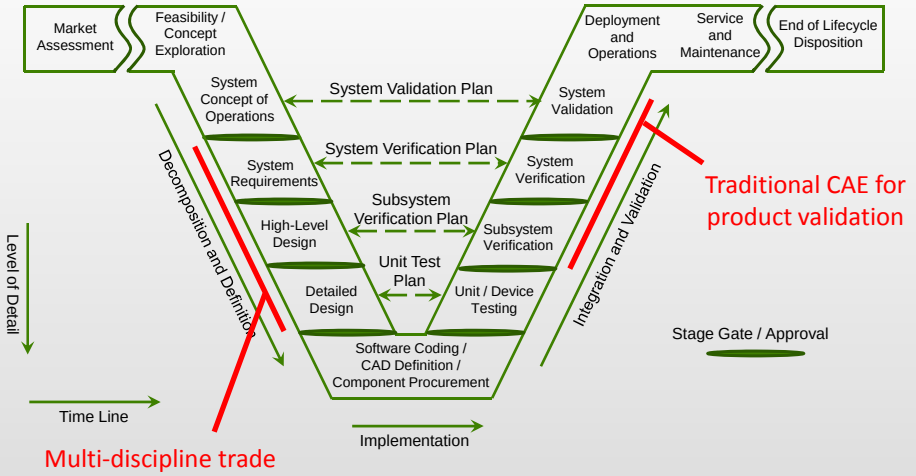
Many diagrams are "control volumes" used by engineers



http://katerinaelias.files.wordpress.com/2013/04/kretslopp-eng-09-2009-300ppi.jpg

The Systems Engineering "Vee"

A hierarchy of abstractions supported by PLM



Adapted from: US Federal Highway Administration:
http://ops.fhwa.dot.gov/publications/seitsguide/
"Systems Engineering for Intelligent Transportation Systems"

Simulation for the Circular Economy

Considering different criteria and load cases

- Simulation is based on physics – we simply have new requirements and criteria
- Simulation can partly compensate for a lack of experience when requirements change dramatically
- Examples:
  - Design for disassembly: Current products are designed to be discarded. Redesign fasteners so they survive disassembly and can be reused
  - Materials selection: Structural bamboo has very different properties than metals, especially for fatigue. Designers have no experience using it
- End-of-use and sustainability drive requirements all the way back to the product concept phase

It's a lifecycle thing!

Example – Topology Optimization

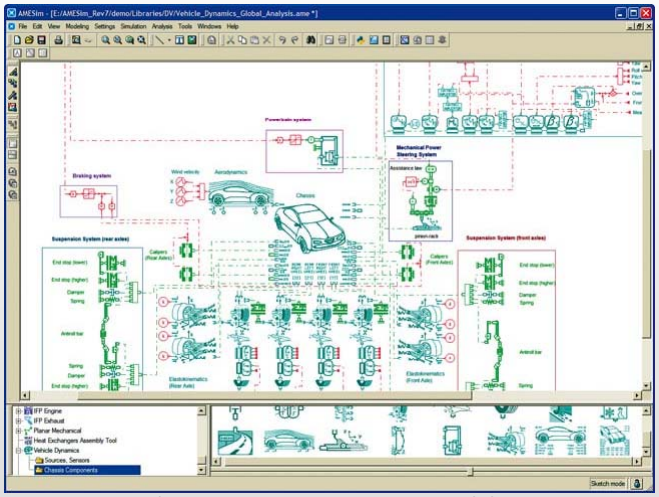
Simulation is used to synthesize optimum, efficient structures

- Define available design space and loads
- Simulation places material in optimum locations to meet strength and stiffness requirements
- Materials selection is part of the process
- Manufacturing constraints are included
- Savings in cost (less material used) and in lifecycle energy consumed
- Additive manufacturing (3D printing) is used for complex geometries

http://news.bbcimg.co.uk/media/images/70478000/jpg/_70478313_nacelle.jpg

Example – Energy System Analysis

Simulation is used to optimize fuel economy and develop control systems



The energy systems in an automobile

http://www.deskeng.com/pics/0311/LMS_Figure2_650.jpg

Comments on Systems Modeling

A perceived trend to openness

- Older system simulation tools generally have a proprietary modeling language
- Controls system simulation is dominated by tools like Matlab / Simulink that work in the frequency domain
- For mechanical systems, time-domain analysis is often preferred, along with acausal models
- Modelica is a modeling language that has found wide acceptance
- Functional Mock-up Interface (FMI) provides for co-simulation of systems models
- Some are proposing open-source component models

Example – Aircraft Thermal Systems

Advanced materials bring new design issues

- Aircraft structures are now carbon fiber, not aluminum
- Simulation is used to engineer the material plies and layers for each component
- Thermal conductivity properties are completely different
- Thermal system simulations compensate for lack of previous experience in designing for new requirements
- Recycling and reusing carbon fiber composite material is difficult and expensive

http://upload.wikimedia.org/wikipedia/commons/4/45/Boeing_787_Dreamliner_arrival_Airventure_2011.jpg

Specific Capabilities

Considerations for PLM solution providers

- Process orchestration (PIDO)
- System modeling and simulation
- Systems engineering, including integration with requirements
- Materials
- Energy: Thermal, chemical, and electrical systems
- Structural optimization
- Multi-discipline (including 3D)
- Interoperability (Modelica, FMI/FMU)

Customers will be seeking a full range of capability

What is the Business Opportunity?

How can the PLM Economy best support these requirements?

- Sustainability (as in the Circular Economy) is further evidence of the need for full lifecycle support
- Customers will expect a comprehensive suite of cross-domain optimization capability
- Simulation tools are generally capable to address new sustainability requirements
- Major simulation providers are pursuing acquisitions and alliances to round out their capabilities
- This is further impetus for the drive to up-front Model-Based Systems Engineering practices

Summary

Simulation: a critical enabler for the Circular Economy

- The Circular Economy brings new considerations that can be addressed by simulation
- It requires a system focus over the entire (or multiple) product lifecycle(s)
- Emphasis on material selection for reuse and minimum overall impact
- Optimization for efficient designs
- Emphasis on energy efficiency: Thermal, chemical and electrical system simulation

Concluding Remarks

Where have we been?

- The Simulation & Analysis Council focuses on making simulation more effective to support product and manufacturing system development
- Priorities are established by users
- Simulation is an important and the fastest growing component of PLM
- Simulation Governance is a strategy to establish simulation as an corporate capability
- Readiness assessments and ROI tools can be used to develop a roadmap for improving simulation effectiveness

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