Integrating Computational Engineering Tools into Industrial Product Development Workflow

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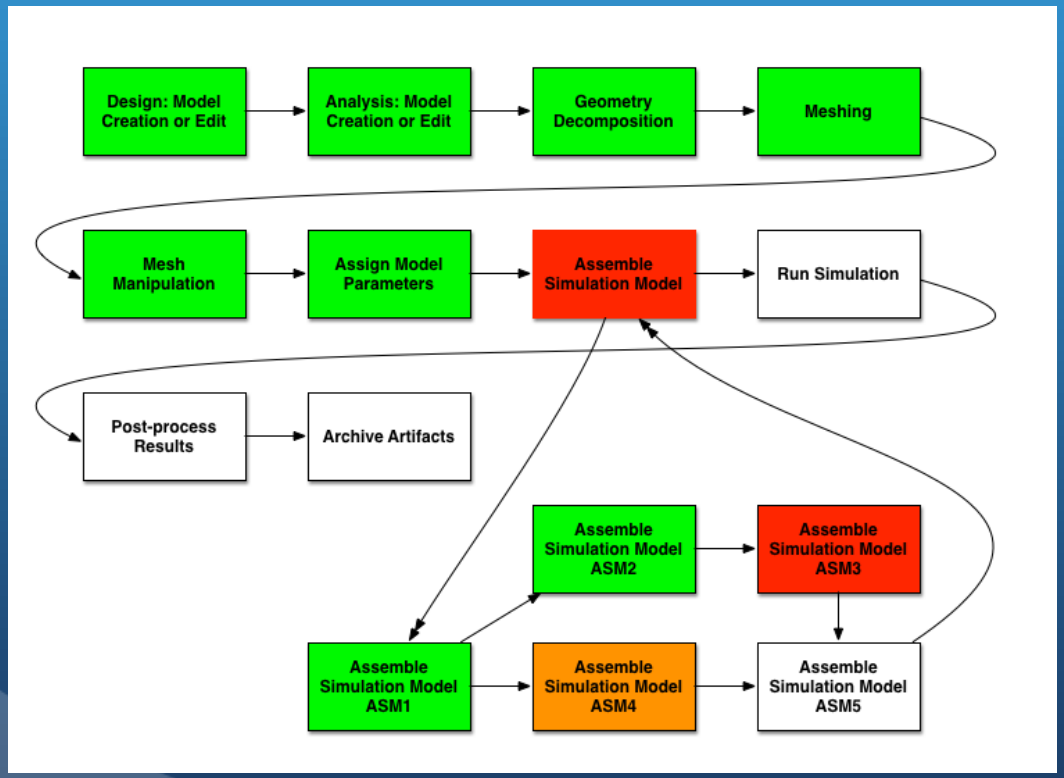


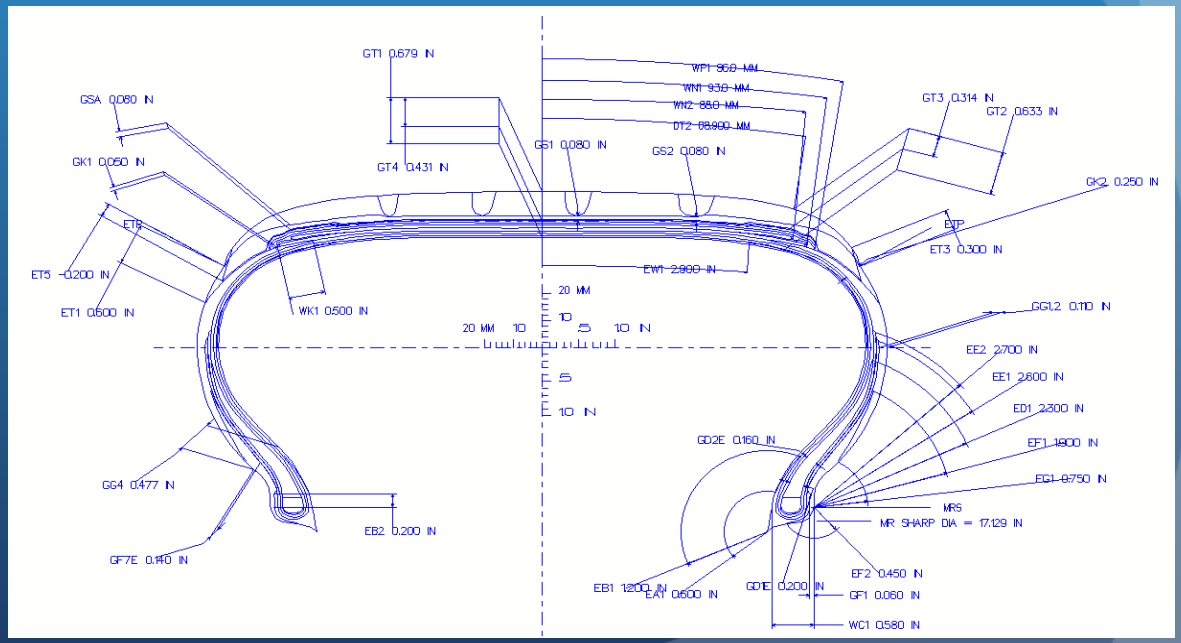
My Background

- While at Goodyear, my responsibilities included
  - Manufacturing process improvement
  - New product development
  - Project management
  - Physics research
  - Physics-based virtual prototyping
  - RD&E's IT systems including HPC
- Now President, DataMetric Innovations, LLC
  - "Intersection of Science, Engineering, and IT"
- The opinions expressed are my own and do not necessarily reflect the views of The Goodyear Tire & Rubber Company.

Systems Engineering Tools

- Platform-based design systems – carcass & tread
  - Carcass system began development in 1986.
    - Existing systems were electronic drafting tools.
    - Commercial packages' "lines & splines" were insufficient.
  - Goodyear's system incorporated
    - Parametric design standards
    - Knowledge-based rules

Similar approach for tread patterns

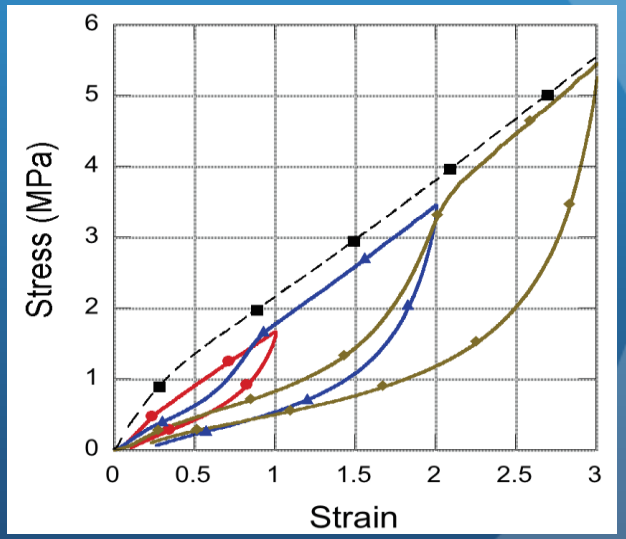


Systems Engineering Tools

- Model-based virtual engineering system
  - Began major development effort in 1992
    - Director of Analysis for a large computational analysis firm recommended their *linear elastic* FEA package. Wrong!
  - Rubber's material properties
    - Highly non-linear
    - Viscoelastic
    - Incompressible
      - Poisson's ratio: .499…
      - Hexahedral meshes required
    - Mullin's effect: stiffness & hysteresis both history dependent
    - Payne effect: modulus depends on temperature, strain, & frequency

Material complexity

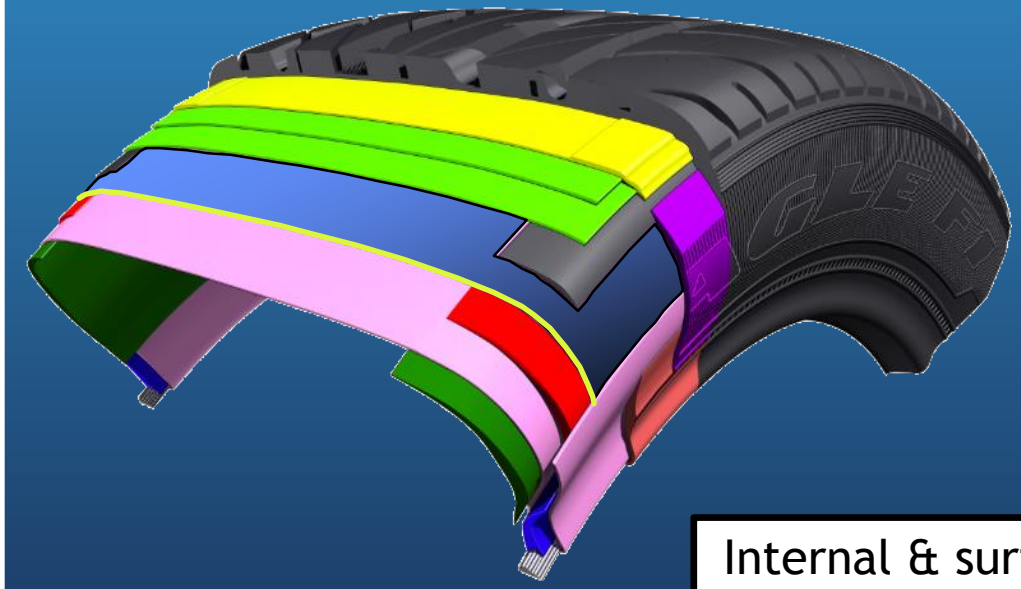
Mullins Effect



Hanson, Hawley, and Houlton,
Los Alamos National Laboratory,
"A Mechanism for the Mullins Effect," 2006.

Systems Engineering Tools

- Model-based virtual engineering
  - Thin layers with large differences in moduli
  - Inextensible fiber reinforcements
  - Detailed tread patterns
  - Wide eigenvalue spectrum



Internal & surface complexity

Model-based Tool Creation

- Goodyear's model-based virtual engineering requirements exceeded 1990's analysis software capabilities.
- Sandia CRADA began in 1993.
  - Partnership was successful beyond expectations.
    - Lab Director in 1995: "Solved previously intractable nuclear weapons design problems"
    - One of Goodyear's standard analyses was reduced from *32 years* [*"if possible" estimate using best commercial software*] to *5 days* in 2005.
    - Goodyear provided significant VV&UQ for portions of Sandia's Sierra Mechanics Tool Suite.
      - Tens of thousands of runs per year on Goodyear's HPC

Goodyear/Sandia partnership solved key technical problems!

Great Analysis Codes Weren't Sufficient

- Niccolò Machiavelli, *The Prince*
  - "It must be remembered that there is nothing more difficult to plan, more doubtful of success, nor more dangerous to manage than a new system. For the initiator has the enmity of all who would profit by the preservation of the old institution and merely lukewarm defenders in those who gain by the new ones. This coolness arises partly from fear of the opponents,… and partly from the *incredulity of men, who do not readily believe in new things until they have had a long experience of them*."

Paradigm shifts require both cognitive and emotional adjustments.

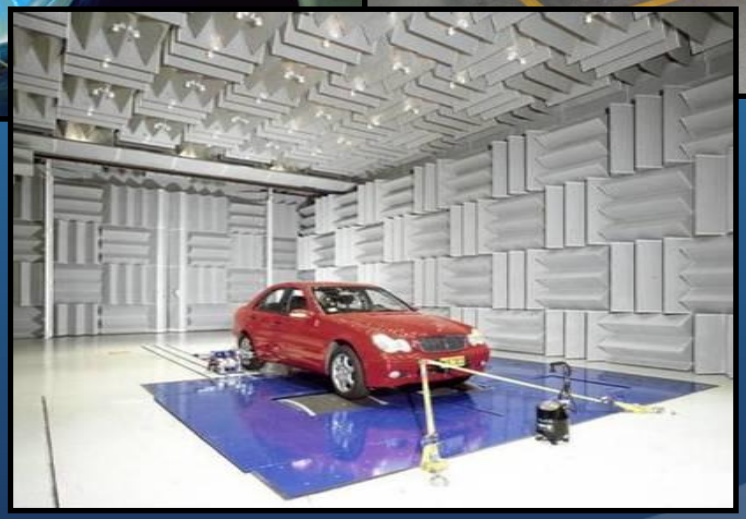
Extensive Test Track Facilities

San Angelo, Texas

Americana, Brazil

Seven test tracks worldwide

Extensive Laboratory Test Facilities



Design/build/test

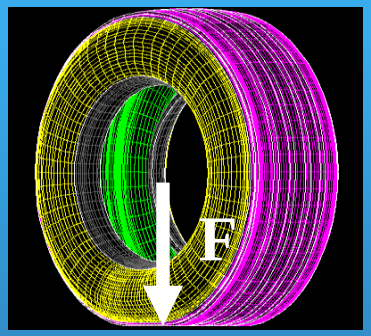
Workflow Was Critical

- Physical prototype-based engineering had been developed, validated, and systematized over a period of 100+ years.
- No one wanted to be the first to take the risk of converting to virtual prototyping, even with validated computations.
- *Designers had confidence in and relied upon a logical sequence of physical tests.*

Physical test workflow was critical!

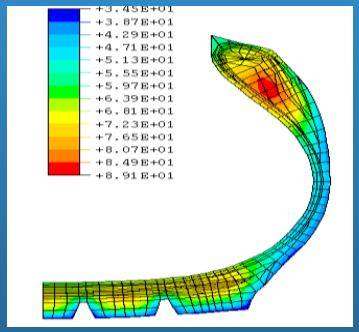
Physical Test Workflow Virtually Replicated

Predict statics



Each virtual test refined the feasible design space in a sequence familiar to the designer.

Predict steady state



Predict transient dynamics

Designers Had to Do Their Own Analyses

- Reliable virtual prototyping and a physical test-based analysis workflow weren't enough.
- P*roduct designers had to do their own analyses.*
  - Designer/analyst interface was problematic.
    - Time delay between a designer's questions and the analyst's answers was too long. Designers forgot their questions.
    - Designers: "Analysts never answered my key questions anyway."
  - Note: virtual prototyping did not eliminate analysts.
    - Analysts transitioned from running "routine analyses" to developing new analytical methods and standardizing them for the designers.
    - Most analysts preferred the new opportunity.

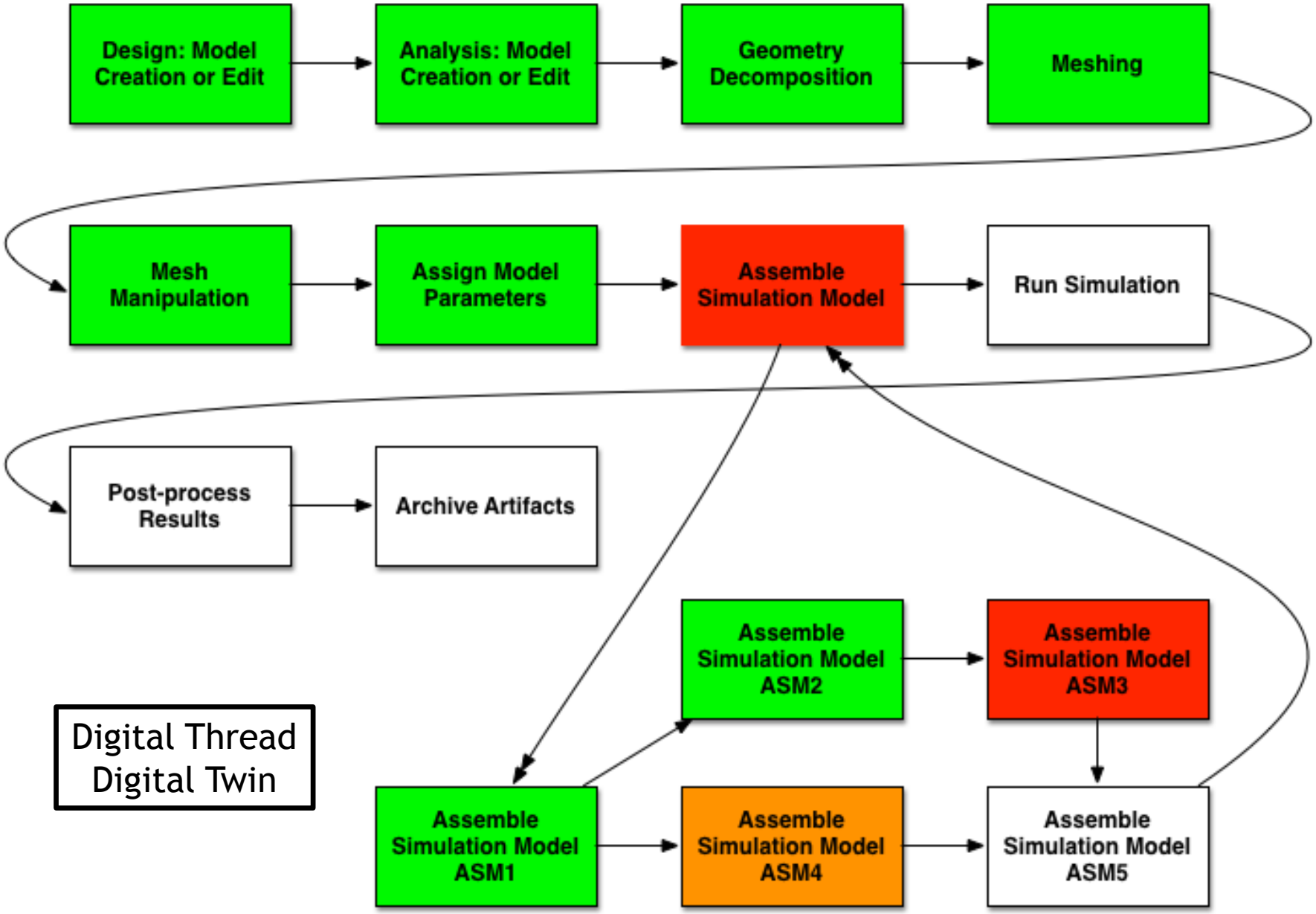
Hands-on analysis expanded designers' knowledge & intuition

Analysis Standardized for Designers' Use

- Entire computational analysis process was standardized and underwent extensive VV&UQ to ensure accurate & repeatable results *regardless of which designer did the analysis*.
  - Data credibility
    - Geometry creation
    - Meshing
    - Boundary conditions
    - Material properties
  - Technical coherence
    - Analysis software
    - Post-processing
    - HPC hardware, compilers, libraries,…

From "art" to "engineering"

Analysis Workflow Automated



Bottom Line Results

- ***New product development time was reduced 75%***, from over three years to less than one, including final prototype testing.
- ***Product testing costs were reduced by 60%***, resulting in $100 million annual savings.
- More new products were developed with more innovative designs as a result of improvements in designers' ***knowledge, intuition, and creativity – "Innovation Engine"***.
- The new process and the resulting first product won both ***R&D 100 and CIO 100 awards***.

Time was and is of the essence.

Air Force Wants to Shorten Next Gen Fighter's Development Timetable

What's your reaction?

Article by Vivienne Machi, *National Defense*, 9/19/2017
Photo By Rob Shenk, Great Falls, VA

Accelerating Technology Development & Procurement

- Subject: Accelerating Enterprise Cloud Adoption
  - "I am directing aggressive steps to establish a culture of experimentation, adaptation, and risk-taking; to ensure we are employing emerging technologies to meet warfighter needs; and to increase speed and agility in technology development and procurement."

    Patrick M. Shanahan, Deputy Secretary of Defense, 9/13/2017