Evolving Simulation with System Thinking & SBPD

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A history rooted in innovation

Founded in 1919

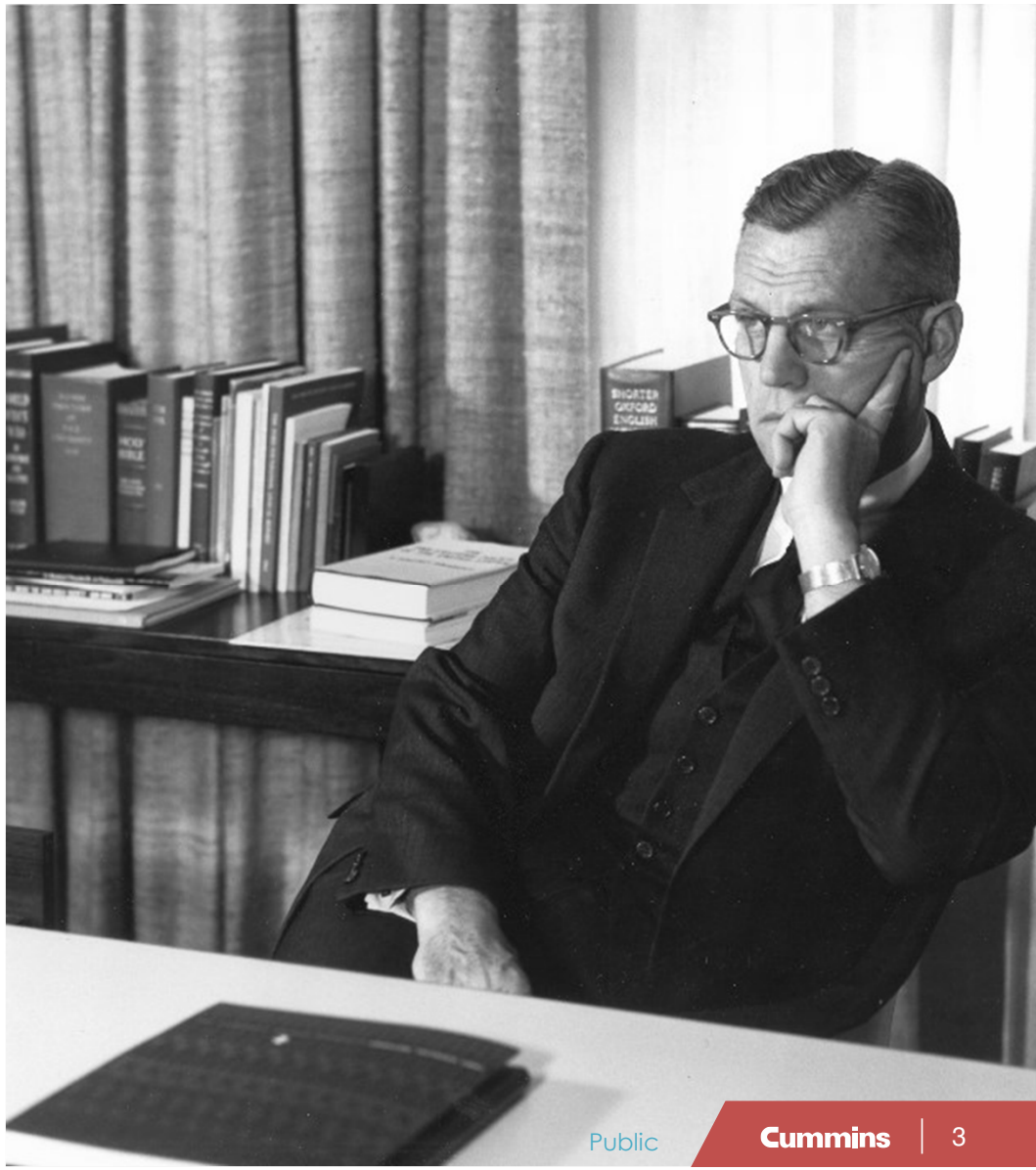
Cummins was founded by Clessie Cummins and W.G. Irwin, who believed in the power of ideas and had a shared vision of what ingenuity and hard work could achieve.

The power of diesel

Cummins took the available technology and transformed diesel into a reliable and everyday power source.

J. Irwin Miller: A visionary

- Laid foundation for future global growth
- Embraced the stakeholder model
- Integrated values into the fabric of our business



Our history

For more than 100 years, we have defined ourselves by our unwavering values and our promise of innovation and dependability. In the next 100, we will continue to challenge the impossible. Here's a look at some highlights from our past 100 years:

1929

Cummins takes Irwin for a ride in a used Packard limousine that he equipped with a diesel engine on Christmas Day, convincing Irwin of the engine's potential. Irwin invests a much-needed infusion of cash.

1944

Miller becomes Executive Vice President of Cummins.

1962

Cummins begins operations in India, first as a joint venture with one plant in Pune.

1986

Cummins purchases 86 percent of the Onan Corporation in Minneapolis, Minnesota (USA), which would become the basis for its Power Generation Business.

2017

Cummins redefines Our Story including the Mission and Values around its Vision of "**Making people's lives better by powering a more prosperous world.**"

1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020

1919

Clessie Cummins creates the Cummins Engine Company based in Columbus, Indiana (U.S.A). William G. Irwin, who employed Cummins as a driver, supplies nearly all of the $50,000 in startup capital.

1937

Cummins earns its first profit.

1932

Cummins barnstorms across the country, demonstrating the power and fuel efficiency of the diesel engine in his Coast-to-Coast Cummins Diesel Test Bus.

1951

Miller becomes Chairman of the Cummins Board.

1975

Cummins enters China as part of a deal involving heavy construction equipment with Cummins engines.

2019

Cummins celebrates its 100-year anniversary.

2000

Cummins Engine Company becomes Cummins Inc. to acknowledge it is also a leader in global markets including filtration and power generation.

Powering a more prosperous world

190	Countries and territories*
73,600	Global employees
104	Years of industry leadership
10,600	Cummins certified dealer locations
$1.2B	Invested in research and technology in 2022

** Approximation of countries and territories with Cummins service*

As published in the 2022 10K found on cummins.com.

Our global manufacturing and distribution footprint

ENGINE	*U.S., Brazil, India and U.K.*
COMPONENTS	*U.S., Australia, Brazil, China, France, Germany, India, Mexico, South Korea and U.K.*
POWER SYSTEMS	*U.S., Brazil, China, India, Mexico, Romania, U.K. and Nigeria*
DISTRIBUTION	*U.S., Australia, China, South Africa and U.K.*
ACCELERA™ BY CUMMINS	*U.S., Belgium, Canada, China, England, Netherlands, Spain and Germany*

**The above reflects principal manufacturing facilities for each segment. In addition, engines and engine components are manufactured by joint ventures or independent licensees at manufacturing plants in the U.S., China, India, Japan, Sweden, U.K. and Mexico. We operate numerous management, research and development, marketing and administrative facilities globally.*

New technologies and innovation

- Electrified powertrains
- Fuel cells
- Hydrogen production technologies
- Automated manual transmissions
- 3D printing and additive manufacturing
- Vehicle connectivity
- Big data
- Artificial intelligence

PLANET 2050 aspirational targets

DOING OUR PART TO ADDRESS CLIMATE CHANGE AND AIR EMISSIONS

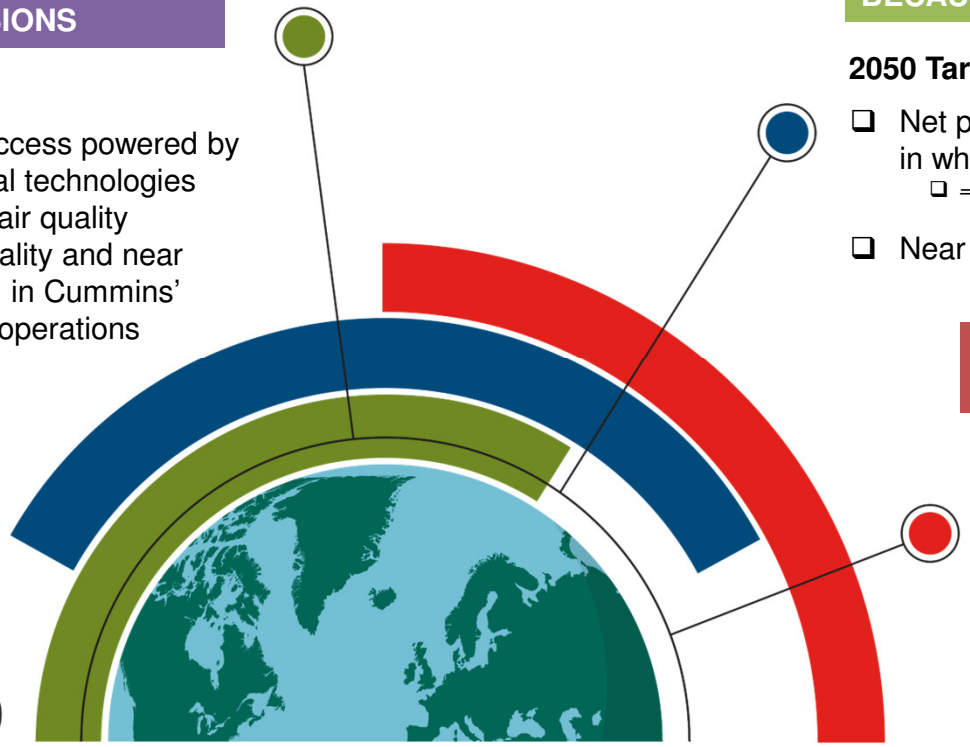
2050 Targets

- ❑ Customer success powered by carbon neutral technologies that address air quality
- ❑ Carbon neutrality and near zero pollution in Cummins' facilities and operations

COMMUNITIES ARE BETTER BECAUSE WE ARE THERE

2050 Targets

- ❑ Net positive impact in every community in which we operate
  - ❑ *= sum of environmental good > local environment footprint*
- ❑ Near zero local environmental impact



USING NATURAL RESOURCES IN THE MOST SUSTAINABLE WAY

2050 Targets

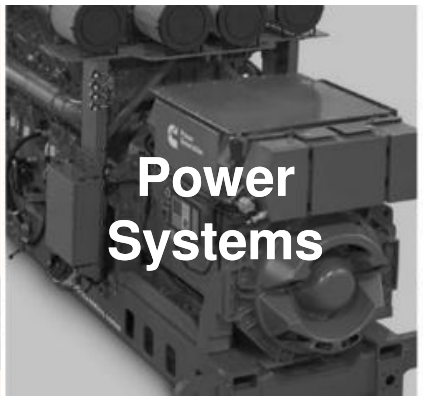
- ❑ Nothing wasted
  - ❑ Design out waste in products and processes
  - ❑ Use materials again for next life
  - ❑ Reuse water and return clean to the community

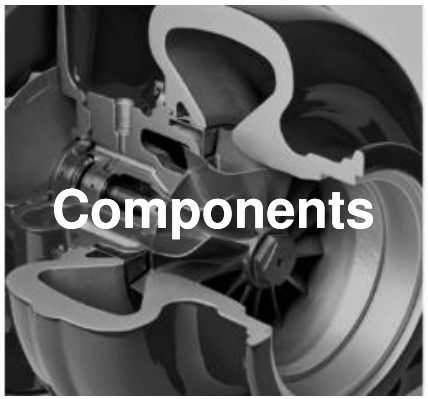
PLANET 2050

References to "facilities" relate to all consolidated operations and joint ventures subscribing to Cummins' Enterprise Environmental Management System. Goals will be periodically assessed for progress and continued practicability

Five operating segments

Cummins has a long track record of delivering leading power solutions.
As we look ahead, we know our industries and regions will continue to change,
and we are committed to bringing our customers the right technology at the right time.





Accelerating toward

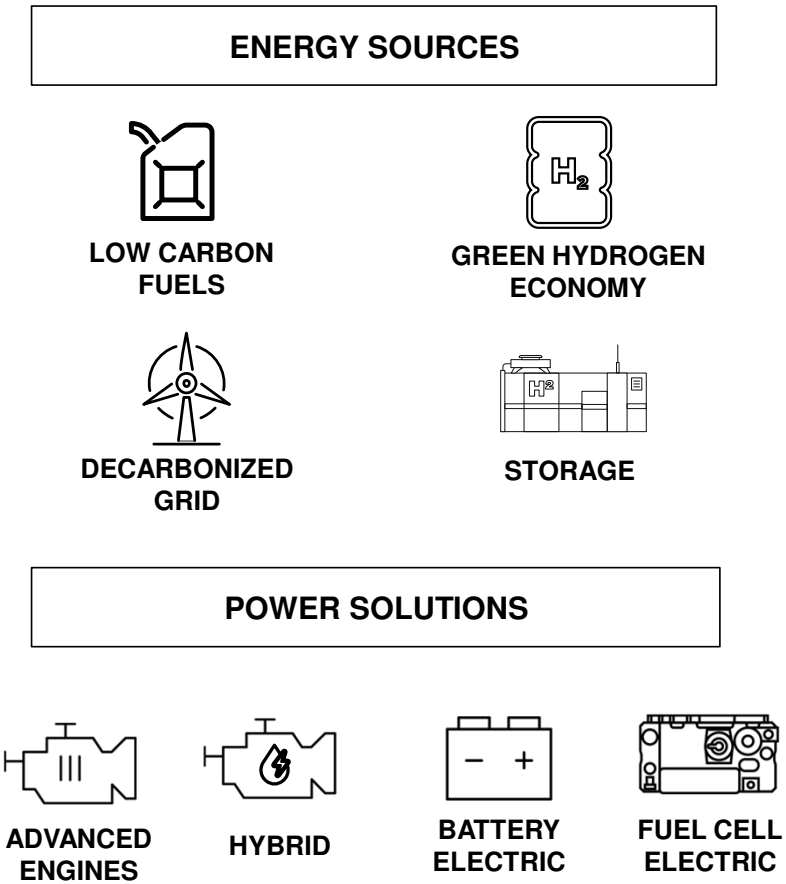
Destination Zero

Cummins will continue to innovate and invest as we advance our strategy, but we can't do it alone.

Action is required today

Progress requires partnership

Technology leadership is critical



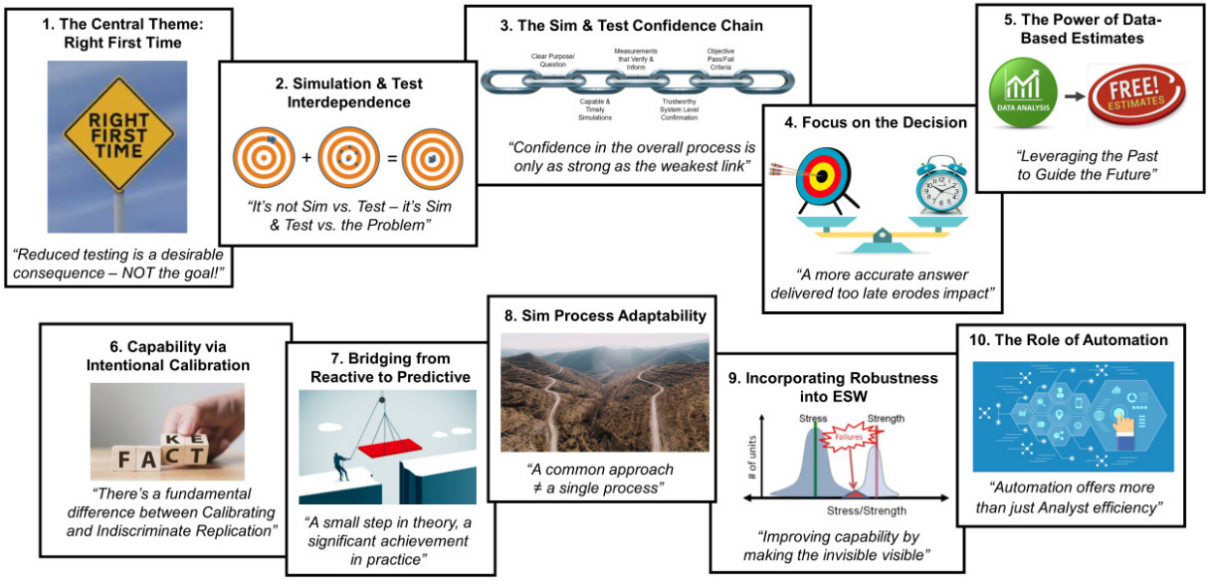
Simulation Based Product Development

We have been doing it partly for long time, but now focus is on getting the design **"First time right"** and, hence having to do less testing.

- Robustness/Variation Studies
- Time Efficiency
- Data Driven Decision Making
- Closed Loop Process

All this calls for Simulation Automation

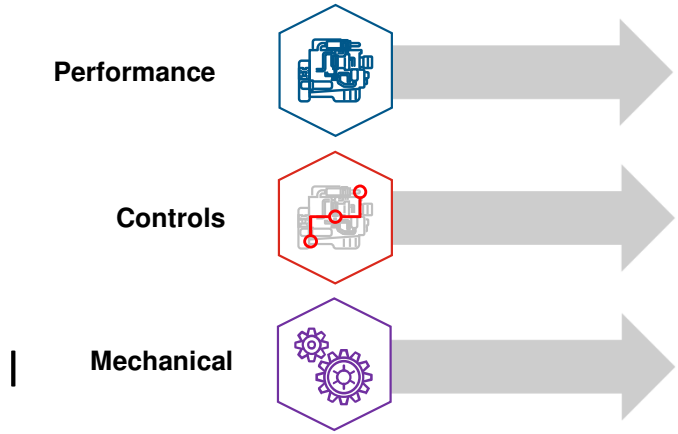
& System Level Trade-Offs



System Engineering

From…

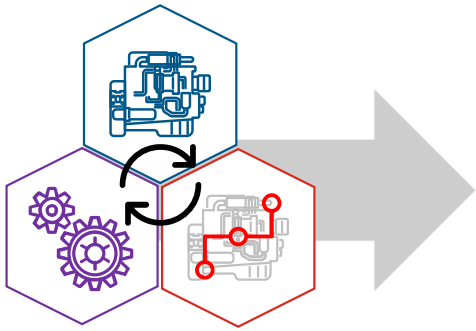
Functional



- Separate process lanes relaying static set of information between disciplines
- Models utilized for single discipline optimization
- Deep dive into trade-offs when major risk arises to delivery

Systems

To…



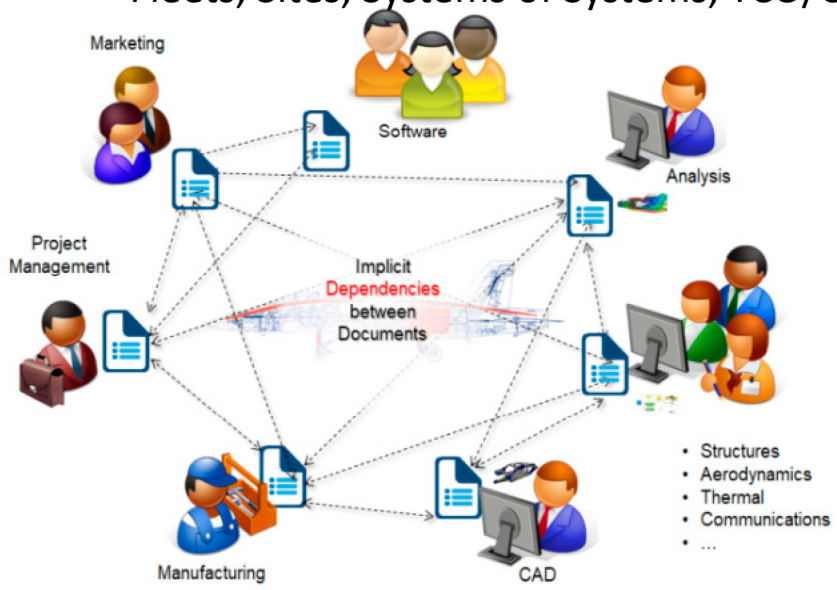
- Integrated process lanes with continuous information exchange
- Models integrated for MDO approach
- Trade-offs managed concurrently and risk mitigated proactively
- **"Democratization of data and models"**

Benefits:

- Early risk identification
- Architecture can be optimized
- **Quality and Efficiency of Product Development Improves**

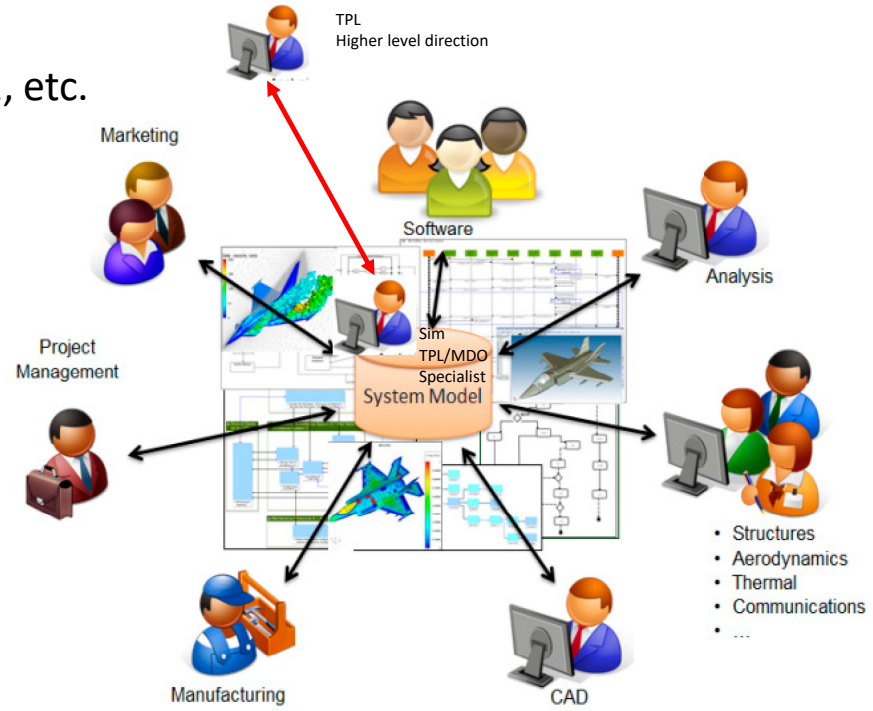
System Engineering

- Managing Complexity
  - Engines to Power to Powertrains
  - Fleets, Sites, Systems of Systems, TCO/CO2, etc.



(a)

Customer Voices in System Context
System Functionality
Critical Parameters Maps

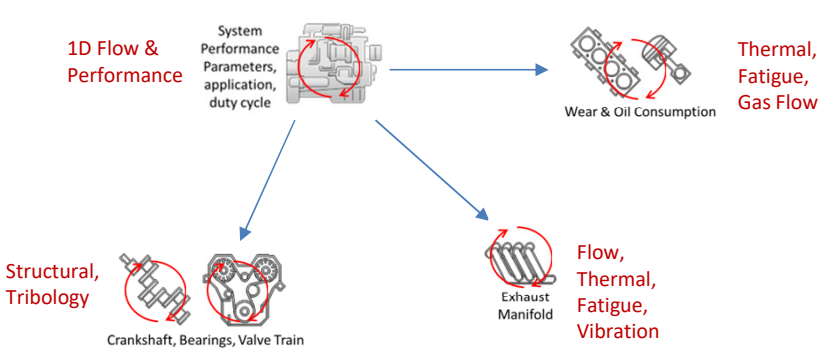


(b)

P-Diagrams
Decision & Options
Boundary Diagrams
others…

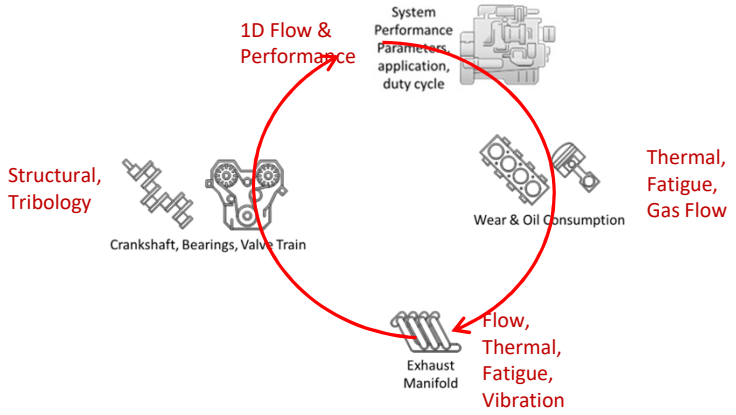
System Level Simulation & Multidisciplinary

From…



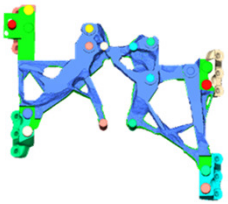
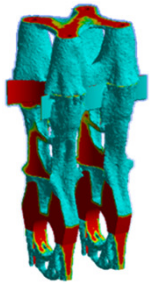
- Multiple design loops at Function & Sub-System level
- Not closed loop process at System level
- Traditional & well understood by all teams

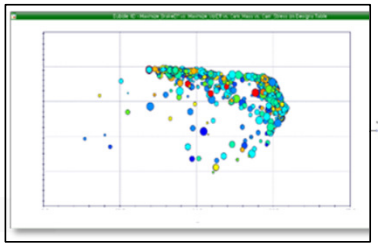
To…

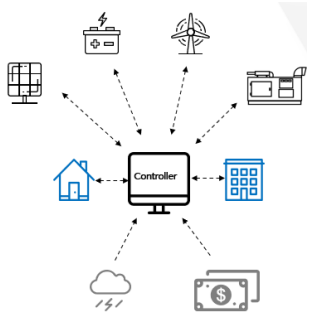


- System Engineering approach - One loop considering multiple functions (Multi-Disciplinary) and multiple sub-systems (System-Level)
- Intends to be Closed loop at System Level and hence directionally takes us to “First Time Right”
- More complex to manage & needs cultural shift
- Requires automation platform

Evolution of Multi-Disciplinary Optimization





2013

- Topology optimization utilized in few teams globally
- modeFRONTIER used for automated calibration
- Primarily applied mechanics & PSBU
- **Very few users**
- **Minimal HPC Usage**

2015

- Single discipline optimization with modeFRONTIER globally
- Integrations with ANSYS, GT, Simulink
- Multiple business units
- **Gradually increasing the # of users**
- **Some HPC Usage for long solving physics in loop**

2016-2017

- MDO Proof of concept project completed
- Revealed path for cross discipline optimization
- All business units, globally
- **Heavy HPC Usage for 10s of jobs in parallel – 10000 design points in total**

2018-2019

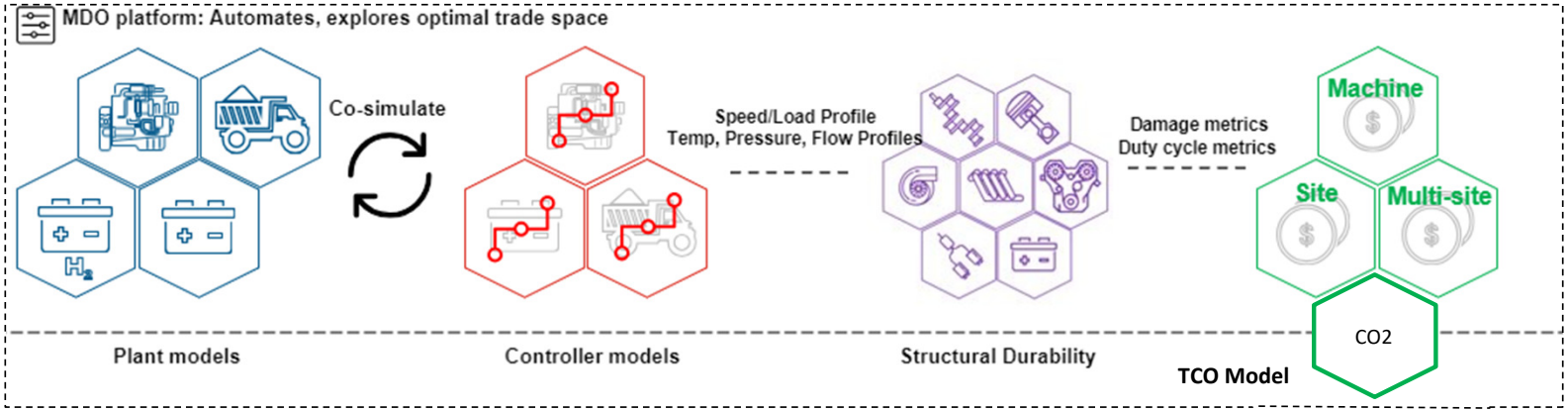
- MDO vision well established and growing in pilot BU
- Volta trial
- **Increased number of users globally**
- **100s of jobs in parallel on HPC – 50000 design points in total**

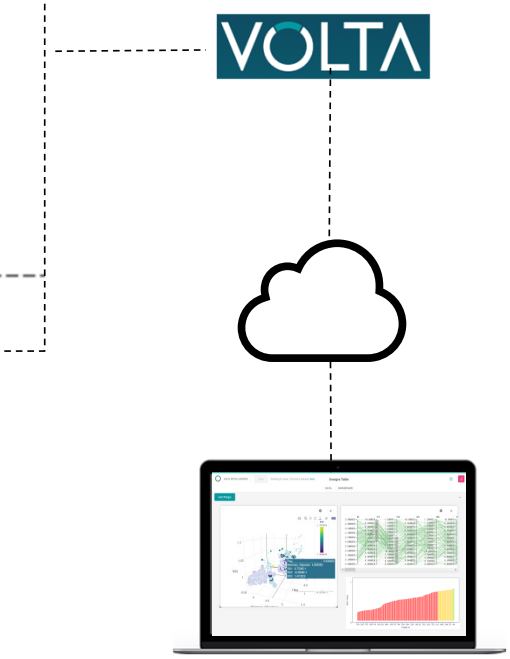
2020 - 2023

- MDO platform: Automates, explores optimal trade space
- Business Process Mapping and Collaborative workflow development environment where we are starting to explore Volta more.
- **Culture expects the use of automation and optimization!**

Impact - For one of key component design used MDO instead traditional manual process & benefited with 1 month lead time reduction and improved fuel economy by 2.5%

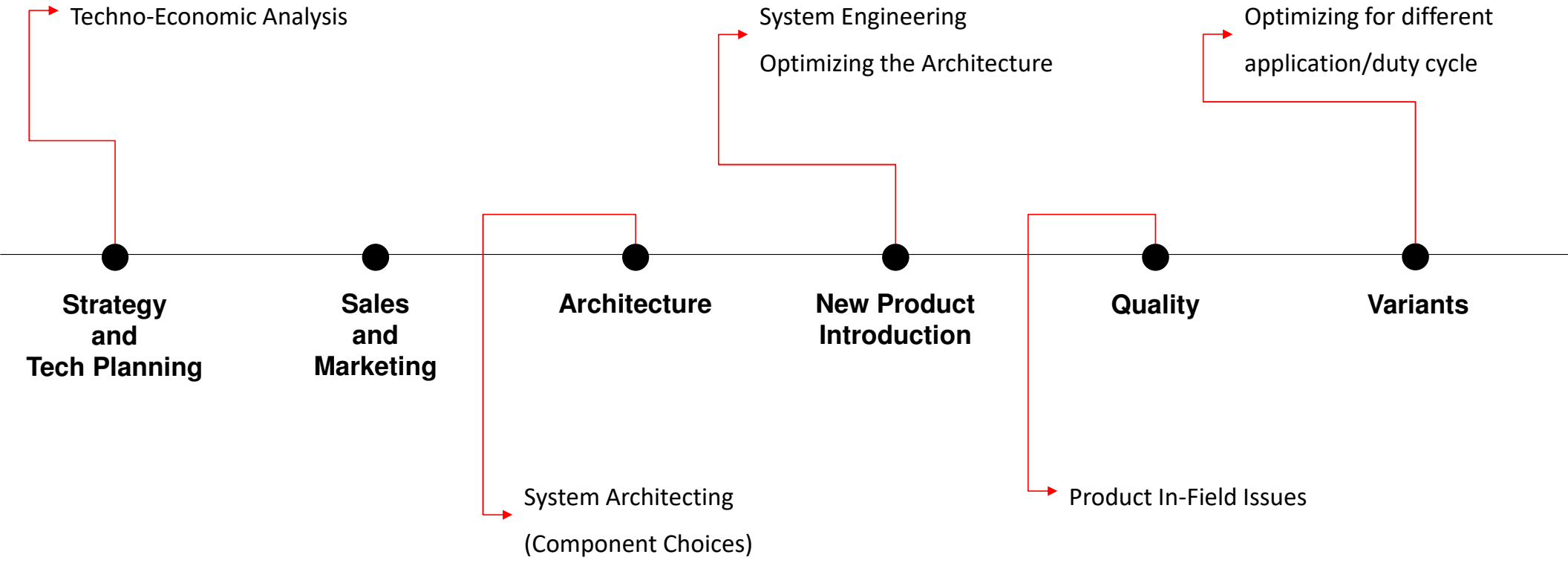
Democratization of TEA





- Linked physics-based simulation models with complex total cost of ownership models to understand technical and business trade-offs and make better product decisions.
- Using MDO platform to automate the exploration of the trade space. Custom web-interface for TEA to democratize MDO workflow usage
- Customized pre and post processing for specific user needs. So, they can evaluate what-if scenarios given their customers unique inputs and needs
- Model consumers can leverage optimization workflows built and certified by model owners, Leverages established model library from core disciplines

Through Product Lifecycle



Conclusions

- System engineering & Simulation Based Product Development approach is key to success.
- Simulation Process Automation is crucial part of SBPD, as it facilitates time efficient, data driven and closed loop decision-making.
- Culminates cross-functional & system level thinking in the team as everyone gets to see interaction with other pieces which they are not working on.
- Enables faster decision making, reducing larger changes downstream and, hence saving cost. Sometimes shows dead ends earlier to stop wasteful efforts.
- At Cummins we view a focus on integrating MDO into our simulation culture as a key accelerator to the democratization of simulation models and data.

Watchouts

- Having clear understanding of the problem is key to successful implementation of these tools, otherwise it is just more garbage.

- Ever-Changing requirements can make it difficult to exactly understand what is needed and how to use these tools to achieve that.

- Requires cultural shift, which takes time, as people need to adjust to different way of working. They do see benefits once they try it, but there can be a resistance initially to move away from status quo.

Thank You