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The Human Algorithm: Integrating Experiential Data into Multi-Attribute Optimization

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> You've got to start with the customer experience and work back toward the technology.
>
> – Steve Jobs

- While not all of us may be designing the next iPhone, this principle - starting with the experience - is the foundation of creating products that customers don't just buy, but *love*.
- Our challenge as engineers is to translate this vision into the reality of vehicle development.
- This means delivering the right customer experience, at the right target level for our brand, while managing the difficult trade-offs between performance, cost, and quality.

The Gap Between Optimal Data and Optimal Experience

Where the Pareto Front Meets the Real World

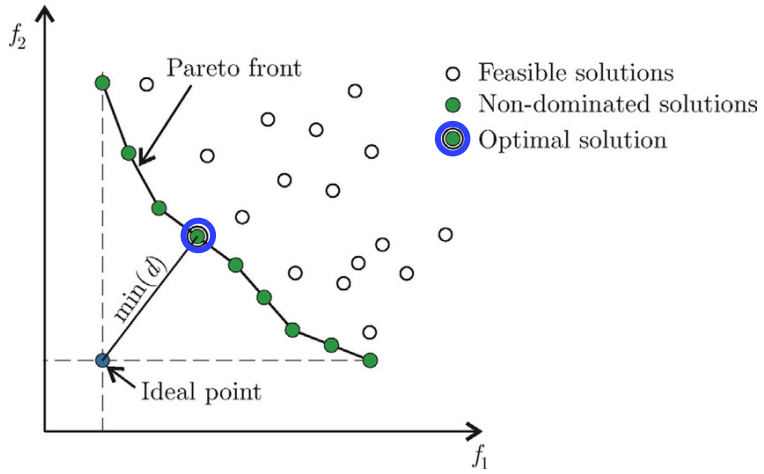
Algorithmic Optimum

As optimization experts, we are masters of the Pareto front. We use powerful tools like ModeFrontier to find the most efficient designs based on quantifiable metrics: minimize mass, maximize stiffness, reduce cost.

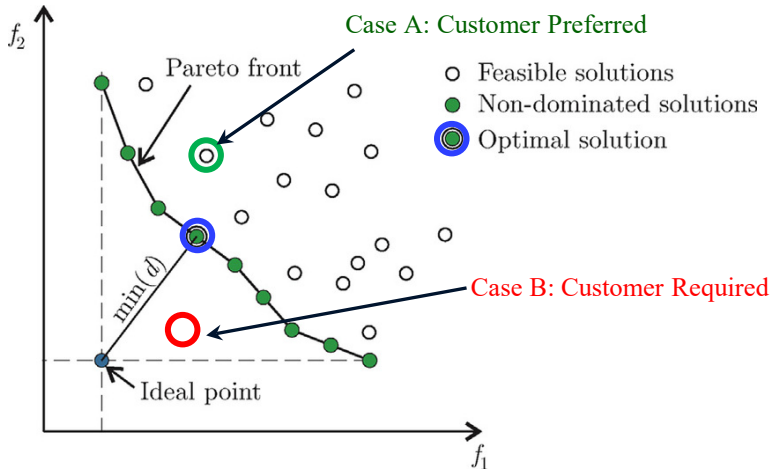
Experiential Optimum

But what happens when the key attribute is subjective? When it's about 'feel,' 'sound quality,' or 'comfort'? The mathematically 'best' solution is not always what a customer prefers (Case A). In other situations, the optimum design may even be entirely unacceptable from an experience standpoint (Case B).

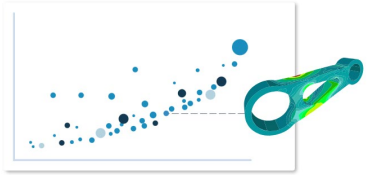
Classic Pareto front Mathematically Optimal



What-if the Customer-Preferred or Acceptable Solution Exists Elsewhere



A Framework for Integrating Experiential Data



Courtesy ESTECO Engineering

OPTIMIZE: Run MDO to generate a set of technically efficient designs.

DECIDE & REFINE: Use qualitative feedback to make a confident decision or refine the constraints for the next MDO run.

EXPERIENCE: Synthesize these designs into a real-time, immersive simulator(s).

EVALUATE: Have expert evaluators or customers assess the designs in full context.

- To bridge this gap, we need a structured, repeatable engineering process. Emphasizing the design for 'The Human Algorithm'.
- It's not about abandoning data; it's about augmenting it. Use MDO to tell us what's possible and use the simulator(s) to tell us what's preferable. And use that human insight to make better decisions, faster.

A Unified Simulation Ecosystem for Decisive Trade-off Analysis - Ford Simulator(s)

NVH Desktop Simulator (component to full vehicle simulation)

Compact NVH Desktop Simulator (combined NVH and Vibration simulation)

Low Travel Simulator Vehicle Dynamics / Real time simulator for ride and handling experience (NVH may be included)

On-Road Real Time Simulator Holistic NVH experience

Note: Software in the loop is often deployed to the simulators to include key calibration and controls for Realtime driving experiences (e.g. powertrain state, vehicle performance, motor controls)

Our common architecture creates a unified ecosystem. One model (ideally) can be deployed on any simulator, ensuring we use the right tool to inform the right decision.

Optimizing for NVH

Balancing eMotor Control Strategy for NVH and Drivability

Challenge:

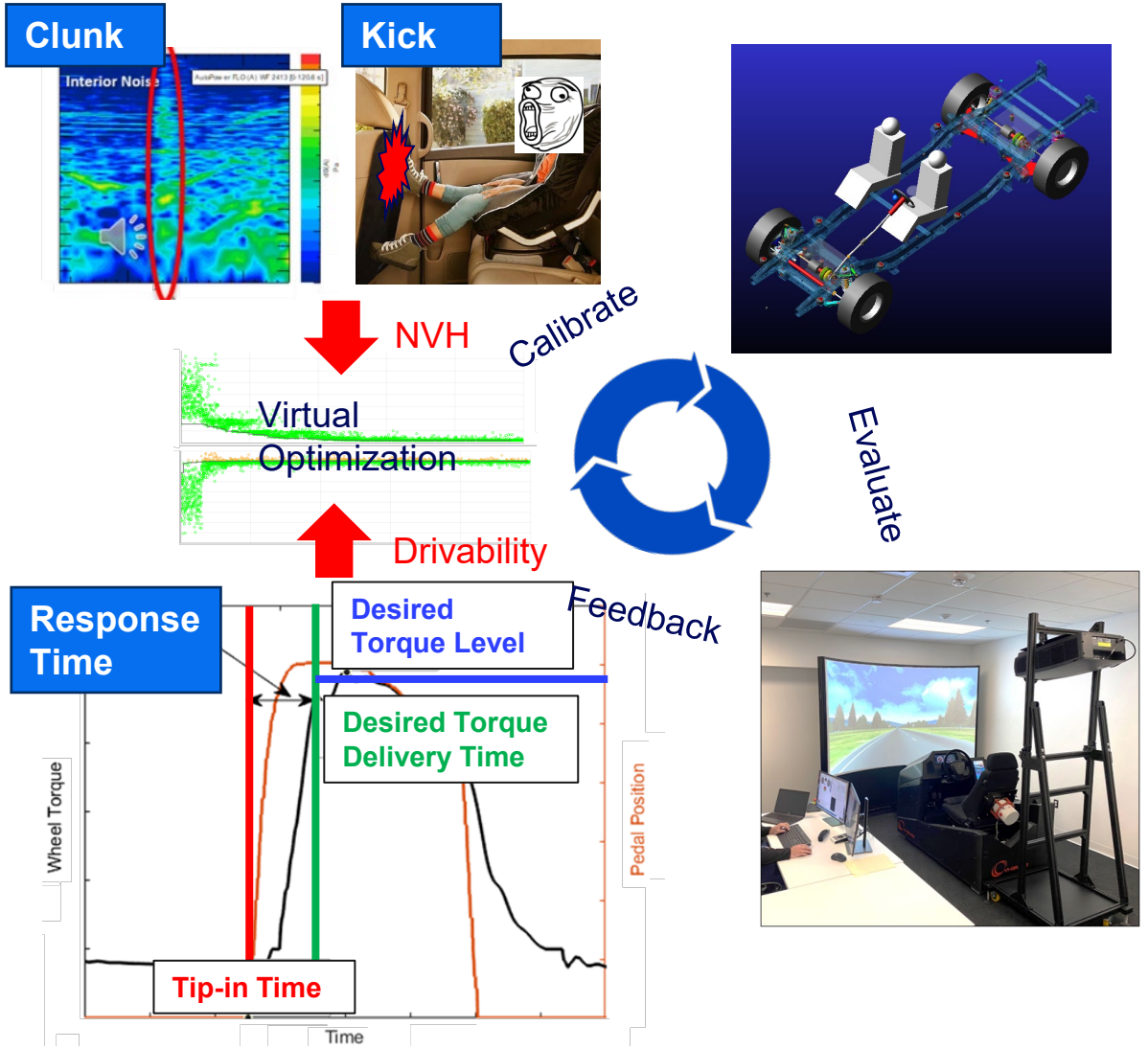
- The perception of quality is defined by the driver's experience:
  - In EV, transient harsh events like "Clunk" and "Kick" during acceleration changes are significant detractors.
  - A calibration that minimizes the unwanted noise and vibration without creating a laggy throttle response requires a complex interplay between hundreds of parameters.

Action:

- The 'Human Algorithm' Approach: Instead of optimizing each attribute in isolation, we created simplified 'feel parameters' in the compact NVH simulator and optimized using ModeFrontier with system model including ADAMS, AMESim, and Software-In-the-Loop models.

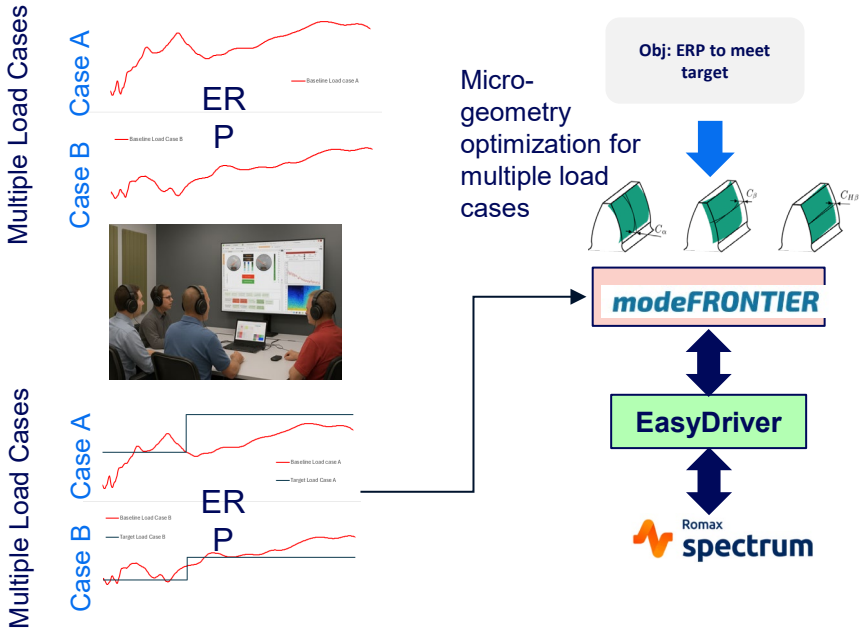
Result:

- This allowed calibration engineers to directly and instantly experience the trade-offs of different calibration sets in real-time.



A process that used to take weeks of iteration was reduced to days. We rapidly converged on a calibration that delivered the brand's desired 'performance feel' while ensuring NVH and efficiency targets were met

The Importance of Context in Sound Quality



Micro-geometry optimization for multiple load cases

Obj: ERP to meet target

modeFRONTIER

EasyDriver

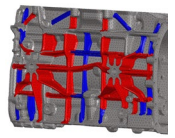
Romax spectrum

Light Weighting

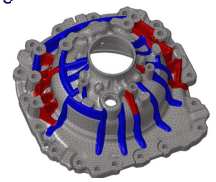
Obj: Reduce Weight Constraints : Maintain NVH and durability performance

Unified Model (MMO)

Altair OptiStruct®



Weight Reduction : xx Kg



Sensitive regions (to be retained)

Non-Sensitive (can be removed)

Meet target with weight reduction

Confirm Worst-Case Variation/Conditions

1 Initial Optimization

Initial MDO was performed at the sub-system level. But subjectively, improvement was required.

Further full system models were developed to develop further improved gear and case designs.

2 Simulator Insight

Listen to sound in the context of a full vehicle simulation - with road and wind noise

NVH Simulator includes full path analysis from unit source whine levels to customer with predicted wind and road noise context.

3 New/Better Optimization Target

Achieve the best-balanced design for sound in context.

Context is everything. This insight changed our fundamental optimization target from a simple sub-system physical metric to a psychoacoustic one.

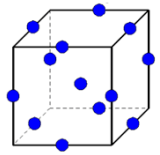
Robust Design in the Face of Production Variation

Using Monte Carlo & Weibull Analysis Parameter Fit to Evaluate Real-World Performance

- **Challenge:** Theoretical "best" designs often fail to account for manufacturing variability, creating a performance gap between the design lab and the real world. This inconsistency poses a direct risk to program targets and warranty costs.
- **Action:** Integrate production variation models directly into the optimization workflow. By running a Monte Carlo simulation as an inner loop, we can evaluate statistical performance over the design space. (Tools used include script-based tools driving Vehicle CAE models but can include ModeFrontier)
- **Result:** This allows us to 'feel' the impact of variation. We confidently select a more robust design to deliver required performance across the production spread. This strategy prioritizes reliable fleet performance and adherence to customer loss targets.

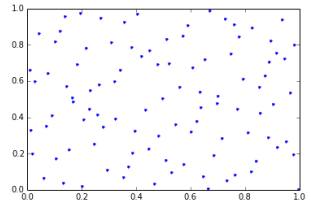
1) Define the problem: Design variables x, uncertainty variables u (manufacturing variation e.g. balance) (note u variable mean values may be included in x, e.g. mount rates)

2) Outer loop DOE model over Design Space variables x (choose DOE design method)

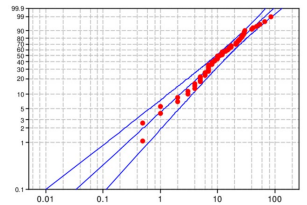


INNER LOOP

OUTER LOOP

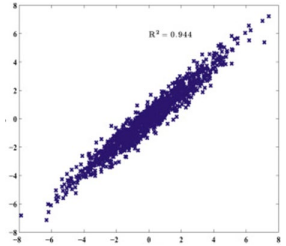


3) Monte Carlo at each DOE point for u variables



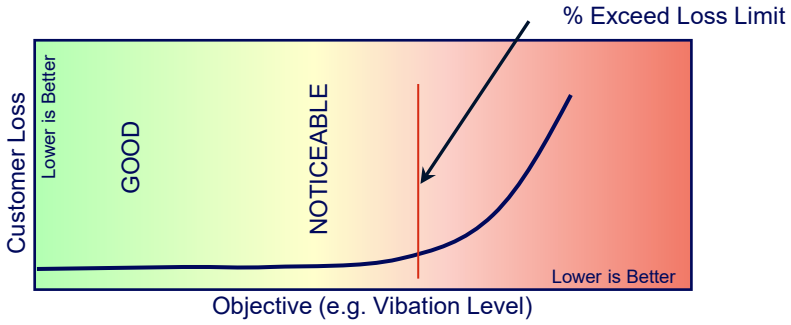
4) Weibull fit shape (b) and scale (a) parameters, store b/a for DOE point

5) Response Surface / Parametric fit (regression) responses b/a with design variables x



6) Define constraint / objective % exceeds customer loss limit

7) Optimize & select design to meet limits



Customer Target Constraint

The goal is not peak theoretical performance, but the best real-world fleet performance to customer loss or subjective limit(s).

Case Study: Optimizing for NVH, Vehicle Dynamics, Durability

Optimizing for NVH, Durability and Dynamics during Wheel Impact Events

Challenge:

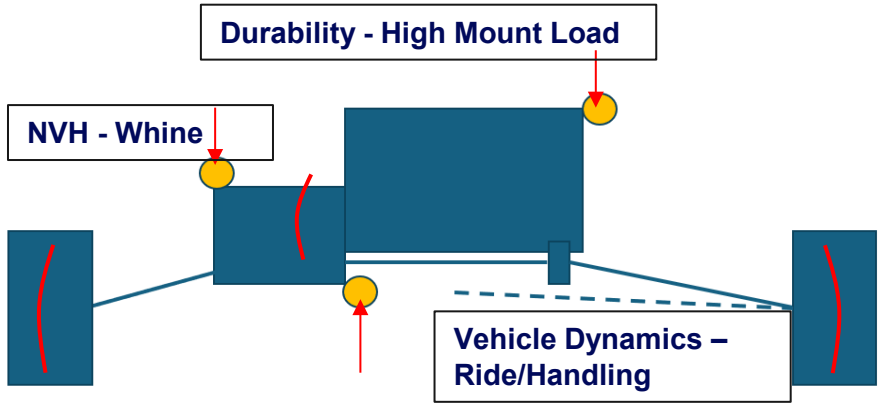
- For certain powerplant architectures, the vehicle system may experience high load (mounts/brackets) during wheel impact events.
- Reducing this mount load requires intricate balancing among NVH, Durability and Vehicle Dynamics.

Action:

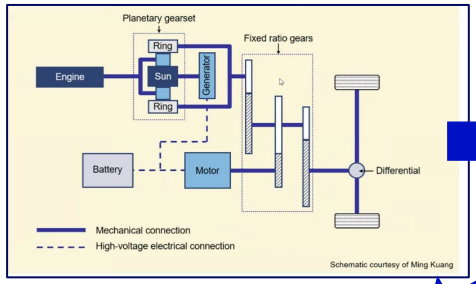
- Team developed a multi attribute optimization approach across multiple analytical platforms to find acceptable solutions. With ModeFrontier driving multiple analysis platforms.

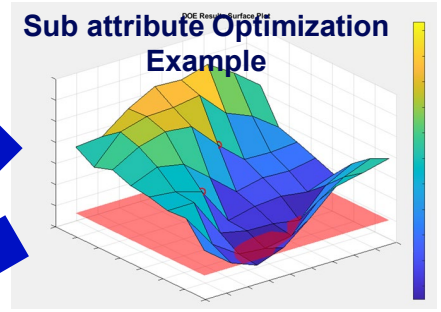
Results:

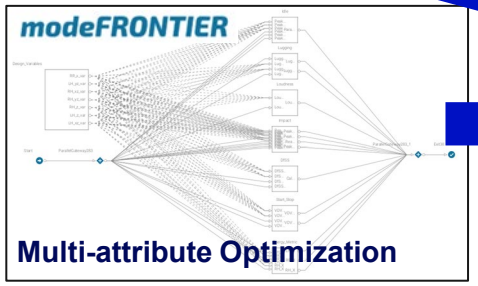
- Some of the attribute turned out to be subjectively worse than they may have appeared on paper, so the objective weighting needed adjustment.
- The human experience provided the decisive data that the algorithm couldn't.
- The team unanimously selected a design that was not the 'best' on paper for either attribute alone but provided the most pleasing and brand-appropriate balance.



Adjust multiple subsystem parameters to balance the metrics







	Design 1	Design 2	Design 3	Design 4
NVH				
Durability				
VehDyn				

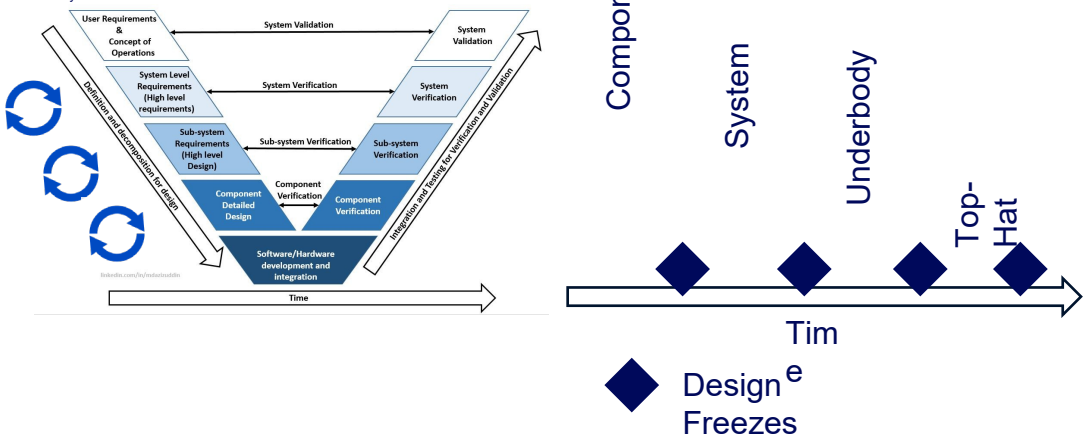
A Challenge for the Future: From the "V" to a Continuous Loop

Rethinking Systems Engineering for True Multi-Attribute Optimization

The Traditional "V" Model

- We cascade requirements from the vehicle level down to components.
- Optimization often happens independently within each subsystem silo.
- This forces *early design freezes* based on cascaded targets, locking in trade-offs before their vehicle-level impact is truly

Courtesy: Mohammad Azizuddin I.



Continuous, Set-Based Optimization

- We maintain a direct link between customer experience and component design throughout the process.
- We use MDO platforms to manage sets of viable designs, not single point solutions.
- This enables late design decisions, allowing us to optimize for the total vehicle experience until the last responsible moment.

- The future challenge for all of us is to break this model. To move to a continuous, set-based / “always-on” design approach.
- This is more than a technical challenge; it's a cultural one, and it's the next great opportunity for our field.

The Value of The Human Algorithm

Better Decisions, Faster Development, and Products Customers Love

De-risks Decisions:

Provides confidence to resolve complex trade-offs that are ambiguous on paper.

Accelerates Development:

Replaces debate over conflicting data with decisive, experience-based alignment.

Drives Customer-Centricity:

Creates a direct, tangible link between detailed engineering work and the final customer experience.

Enhances Optimization:

Makes MDO more powerful by feeding it better, experience-informed objectives and constraints.

Your Next Optimization Frontier is Human

Our Goal:

- The ultimate goal of our work is not a point on a chart, but a product that delivers a superior experience.
- The future of engineering excellence is not just about building better algorithms, but about building better, more seamless integration between those algorithms and human experience.

The Challenge:

- Look at your current projects. Where is the gap between your data and the experience of your customer?
- How can you integrate experiential data into your next optimization run? The tools are here. The opportunity is to build the human into your algorithm.

Thank You

Questions & Discussion

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