CAFE Model: Database Integration

Kevin Green, Ryan Keefe
Volpe National Transportation Systems Center

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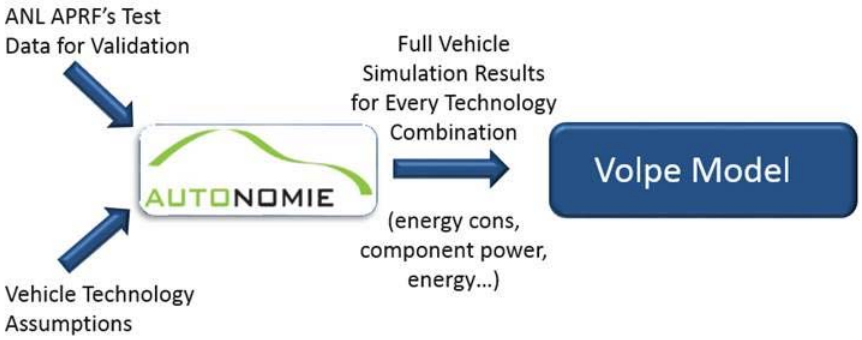
Full vehicle simulation of every vehicle and technology combination is impractical

Full vehicle simulation might be the ideal, but…

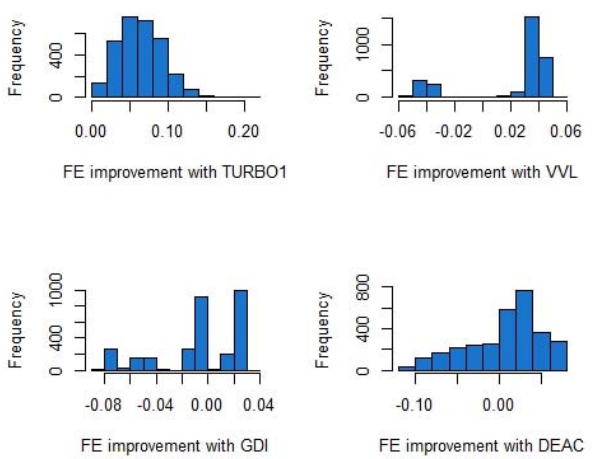
- Analysis fleet has ~ 1,200 LD vehicles
  - With 500+ unique tech combinations across 5 technology classes and a dozen body styles
- Would require detailed data for all current and potential future technologies on every vehicle model
- Number of input files, modeling runs and output files would be enormous.
  - Runtimes too long to support decisions

Autonomie database integration balances ideal solution and practicality.



Technology effectiveness in CAFE model has evolved

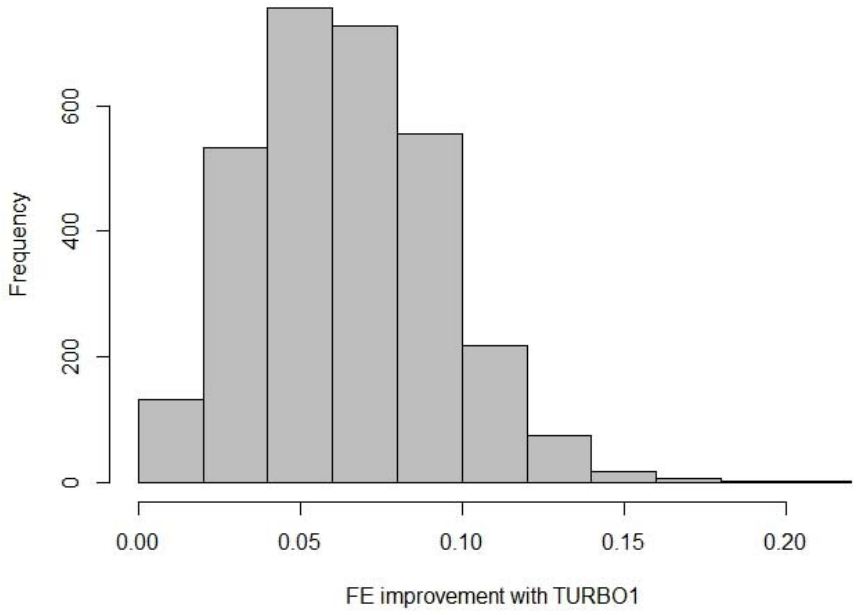
Technology	Abbreviation	Improvement
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	2.18%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	2.01%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	2.81%
Continuously Variable Valve Lift (CVVL)	CVVL	3.57%
Cylinder Deactivation on DOHC	DEACD	0.44%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	1.56%



- Previous versions:
  - Single value to represent improvement across all technology combinations
  - Several dozen pair-wise adjustments to account for synergies and dis-synergies for combinations of technologies.
- For the Draft TAR:
  - Technology's improvement depends upon combination of technologies already present on vehicle
  - Implemented through 20K – 30K synergy factors that fully represent Argonne database results

"Incremental effectiveness" varies with the point of reference

- Many possible points of reference for a single technology
  - "Incremental" effectiveness is really a distribution for every technology
- No single value can represent the distribution
  - Even adding synergy pairs can't capture full information of database
- Need a richer representation of technology possibilities

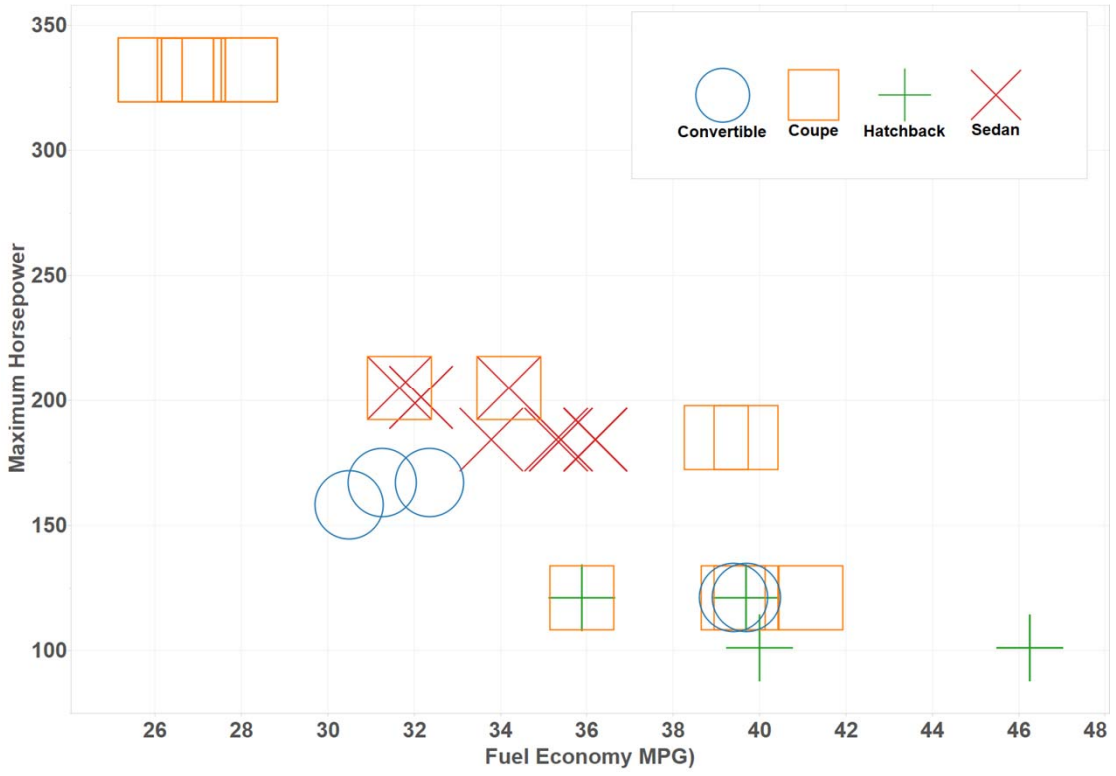


Implementation: Absolute or Incremental fuel consumption?

- The simulation database is inherently *absolute*
  - No real path dependence, just technology states
  - Multiple baselines possible
  - *Incremental* effectiveness of any technology is a distribution across all possible combinations
- CAFE model applies *incremental* effectiveness values & synergies
  - Absolute fuel economy values are based on the actual (compliance) fuel economy of the analysis fleet (e.g., each vehicle in the MY 2015 analysis fleet)
  - The CAFE model applies incremental effectiveness when adding given technology to any vehicle
  - Follows decision tree logic not enforced in database

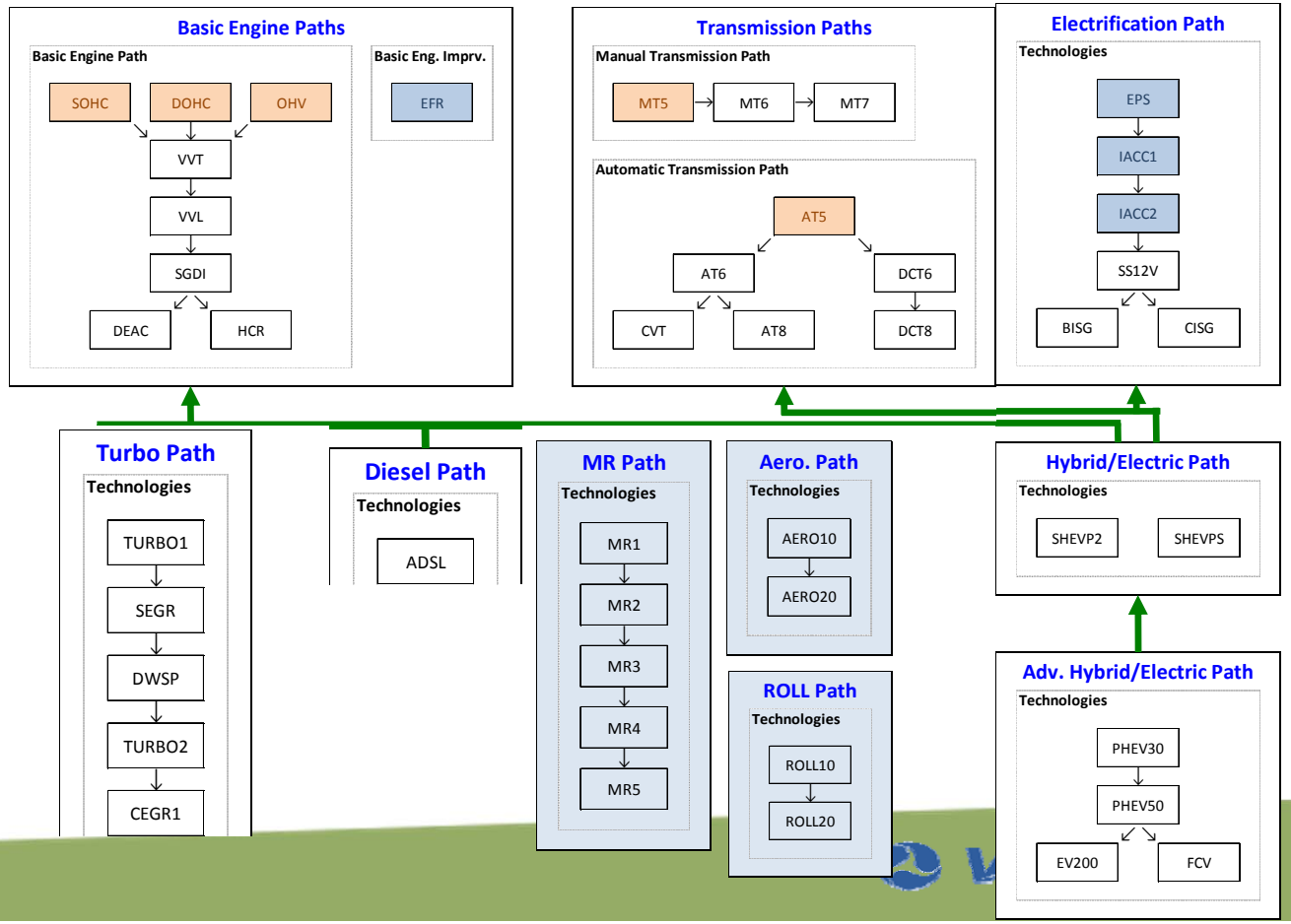
Technologies applied to heterogeneous analysis fleet

- Within one technology class of MY 2015 analysis fleet:
  - Many different OEMs
  - Wide variation in power and FE
  - About ~200 unique technology combinations
  - Single technology class may cover several body styles
- Translating absolutes in the simulation database into incremental values allows broad applicability



Imposing linearity and separable paths make incremental effectiveness values work

- All technology combinations can be represented by:
  - A small number of technology groups
  - A state variable for each group
  - Branch information within each group to handle splits
  - E.g., DOHC;VVT;AT6;BISG;MR2;AERO1;ROLL1
- Reference point for "incremental effectiveness" imposes linearity within groups
  - Represents baseline, apples-to-apples comparison outside of given group



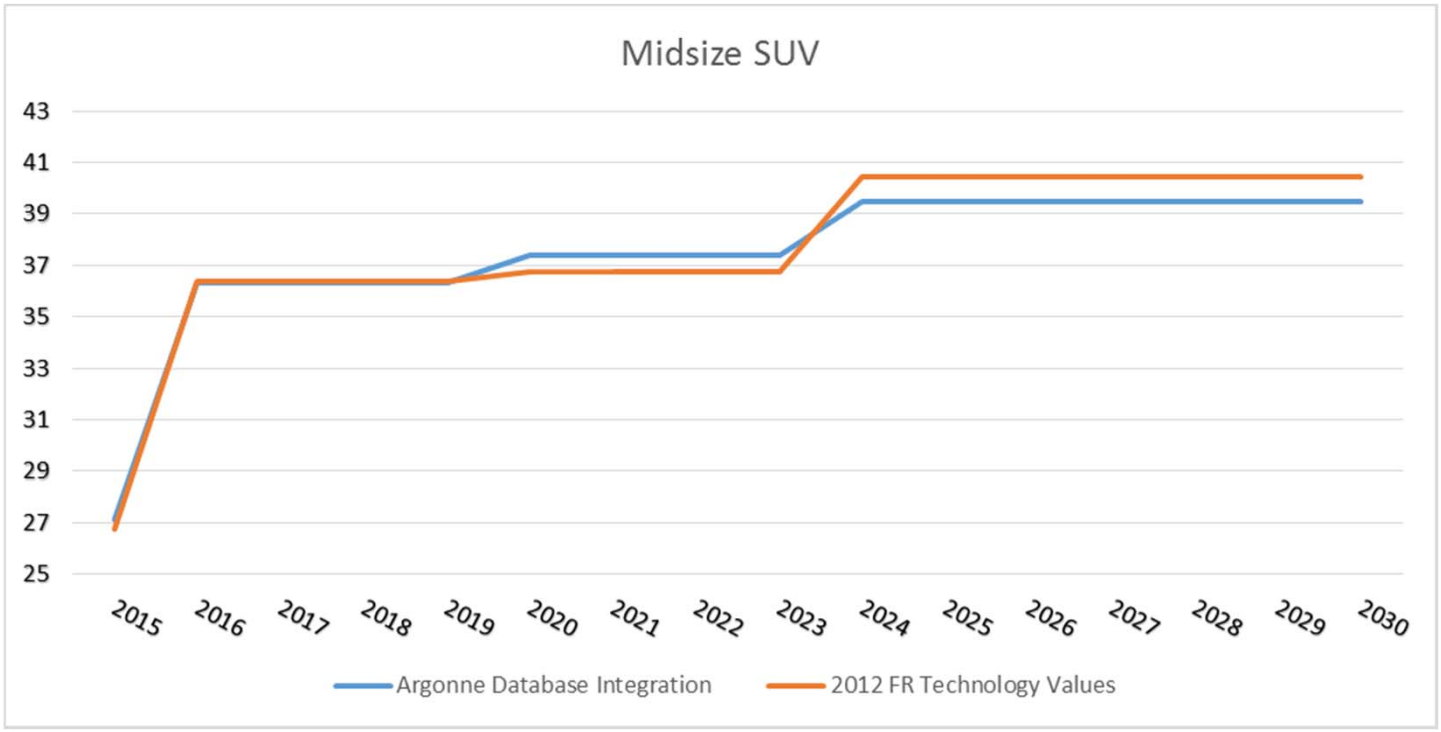
Implementation relies on combination of incremental effectiveness values and expanded synergy set

- Each technology, i, reduces fuel consumption by x_i%, (FC_0*(1 – x_i))
- When technology j is applied, then FC = FC_0 *(1 – x_i)*(1 – x_j)
- After each technology is applied, the model corrects product of incremental values with synergy factor
- The synergy factor is defined as:
  - $\frac{FC_{database}}{FC_0 * \prod(1-x_i)}$

- Old synergy factors were pairs
- New synergy factors are 7-tuples
  - Each discrete group has a state representation for each combination
- In general, each combination can be represented by:
  - [CONFIG, ENG, TRANS, ELEC, MR, AERO, ROLL]
  - Where each element of the vector is the current state of that path

This combination reproduces the percentage change in FC when moving from one point in the database to another.

Comparison of technology application approaches for Midsize SUV



- 2016 Redesign adds:
  - CEGR1, EPS, IACC1&2, Aero1, Roll1
- 2020 Refresh adds:
  - Roll2, LDB
- 2024 Redesign adds:
  - SS12V, MR2&3, Aero2