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Novel Large Scale Simulation Process to Support DOT's CAFE Modeling System

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Introduction

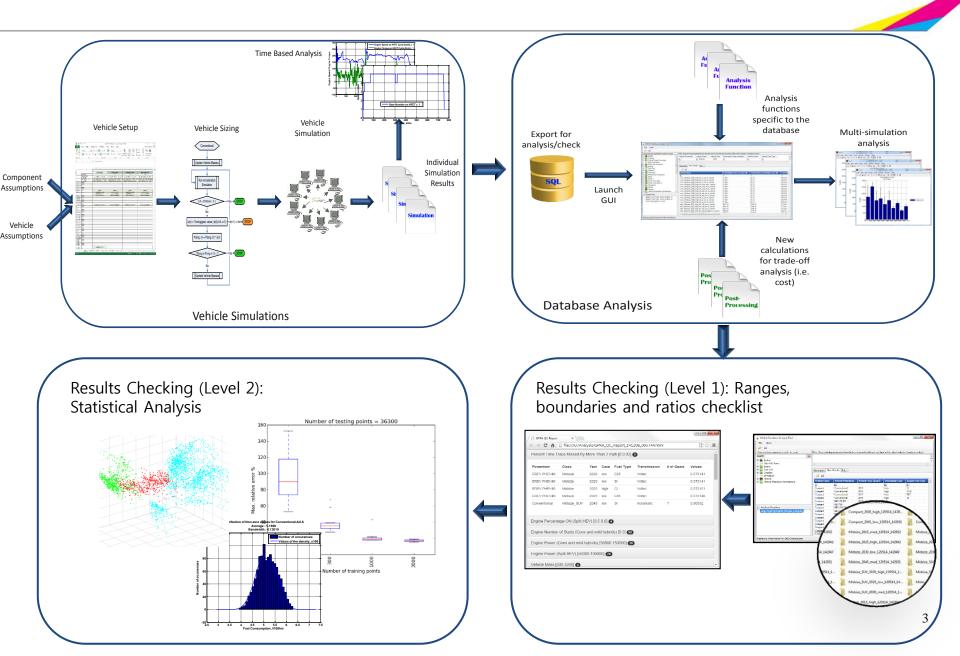
• DOT, NHTSA and EPA together issued a rulemaking to establish CAFE for MY2017-2021 and made use of the CAFE Compliance and Effects Modeling System. The Volpe model relies on numerous technology-related and economic inputs.

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- ANL works with DOT/Volpe to feed the CAFE model with vehicle energy consumption and component performance (i.e., power, energy...).
- ANL perform full vehicle simulation runs using Autonomie.

Simulate hundreds of thousands of vehicles to model anticipated future vehicle technologies. Develop Large-Scale Simulation Process to accelerate and facilitate the assessment of individual technological impacts on vehicle energy consumption

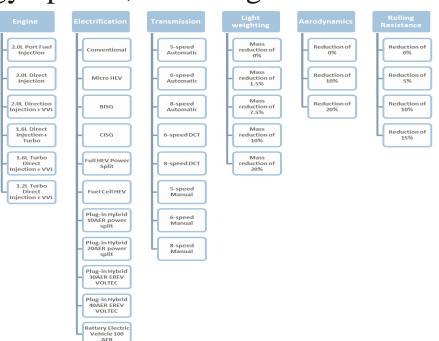
Overall Process Overview



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How Many Technology Combinations?

- The Volpe model currently relies on multiple decision trees to represent component technology options, including:
 - Engine
 - Powertrain electrification
 - Transmission
 - Light-weighting
 - Aerodynamics
 - Rolling resistance



• The objective is to provide an efficient tool to perform individual vehicle simulations representing every combination of vehicle classes, powertrain, and component technologies.

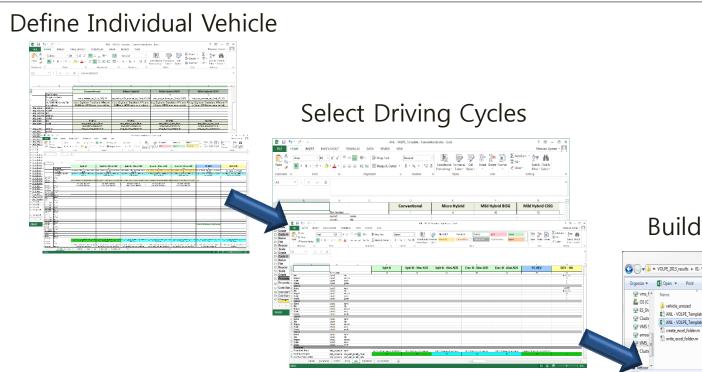
EVS 28 Technology for Humans The current list includes:

- 5 vehicle classes (Compact, Midsize, Small SUV, Midsize SUV, Pickup);
- 17 engine technologies;
- 11 electrification levels, comprising 4 no- or low-electrific ation levels (conventional vehicle is equivalent to no-electr ification level) and 7 levels of hybridization;
- 8 transmission technologies (applied to no/low-electrificati on-level vehicles only);
- 5 light-weighting levels;
- 4 rolling-resistance levels; and
- 3 aerodynamic levels.

> 150,000 vehicle combinations

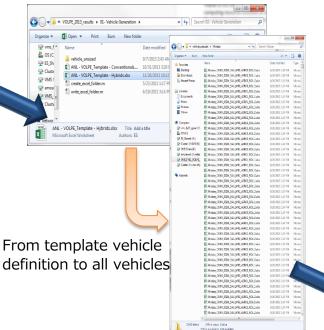
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Vehicle Simulation Process (1/2)

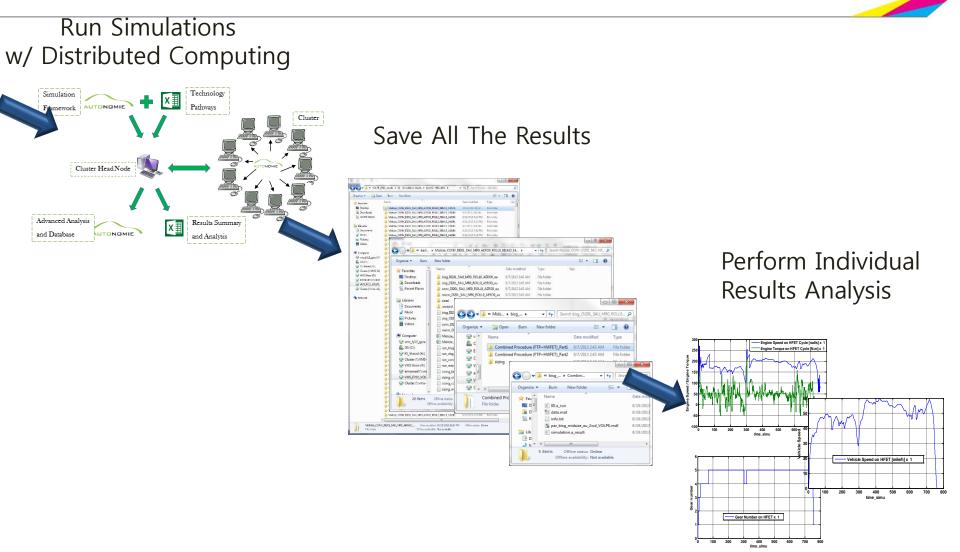


- Define vehicle configurations, component models, initialization files, preprocessing files....
- Define component performance data (e.g., power, mass, final drive ratio, aero, etc...).
- Define control (Force EV mode, engine turn on thresholds, shifting parameters, etc...)
- Select sizing rule to run the vehicle performance test.
- Select drive cycles and standard procedures to be run.

Build Each Vehicle



Vehicle Simulation Process (2/2)



EVS 28 rechnology for Humans <u>Challenge</u>: Manually analyzing very large number of data sets has proven cumbersome, error prone and very time consuming

- Autonomie has numerous post-processing tools, but they focus on individual vehicles analysis
- For large datasets, the requirements are different
 - Managing lots and lots of data (number of files, disk size, access time, etc.)
 - Looking at high level indicators and spotting overall trends
 - Performing post-processing calculations without rerunning all of the vehicles
- Autonomie's normal output files are unnecessarily cumbersome for this sort of large scale data manipulation

<u>Solution:</u> Leverage Autonomie structure to develop a new post-processing process centered around large data set analysis

Database Generation

- A new process was developed to generate a targeted database containing information from a very large number of Autonomie results
- The inputs are:
 - A folder containing all of the Autonomie result files. Example study (296 GB of data, 7,503 .a_result files)
 - An XML file that list the parameters to include into the database
- The output is an optimized database containing only the requested information. Example study (30.4 MB of data, 27 min. to generate database)
- New, targeted databases can be created with any subset of any study.



Database Analysis (1/2)

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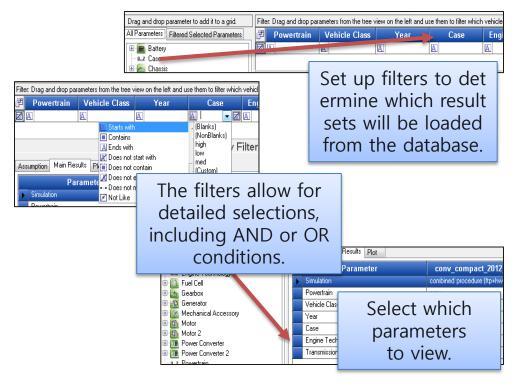
SQL Database Created Based on Selected List of Parameters

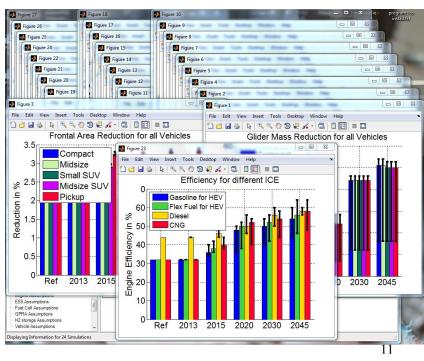


- •FTP Electrical Consumption
- •HFET Fuel Consumption
- HFET Electrical Consumption
- Combined Fuel Consumption
- Combined Electrical Consumption



Graphical User Interface Created to Check Simulation Results



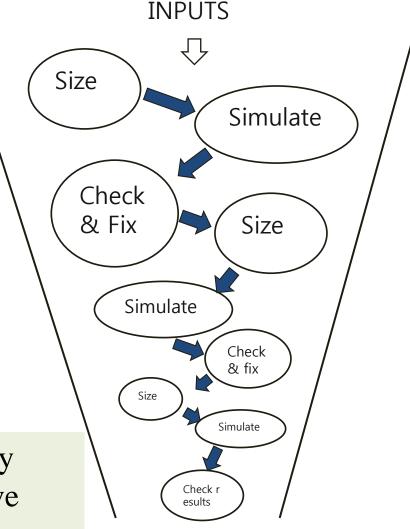


Automated Checking Process



- Hundreds of thousands of vehicles are simulated
- Due to the large number of results, this could lead to
 - Increased number of iterations.
 - Erroneous results propagating to further steps of the study.
 - Delays in generating results.

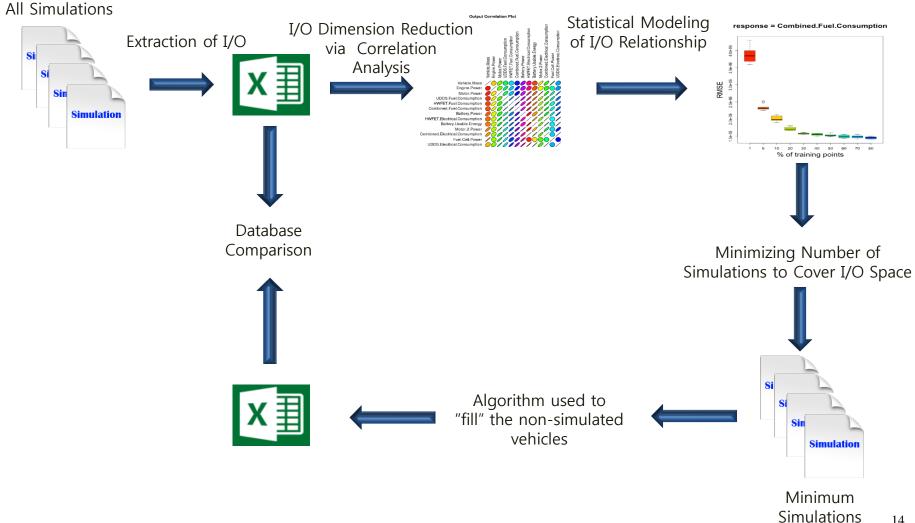
Automated checking process can greatly reduce simulation iterations and improve quality of results.



Automated Checking Leverages Database Generation Process Used for Large Scale Simulation

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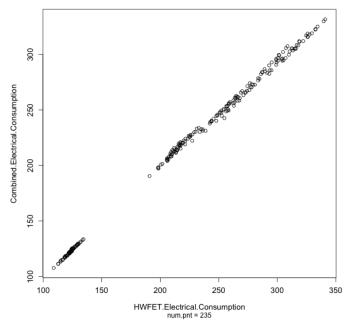
Simulation Reduction through Statistical Analy



Partitioning and Selection/Reduction of Outputs^{vs}²⁸

- Partition input space:
 - Within each partition, the same sets of outputs are desired/valid
- Within each partition:
 - Determine (e.g., by evaluating a space-filling design) which outputs are linearly correlated
 - This defines a minimal set of outputs that should be modeled within each partition

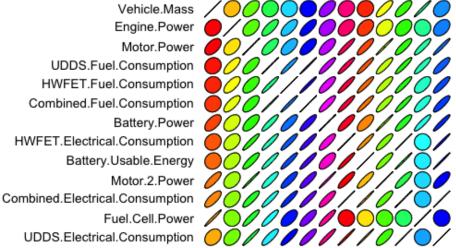
HWFET.Electrical.Consumption Vs. Combined.Electrical.Consumption ; corr=1



Ex.- All pairwise correlations

Output Correlation Plot

Vehicle.Mass Engine.Power Motor.Power UDDS.Fuel.Consumption HWFET.Fuel.Consumption Battery.Power HWFET.Electrical.Consumption Battery.Usable.Energy Motor.2.Power Combined.Electrical.Consumption Fuel.Cell.Power UDDS.Electrical.Consumption

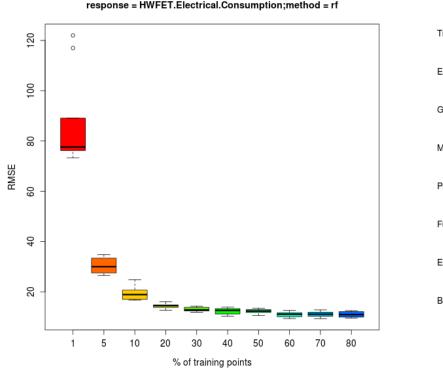


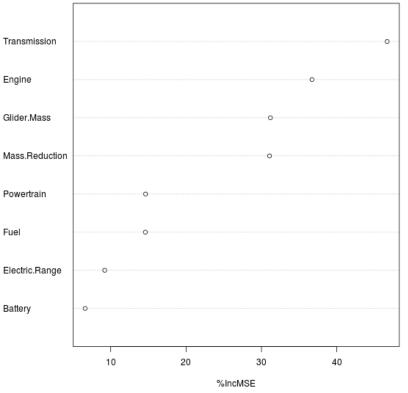
Active Learning/Sequential Design

- Initial space-filling design evaluation
- Determine additional vehicles for evaluation
 - Based on the uncertainty associated with their current prediction for each output
 - Based on potential to reduce overall uncertainty
- Goal: Evaluate the minimum number of vehicles

Ex.- Input importance analysis for the output **Engine Power**



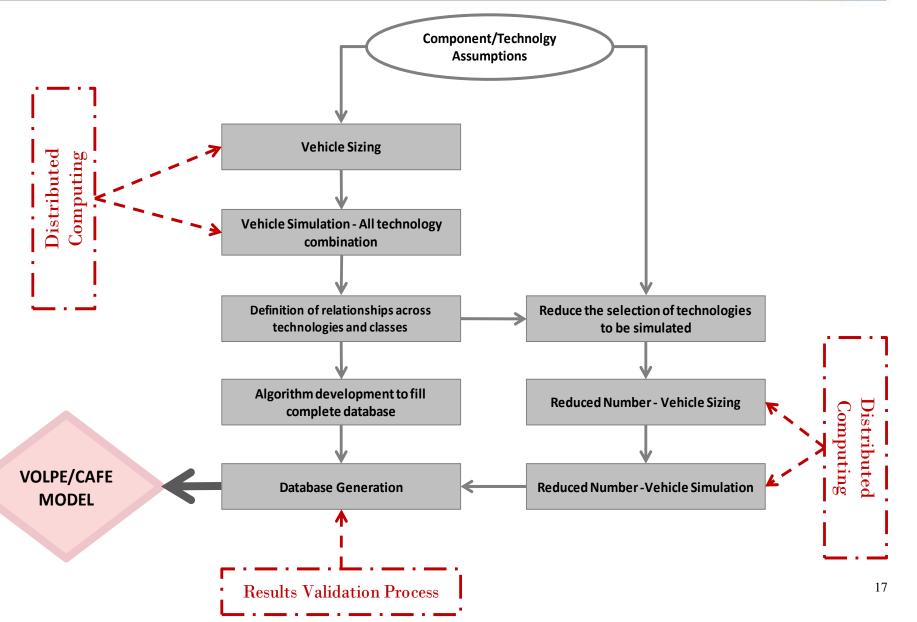






Conclusion Final Process Overview





Conclusion

- EVS 28 Forking
- A large Scale Simulation Process has been developed to help support CAFE.
- The process efficiently simulates hundreds of thousands of vehicles to model future vehicle technologies
- Three vehicle classes have been completed do far (>100,000 individual vehicles or more than **half a million of simulations** incl. sizing iterative algorithms and standard procedure runs).
- A statistical model has been established in ordered to find relationships and reduce future number of simulations.
- The process could be leveraged by any companies to evaluate the cost/benefit analysis of future technologies.



Thank you

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Contact / Website

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