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Fuel consumption prediction and validation using real-world cycle data and OEM vehicle data

S. Kamguia Simeu, R.Vijayagopal, A. Rousseau

Argonne National Laboratory, 9700 S Cass Ave, Lemont, IL, USA

Abstract

The light-duty passenger vehicles modelling has created substantial concerns due to the uncertainty from real-world operating conditions when it comes to fuel consumption analysis. Obtaining the right kind of data for vehicle modelling can in itself be challenging, given that while OEMs advertise the power and torque capability of their engines, the efficiency data for the components or the control algorithms are usually not available for independent verification. Therefore, the accuracy of a vehicle model defined only by high-level public data might not be good. A relevant and trustworthy OEMs vehicles database attribute would be the key to proper independent verifications of vehicle capabilities and validations of modern-day simulation tools.

By combining the publicly available OEM's data with some vehicle data fleet on real-world cycles and different baseline vehicle models generated, this paper examines the level of accuracy on fuel consumption prediction that can be achieved by such a model. The baseline vehicle models used are generated using Autonomie [1], a simulation tool developed by Argonne National Laboratory capable of simulating various kinds of vehicles. The paper will further provide an analysis of the potential best approach - as well as the accuracy level associated - for the modelling procedure and fuel consumption prediction according to data available.

1 Introduction

Several studies have been carried out using simulation tools to evaluate the impact of vehicle technologies under real-world conditions. All these were conducted using models that were verified with test data from dynamometers. As part of the other projects sponsored by DOE, University of Michigan has collected a large amount of data from instrumented vehicles under real-world driving conditions. This project utilizes that data to verify the accuracy of simulation models. This effort helps to define levels of confidence in the simulation results involving real-world driving conditions. Past studies have shown that vehicle energy consumption can be accurately predicted on standard cycles with validated models if the vehicle model is built using sufficient data collected from dynamometer tests [2][3]. However many times, modellers are faced with the challenge of building vehicle models using standard library components and scaling them to the power rating needed in a vehicle.

The first step in this study has been to generate vehicle models by sizing the baseline vehicle models on Autonomie using available OEM's data and to compare the simulated vehicle energy consumption with published data on standard driving cycles in order to validate the vehicle model generated. The models created were then used to predict fuel consumption in real world cycles scenarios, and results were validated by a comparison of the simulated vehicle energy consumption with real world measurements. However, the data collected from real-world drivers are usually full of mistake and inconsistencies. One of the main challenges in the study is to include an automated procedure of querying, collecting and processing the data from vehicle test fleet on real-world cycles.

2 Approach & methodology

The inputs provided by the University of Michigan was used as the on-road referral data for our models comparison and the validation of the real word driving cycle fuel consumption: total 93027 trips recorded for 369 vehicles.
Many on-road cycles came with various issues. So, before referring to those data, we needed to (1) identify, list and fix (if necessary) data issues, (2) filter out unrealistic or unfixable cycles, (3) convert on-road driving cycle data into Autonomie format and (4) add leading and trailing sections, where necessary.
Basically, we have created specific vehicle models (e.g., model year 2015 Honda Civic Lx) based on vehicle technology database, compared the model predictions against EPA regulatory cycles then developed a process to import University of Michigan's test data. Lastly, we have calibrated models to match the vehicles used by University of Michigan (UofM).

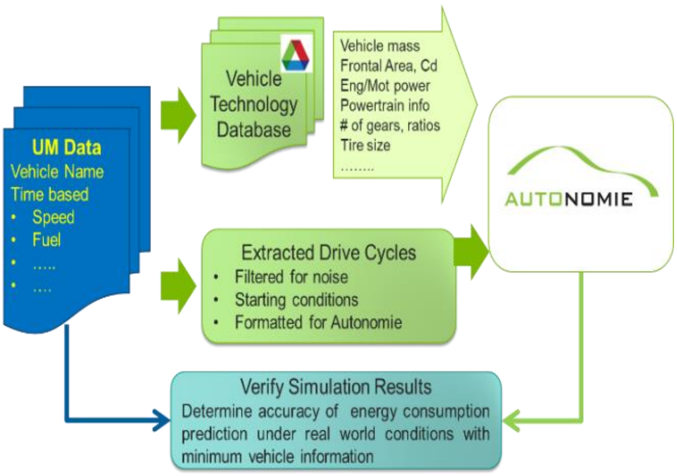

Figure 1: Approach overview procedure

2.1 Vehicle attributes

Generic engine maps (mostly IEV engines) and pre-set vehicle parameters, i.e., transmission parameters and road load assumptions, were generated with Autonomie to reflect different classifications of vehicles and will be used as the baseline models. To create these baseline vehicle models for the procedure, each vehicle is sized to meet the same vehicle technical specifications, such as performance and grade-ability [4]. The vehicles used for this study are the conventional and hybrid electrified vehicles (HEVs), through different timeframes (from 2010 to 2017) for gasoline and diesel fuels. The vehicle fleet used for this project has been selected to overall represent the most used vehicles used in U.S.

2.2 Data collection

Some OEM vehicles information were collected according to the data publicly available. The data usually required but not necessarily accessible included:

- Manufacturer, brand, model, vehicle weight and design year;
- Road load assumptions such as the wheels characteristics and the Road Load coefficients;
- Transmission parameters such as the transmission type and architecture, the engine/battery type and characteristics, and the gearbox ratios;
- Fuel Economy on cycles.

2.3 Building vehicle models using OEM data

2.3.1 Methodology

The first approach to build a vehicle model, as the figure 2 shows, was to combine actual OEM referral vehicle data and the baseline vehicle models to come out with the matching vehicle models. Then we compared the fuel consumption on similar cycle as a first validation method for the models built.

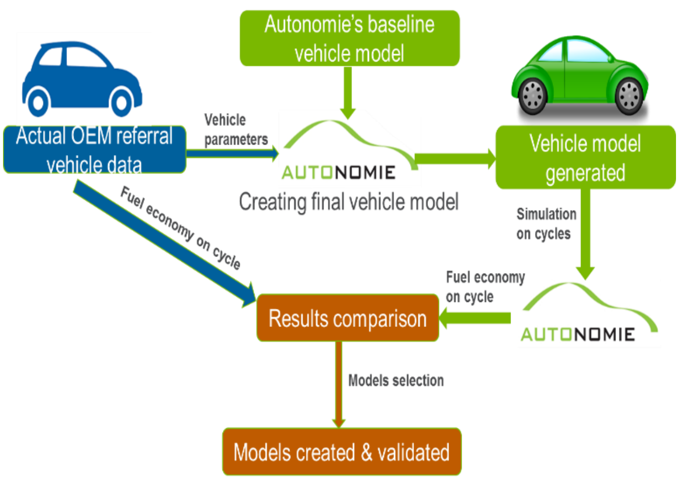

Figure 2: Methodology to create and validate models

2.3.2 Example of the 2015 Honda Civic Lx

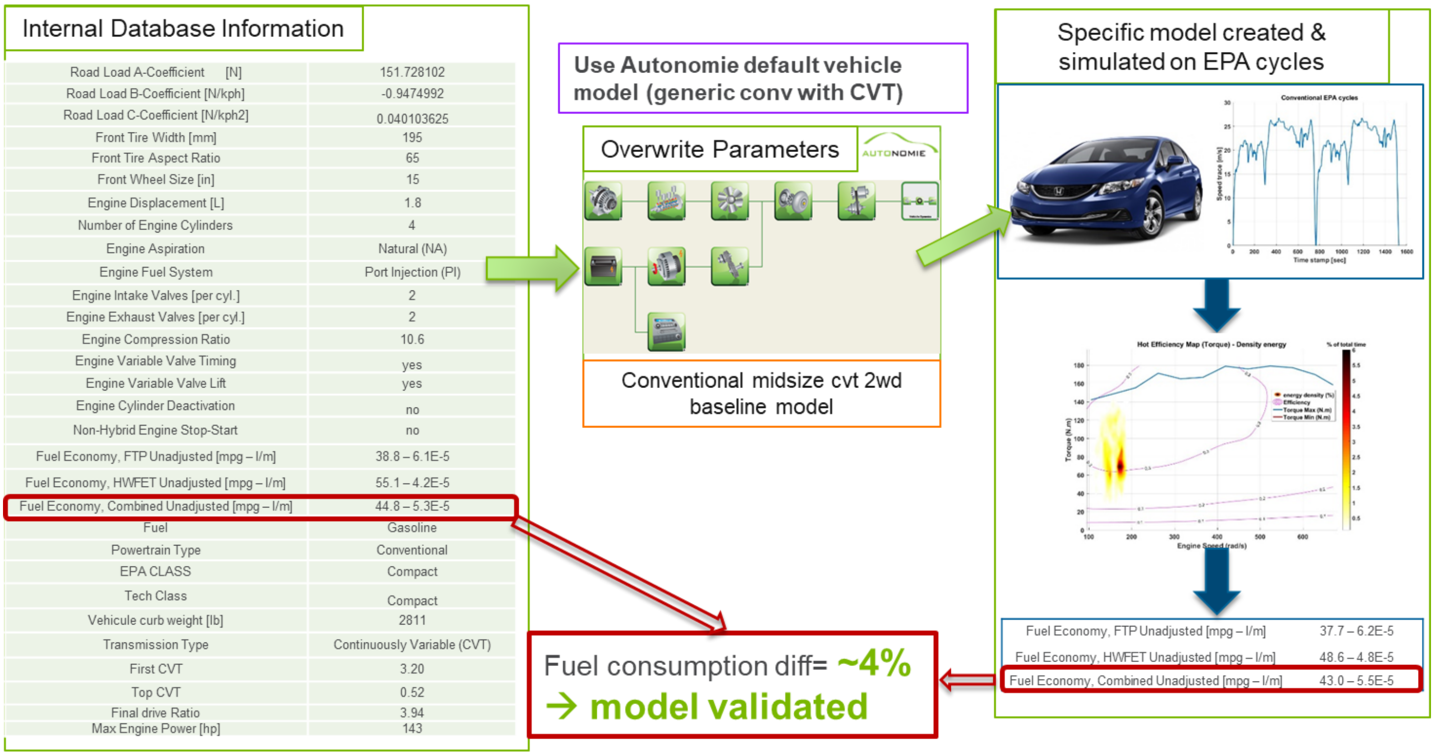

Figure 3: Autonomie's vehicle model development & comparison process on-road data

2.3.3 Data collection and available information

For the data acquisition on the vehicle, the University of Chicago used the On-Board Diagnostics (OBD) sensor. A total of 93,027 trips were recorded for approximately 369 vehicles: 352 conventional and hybrid electrical vehicles and, 17 plug-in electrical vehicles.

Table 1: University of Michigan vehicles testing fleet

Powertrain	Number of vehicles(07/27/17)
ICE & HEV	352 (95.4%)
PEV	17 (15 PHEV, 2 EV) 4.6%
T0TAL	369

2.3.4 On-road driving cycle cleaning

Firstly, the data was to be made usable for driving cycles knowing that the data collected from real-world drivers are usually full of mistakes and inconsistencies. Therefore, we started by identifying, listing and fixing common inconsistencies that occurred during the data acquisition. Those usually found on the cycle include:

- Random time stamp;
- First and last vehicle speed different from zero on the cycle;
- Random vehicle speed dropping;
- Lake of data during a certain timeframe;
- Inconsistent distance travelled during the cycle.

Figure 4 shows an example of the vehicle speed trace on cycle with the inconsistencies associated

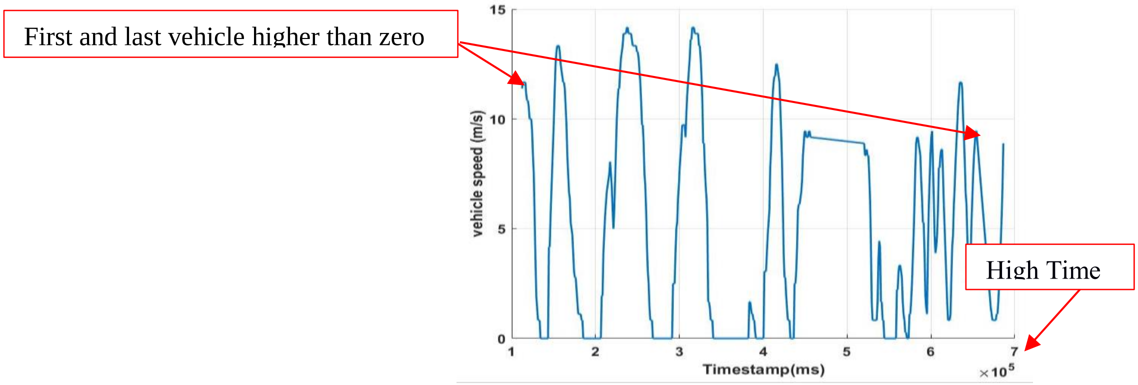

Figure4: Untreated vehicle speed trace on a real-world cycle

Regarding the first (and last) speed problems for instance, it was assumed that during the first (last) 20 seconds, the vehicle has a constant acceleration (deceleration) grade, as displayed in the figure 4. This assumption helps to waive a potential speed transitory period that appears when the vehicle speed reaches the real starting speed, corresponding to the beginning of the actual driving cycle.

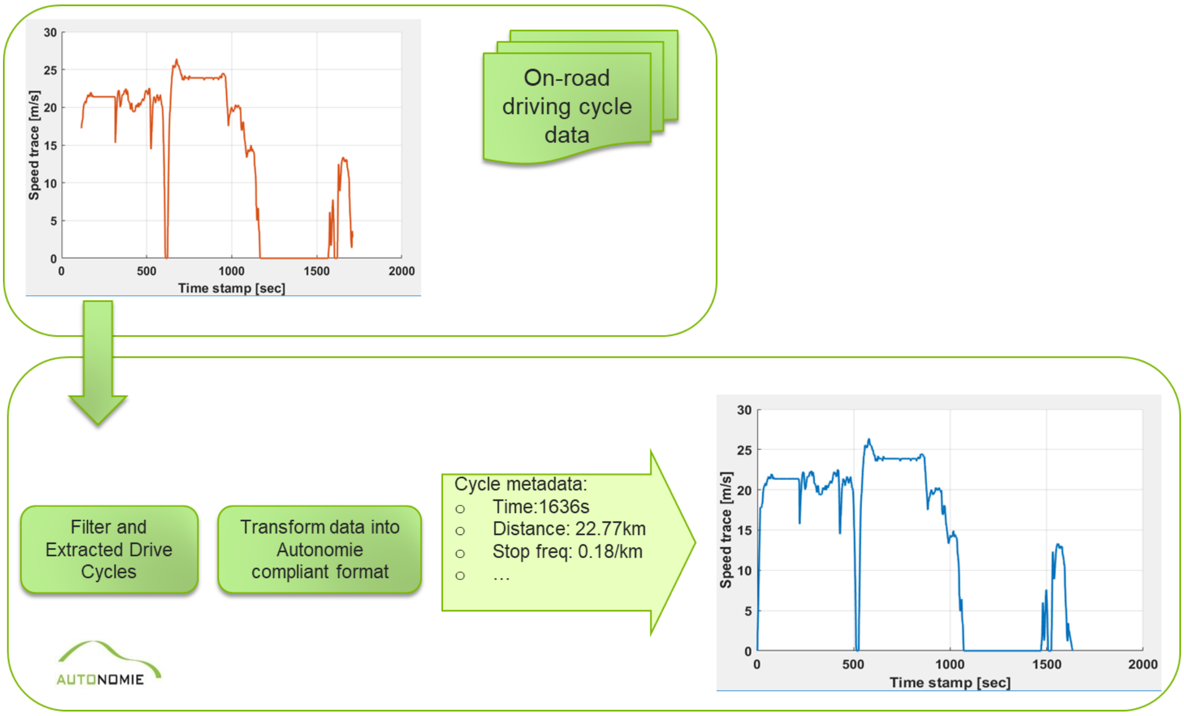

Figure 5: Process to clean extract a vehicle speed trace on real-world cycle

3 Project results

3.1 Vehicle modelling

During this study, over 200 vehicles from model year 2011 to model year 2018, have been considered, so far, to match the UofM’s vehicles fleet provided. That includes 143 conventional vehicles, 52 HEVs, 13 PHEVs and 2 EVs.

The figures 6 and 7 show the density distribution of the vehicle fleet modeled, using the methodology described on the part 2.3. The following charts only consider the conventional vehicles and the hybrid electrical vehicles (HEV).

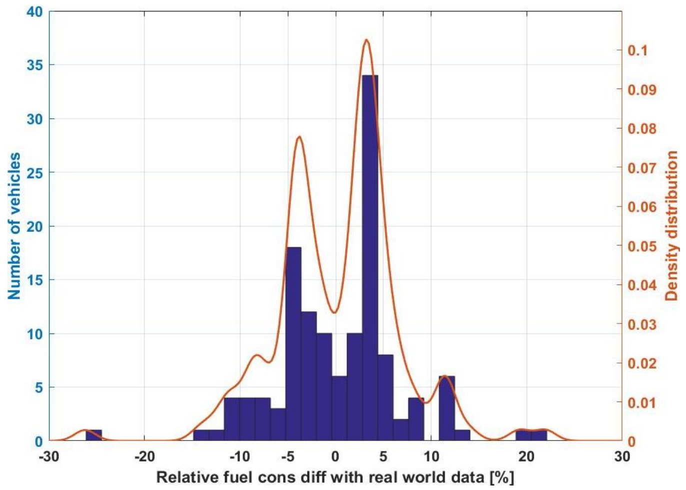

Figure 6: vehicles fleet histogram distribution according to the relative fuel consumption difference with public EPA vehicle information

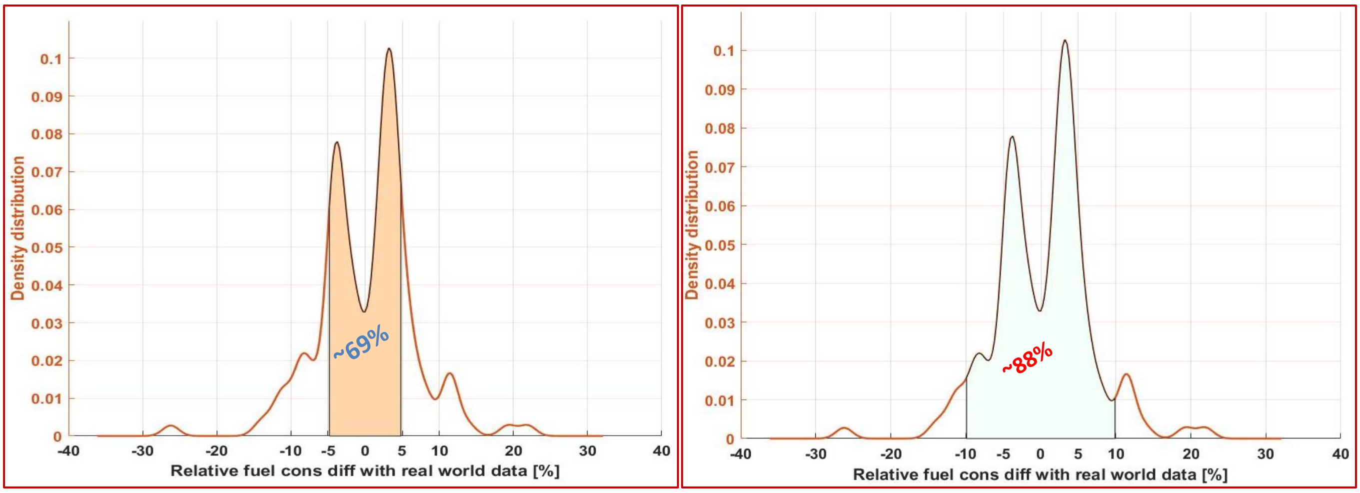

Figure 7: vehicles fleet density distribution according to the relative fuel consumption difference with public EPA vehicle information

The figure 7 shows that around 88% of the conventional and hybrid electrical vehicles modeled have been validated on EPA regulatory cycles with a fuel consumption difference less than 10%.

3.2 Case study of a conventional: 2017 Mazda3

For this case study, we assumed 600W for the accessories load during the cycle simulation. This value represent the U.S drivers average accessories energy consumption.

Table 2: 2017 Mazda3 characteristics

	Unit	Value
Model Year	-	2017
Vehicle type	-	Conventional
EPA class	-	Compact
MSRP	$	25475
EPA FE (city/hwy)	MPG	26/35
0-60mph	s	8.1
Curb weight	kg	1361
Powertrain architecture	-	ICE
Engine	-	2.5L, 184hp
Engine tech.	-	Chain-driven dual overhead cams, 4 valves per cylinder with variable intake valve timing (VVT)
Net power	hp	184
Transmission	-	Planetary Automatic
Final drive	-	3.59
C_d	-	0.31
Frontal area	m^2	2.24
Autonomie model accuracy	**%**	**1.6**

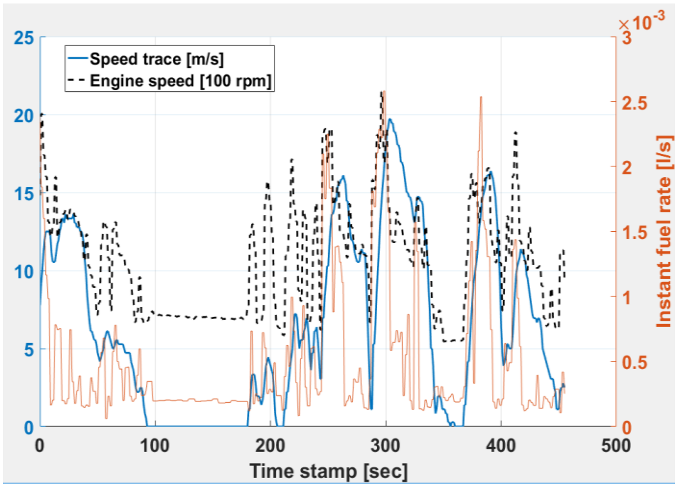

Figure 5: Real world data for a cycle

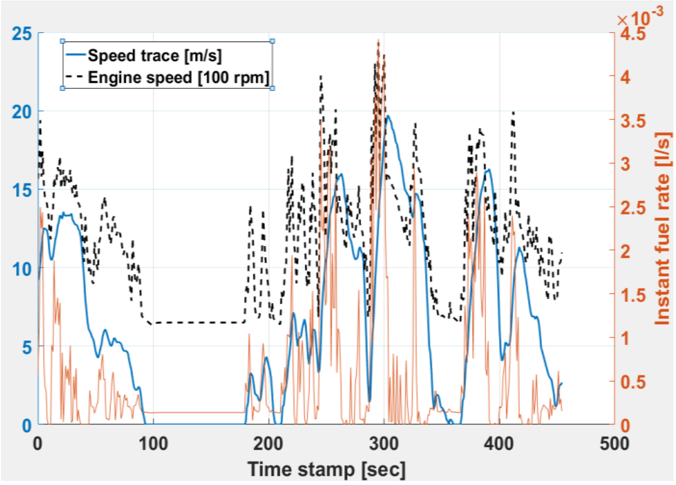

Figure 6: Autonomie results for a cycle

Table 3: Autonomie models accuracy on four real world cycles

	Distance [km]	Real world fuel consumption [l/100km]	Autonomie fuel consumption [l/100km]	**Fuel consumption difference [%]**	Real world fuel economy [mpg]	Autonomie fuel economy [mpg]
Cycle 1	7.3	7.4	6.8	**8.5%**	31.9	34.7
Cycle 2	2.9	8.0	8.4	**4.3%**	29.3	27.9
Cycle 3	3.3	8.1	8.0	**0.8%**	29.2	29.2
Cycle 4	4.2	6.1	6.9	**13.6%**	38.9	34.0

There is a large uncertainty variation across cycles, which need additional data analysis. Indeed Autonomie's models only represent operation under ambient conditions (i.e., 72F with warmed up engine) and the test data does not provide information on several important parameters such as the vehicle accessory load (i.e., A/C, heat…) or the initial state of charge (SOC), for the electrified cars.

Conclusions

In this study, vehicles considered so far (for the manufacturing years from 2011 to 2018) include 143 conventional vehicles, 52 HEVs, 13 PHEVs and 2 EVs. The vast majority of vehicles show <10% fuel economy uncertainty on the standard driving cycles. Therefore, we can attest a good level of confidence on the methodology used and the results obtained. However, Autonomie's models only represent operation under ambient conditions (i.e., 72F with warmed up engine). Because of that, the lack of information on several important parameters (i.e. vehicle accessory load, outside temperature, Initial SOC) can explain the wider prediction uncertainties in certain cases. For the future data collection efforts funded by DOE, we would request the inclusion of more parameters that would help in calibrating Autonomie models.

Contact Information

Severin KAMGUIA SIMEU
Vehicle Modeling & Control Engineer
Argonne National Laboratory
kamguiasimeu@anl.gov
Work: +1 (630)-252-7416

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Authors

Severin Kamguia Simeu is a research and modelling engineer at Argonne National Laboratory. He works in the area of modelling and simulation to evaluate the fuel and energy consumption impact of advanced vehicle technologies**.** He received his engineering degree in mechatronic from ENSEA in France in 2015 and a Master's degree in hybrid powertrain engineering from IFPEN in France in 2015.

Ram Vijayagopal is a research engineer at Argonne National Laboratory. He works in the area of modelling and simulation to evaluate the fuel and energy consumption impact of advanced vehicle technologies**.** He received his Bachelor degree in engineering from University of Kerala in 2000 and MS in engineering from University of Michigan in 2008.

Aymeric Rousseau is the Manager of the Vehicle Modelling and Simulation Section at Argonne National Laboratory. He received his engineering diploma at the Industrial System Engineering School in La Rochelle, France, in 1997. After working for PSA Peugeot Citroen in the Hybrid Electric Vehicle Research Department, he joined Argonne National Laboratory in 1999, where he is now responsible for the development of Autonomie. He received an R&D 100 Award in 2004 and a 2010 Vehicle Technologies Program Award in 2010. He has authored more than 40 technical papers in the area of advanced vehicle technologies.