Editorial

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Biographical notes: Mihai Dorobantu is the Director of Technology Planning and Government Affairs, at the Eaton Vehicle Group. He is responsible for the front end of the innovation process, developing advanced technologies, and relationships with funding and regulatory agencies. Previously, he led the group's advanced R&D team and the Controls Department in Eaton's Innovation Center. Prior to Eaton, he was a Technology Leader at United Technologies Research Center, focusing on gas turbine and vapour compression systems. Before that, he was with Comsol AB, developing finite element simulation software. He received his PhD in Applied Mathematics from the Royal Institute of Technology and Stockholm University, Sweden.

For nearly two decades emissions regulations drove the commercial vehicle powertrain design, culminating with strict standards for criteria pollutants in the US (2010) and Europe (2014), and world-wide deployment of similar measures ongoing. The next two decades will likely be driven by green house gas (GHG) regulations that are addressing three interconnected trends: the increased awareness around CO_2 emissions and need to reduce their environmental impact, the increased cost of fuel in transportation and its drag on economic growth and global security, and expected growth of volume of goods moved in an increasingly more interconnected society.

The commercial vehicle CO_2 emissions are of particular concern as passenger car emissions are decreasing in the face of ever more stringent Corporate Average Fuel Economy (CAFE) and similar standards. We have seen recently regulators around the world focusing attention on GHG regulations for commercial vehicles as a means to reduce CO_2 emissions. The transportation industry is also more open to GHG regulations as there is direct economic value produced by reducing fuel consumption, or better stated, increasing freight efficiency. The year 2014 saw the introduction of GHG standards for commercial vehicles in the USA and Canada. The focus of the first phase of the Environmental Protection Agency (EPA) regulations was to achieve increased freight efficiency with existing technologies and set in place a new regulatory structure. As these objectives were achieved, the regulators are looking at more stringent Phase II standards that will drive new technologies in 2020 and beyond.

The purpose of this special issue is to examine some of the powertrain technologies that could support Phase II standards and also look at methods to quantify the impact of these technologies on vehicles. As we look into the future, we see a number of technology trends around the powertrain, as follows:

- Improved vehicle aerodynamics and rolling resistance, thus reducing vehicle load and demand for power.
- Increased powertrain efficiency, especially through engine downspeeding and reductions of fuel penalties during transients, while maintaining performance and comfort.
- Improved energy management through electrification across the vehicle, including various forms of hybridisation and waste heat recovery
- Increased system optimisation and driver support to use the powertrain based on information outside of the vehicle, such as electronic horizons and predictive methods.

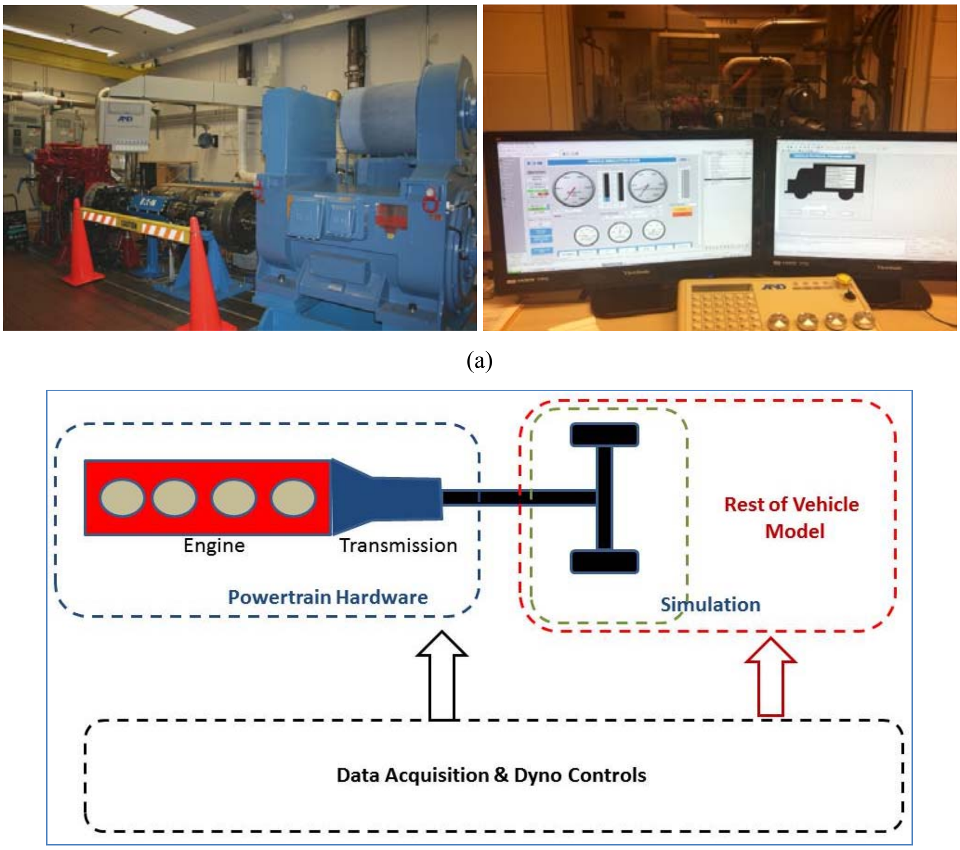
The industry is faced with the question of how to select technologies that achieve the more stringent standards in an economically viable fashion. Adding new technologies typically means adding initial costs, weight, and complexity (hence reliability issues). An opportunity to further improve efficiency without adding new hardware is to take advantage of integration and optimisation opportunities. Also, in the quest for better efficiency, the existing technologies are brought closer to their limits of performance. In this situation, transients and dynamic behaviour become the limiting factors. This opens significant opportunities based on managing transients through controls of deeply integrated and optimised powertrains.

Let us examine an example to illustrate the point. Diesel engines of line haul trucks become more fuel efficient as their speed decreases. However, at decreased engine speed there is a loss reserve power needed for small grades, which results in performance degradation: the powertrain has to shift gears more often. Taken to extreme, a general purpose transmission becomes a barrier to engine downspeeding. The opportunity is to look at engines and transmissions as an integrated and optimised system, choosing transmission shift strategies and engine transient fuelling strategies jointly and thus manage the performance and fuel penalties. These trade-offs do not exist in classical engine and transmission design, where the engine is assumed to have plenty of reserve power at cruise conditions and the transmission design objective might be to minimise the number of shifts. They do represent an opportunity to achieve enhanced fuel efficiency through advanced controls of an integrated and optimised powertrain. Furthermore, these techniques do not add significant hardware to trucks as the benefits are realised mostly in the control algorithms and the way the powertrain is run.

Deeply integrated and highly optimised powertrains raise two important issues from a regulatory perspective: What is the fuel efficiency entitlement of such technologies and what are reasonable testing procedures that quantify the benefits. The former is critical to setting standards stringency and understanding the cost impact of regulations. The latter is important because if the benefits are not correctly quantified, the regulations will steer the industry away from the best cost solutions and drive unnecessary cost, complexity and weight. Measuring the benefits of deep integration and system optimisation realised through advanced controls is difficult because these are not well represented with conventional methods: engine test data is typical steady-state and typically includes engine controllers but not transmissions controls. The alternatives are vehicle model-based computer simulations, but these lack the precision to include sophisticated engine and transmission controllers that are the key to the benefits. Recently, powertrain dynamometer test rigs have been developed on which the entire powertrain, including the real controllers, can be tested against drive cycles. These test rigs and procedures offer ways to quantify the GHG performance of deeply integrated and highly optimised powertrains.

Powertrain testing procedures are being developed at multiple locations, such as Oakridge National Lab, Southwest Research Institute, EPA and Eaton, as well as other truck manufacturers in the USA.

Figure 1 Powertrain dynamometer setup for GHG certification, (a) implementation at Eaton and (b) systems schematics (see online version for colours)



(a)

(b)

Figure 1 illustrates the powertrain test setup at Eaton, which is typical. The powertrain dynamometer is in fact a hardware-in-the-loop simulation of a vehicle, where the engine and transmission system (powertrain) is realised in hardware, including all controls. The rest of the vehicle (axle, wheels, weight, aero and rolling resistance, and driver) is simulated over given routes defined as speed or distance and grade over time. The powertrain interfaces a four-quadrant motor that can apply both positive and negative torque to the powertrain, shown in Figure 1(b).

The division of the vehicle simulation, into a powertrain system realised in hardware and the rest of the vehicle realised in physics-based models, fits naturally with the decomposition of the vehicle system into a ‘passive load’ and an ‘active source’: the passive component creates loads (e.g., vehicle weight, aero and rolling resistance, and road profile) and can be reliably modelled and simulated from first principles. The active component (powertrain) responds with power and torque to load demands, but it is a highly interconnected system involving dynamics over multiple timescales ranging from under a millisecond to several seconds. The active system is hard to model from first principles and model validation becomes a nearly impossible task. This description is applicable to both conventional and the vast majority of hybrid powertrains.

One can look at a powertrain dynamometer from two perspectives: first, it is remarkably similar to a chassis dynamometer. The main difference is that the wheels and axle are simulated in the dynamometer controls and the motor is directly connected to the transmission output shaft. Most important for commercial vehicles, since the number of powertrain combinations is very small compared to vehicle variations, a small number of powertrain tests generates accurate, repeatable and verifiable results applicable to a very large number of vehicles.

However, we can also look at powertrain dynamometers as extensions of engine dynamometers, where the motor is connected to a transmission output shaft rather than the engine flywheel, and the motor controls simulate a vehicle route, rather than the usual engine cycles. Physically, powertrain test rigs are extensions of engine dynamometers with small incremental capital costs, significantly less expensive than their chassis dynamometer counterparts.

From a regulatory perspective, it is important that the test procedures correctly quantify CO_2 emissions, are future proofed against new technologies, are repeatable and affordable. To illustrate the potential of powertrain testing, let us consider the following example with the fuel economy testing results shown in Table 1. Eaton and Cummins deeply integrated their ISX engine and ten-speed line haul transmission and introduced the powertrain under the SmartAdvantage brand. 3% to 6% fuel efficiency improvement over the baseline was reported based on fleet use. The two powertrains were tested on the powertrain dynamometer against potential regulatory drive cycles (65 and 55 mph with up to +/– 2% grade, and the ARB transient cycle). Results shown in Table 1 confirm the fleet reports, but with greater than 99% repeatability coefficient. It is significant to note that vehicle models such as GEM can only predict 1% improvement due to a faster axle that down-speeds the engine by approximately 100 rpm. The rest of the improvements are due to active controls shared between the engine and transmission as well as advanced lubrication strategies, which are not modelled in vehicle simulations, all of which are hard to simulate with validated models.

Table 1 Powertrain dynamometer results comparing SmartAdvantage and baseline powertrains: fuel consumed to complete cycles [kg]

Powertrain	*ARB*	*55 mph*	*65 mph*
Baseline	2.32	5.05	6.00
SmartAdvantage	2.02	5.07	5.79

Application	*Cycle weighting*	*Fuel reduction*
Line haul	86% 65 mph, 9% 55 mph, 5% ARB	3.4%
Mixed city/high speed	22% 65 mph, 28% 55 mph, 50% ARB	4.9%

Note: Fuel consumption [kg] measured against three drive cycles (top) and % fuel improvement across two different drive cycle weightings (bottom).

As powertrains become more integrated and more transient, and as they become hybridised, the modelling and model validation complexity increases and the powertrain-in-the-loop test becomes a simple verifiable, testable and repeatable procedure.

This special issue is a collection of industry papers describing advances in deeply integrated and highly optimised powertrains, focused at understanding how fuel efficiency and lower GHG is achieved and how it can be measured in a reliable fashion. The main theme is how to improve engine performance, primarily through engine downspeeding, while maintaining vehicle performance, and how that behaviour is quantified through powertrain tests. The collection of papers represent state-of-art developments at Eaton, Cummins and Southwest Research Institute.

While the topic of increased fuel efficiency is vast and there are several industry, academic and research institutes contributing, we believe that this collection of papers offers an understanding of how the major technology trends shape modern powertrain design and the methodologies around testing. We strived to select works that represent progress in radically new transmission technologies such as dual clutch transmissions, the effects of hybridisation as the vehicle aerodynamics change, the entitlement of predictive powertrain methods, and the benefits of integrating conventional engines and transmissions. We also tried to cover a large span of commercial vehicles, looking at powertrains in heavy duty line haul, medium duty city delivery and light duty applications. Papers discuss the potential of technologies around the engine and transmission such as hybrids, boosting or waste heat recovery and discuss the trade-off and limits of performance. Finally, some papers cover actual powertrain test implementation and results for both medium and heavy duty are presented, which is novel in the industry.