TRUCK TIRE AND REAL-LIFE FUEL CONSUMPTION

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Abstract

In Europe, the VECTO scheme was implemented in 2019 with first impacts on truck OEMs to come in 2025. It aims at monitoring, then reducing the CO2 emissions of trucks through financial penalties for OEMs if targets are not reached.

The tire rolling resistance coefficient (RRC) is a key parameter in truck fuel consumption reduction for fleets' cost efficiency and in the CO2 emissions reduction for global warming impact.

As the tire is a lever easy to activate to reduce the CO2 score, the truck OEMs are requesting tire manufacturers to provide lower RRC tire, but the first tires to equip a new vehicle are specified by the fleet when purchasing a truck. Facts show that the low RRC tire are not selected by fleets since they know these tires have often a lower mileage and they are not able to precisely monitor the fuel gains through RRC effects.

This leads to the well-known antagonism of low RRC tire requested by truck OEMs and not by fleets, as shown by the vehicle set monitoring enabled by VECTO database.

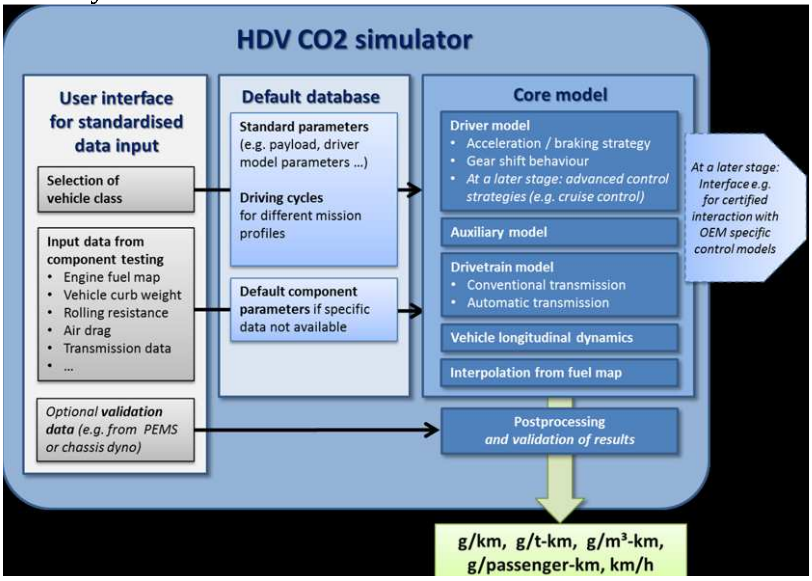
Tire manufacturers are working actively to reconciliate these two expectations of low RRC and improved mileage, but it is theoretically proven that the LCA and TCO of trucks are better improved with low RRC tires than with high mileage tires. Then there is a need to make the fuel gains with low RRC tires more visible for fleets to better convince them.

Michelin has been working for a while on the understanding of RRC impact on truck fuel consumption, and this paper shares a methodology of fuel consumption decomposition on real life CAN bus data to extract the effect of RRC and enable a fair comparison of fuel consumption of two trucks with different tires or of two trips with the same truck and different RRC tires. This study has been done on European and US tractor semi-trailer combinations and must be read in the continuity of the paper presented in HVTT16 and VDI 2021.

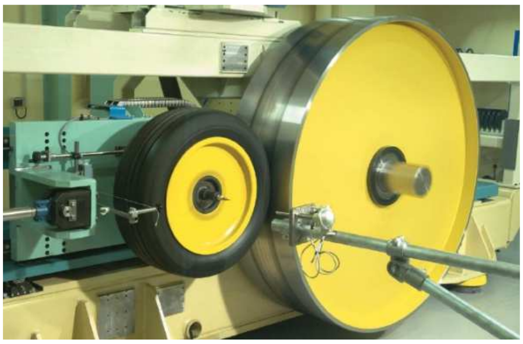
Keywords: tire, rolling resistance, real usage, Heavy Vehicles, CO2 emissions, fuel consumption.

1. VECTO scheme

In 2011, discussions with stakeholders started to set up a scheme reducing the CO2 emissions of trucks in Europe. It took some years to define the best method to monitor and declare the CO2 emissions of a truck sold on the market. As several bodies, gearboxes, engines, tires, etc. can be combined differently to build a truck, it has been advised to choose a simulation approach, finally defined, and coded by TU Graz.



Each component is measured by a standardized method, and test results are entry data to run a fuel consumption simulation. Vehicle categories (subgroups) and attached driving cycles/loading are used in the software to declare the CO2 emissions of each vehicle definition sold on the market. The software is called VECTO (Vehicle Energy Consumption calculation TOol). 9 parameters are considered for the calculation: Aero coefficient, Transmission, torque converters and other torque transmission components, additional powertrain devices, engine, axles, auxiliaries, and tires.

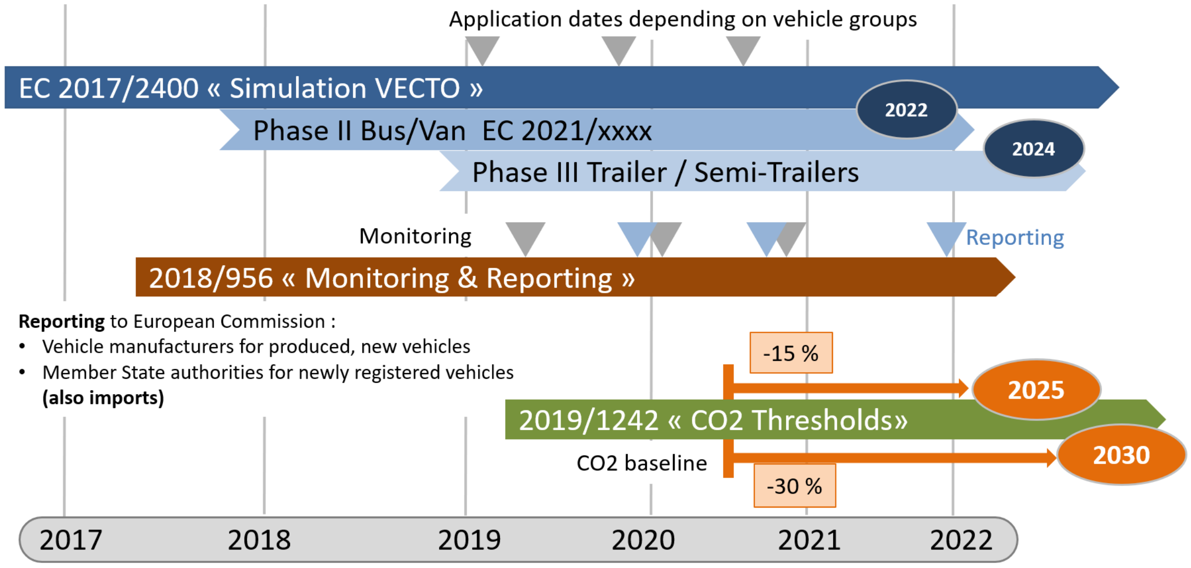


For example, tire RRC is measured according ISO 28580 which has already been described in paper HVTT16:

- Speed = 80kph
- Load = 85% of load index
- 3 hours warm up phase.
- Ambient temperature = 25°C
- Pressure = nominal pressure as per tire markings
- Smooth steel drum as opposite

The other components have their own measurement procedure to make fair comparison between simulations.

The European commission regulation VECTO EC 2017/2400 sets up the determination of the CO2 emissions and fuel consumption of heavy-duty vehicles with the following regulatory framework:



Additionally, European Union Regulation 2019/1242 forces Truck Makers to reduce CO2 emissions by 15% in 2025 and 30% in 2030 with regard to a 2019 baseline. As the 5-LH segment represents the highest volume of registrations and highest Mileage and Payload Weighting factor, main efforts are done on this subgroup to achieve the targets.
5-LH segment needs to decrease from 56,5 to 39 gCO2/t.km of CO2 emissions by 2030, a reduction of 17.5gCO2/t.km.


Average CO_2 performance per subgroup (Q3-Q4 2019)

	REGISTRATION SHARE	CONFIGURATION	GCW [ton]	ENGINE [KW]	CABIN	AVERAGE CO_2 [g/t.km]	PAYLOAD [ton]	ANNUAL MILEAGE [km]	ANNUAL CO2 [% OF TOTAL] EXL 4-UD
4-UD	0.4%	R 4x2	>16	<170	All		2.7	60,000	
4-RD	7.9%	R 4x2	>16	≥ 170 day cab ≥170 <265 sleeper cab	Day & sleeper	**198.1**	3.2	78,000	4,7%
4-LH	1.9%	R 4x2	>16	≥265	Sleeper	**102.9**	7.4	98,000	1,7%
5-RD	0.8%	T 4x2	>16	All day cab <265 sleeper cab	Day & sleeper	**84.0**	10.3	78,000	0,6%
5-LH	62.8%	T 4x2	>16	≥265 sleeper cab	Sleeper	**56.5**	13.8	116,000	68,2%
9-RD	7.2%	R 6x2			Day	**110.9**	6.3	73,000	4.4%
9-LH	9.2%	R 6x2			Sleeper	**64.7**	13.4	108,000	10.3
10-RD	0.1%	T 6x2			Day	**84.0**	10.3	68,000	0.1%
10-LH	9.7%	T 6x2			Sleeper	**58.6**	13.8	107,000	10.1%

ACEA March 2020

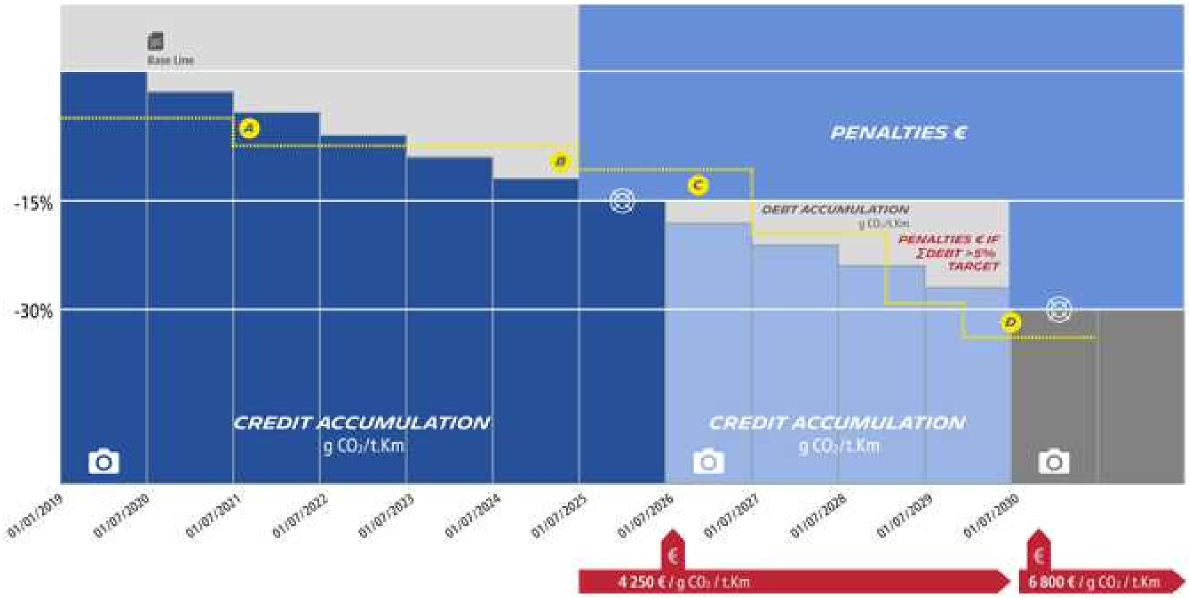
Mileage and Payload Weighting factor penalizing Long Haul Trucks

4-UD = 0.099
4-RD = 0.154
4-LH = 0.453
5-RD = 0.498
5-LH = **1.0**
9-RD = 0.286
9-LH = 0.901
10-RD = 0.434
10-LH = 0.922

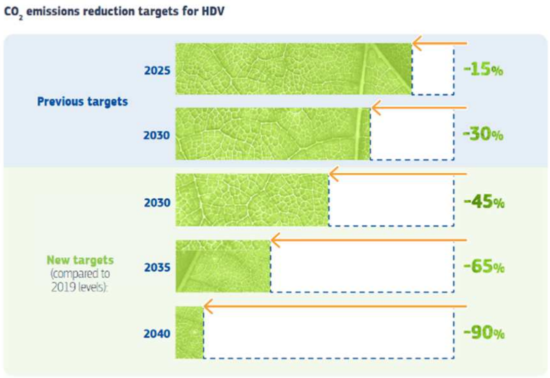
The weight of a 4x2 / SC / ≥ 265 kW is **10x more important** than a 4x2 rigid < 170 kW in the OEM's mix

This coefficient will give a "weight" to each vehicle for the Annual Average CO_2 emission of an OEM.

If the targets are not reached by truck manufacturers, a penalties schedule is defined:



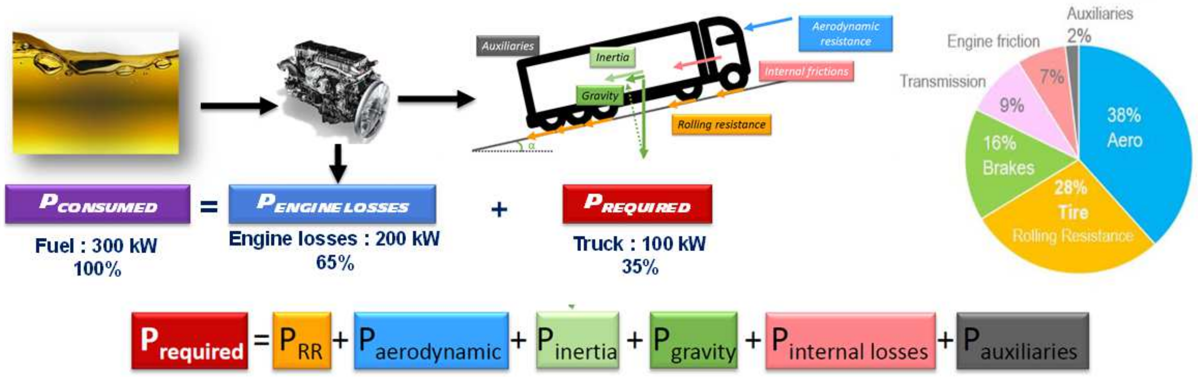
Very recently, the European Commission has proposed stronger new CO2 emission standards for these vehicles from 2030 onwards, and wants to extend the scope to smaller trucks, city buses, long-distance buses, and trailers. Heavy trailers and semitrailers will have new energy efficiency standards. This will cover almost all heavy-duty vehicles emissions.



2. RR contribution to CO2 emissions

The rolling resistance coefficient (RRC) is a means to define the energy dissipation by the tire that generates a resistive force. This phenomenon has been described in several reference papers listed below, especially in the last paper presented in HVTT16. Some reminders must be done here.

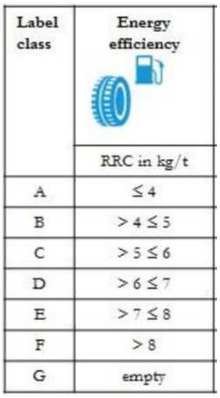
A tire is an element of the vehicle that addresses several technical antagonistic expectations for the overall truck efficiency. Basically, a tire needs to be flexible to endure deflection, to generate a contact patch under the carried load. This is necessary to enable the vehicle to be drivable by generating tire road forces. Therefore, the deflection of this rubber-based object dissipates energy which represents a significant part of the total fuel consumption of the truck. Several studies underline the importance of tire rolling resistance in the fuel consumption (FC) of a truck ; we can consider for a 40t tractor semi-trailer configuration that tires account for nearly 30% of fuel used at 80kph:



The fuel consumption is the result of several contributions each having a different impact depending on usage. For example, between 2 drivers/trucks, acceleration and load can differ, leading to different fuel consumption. It is thus highly difficult to compare the fuel consumption improvements brought about by tire rolling resistance reduction.

3. Trends on low rolling resistance tires adoption

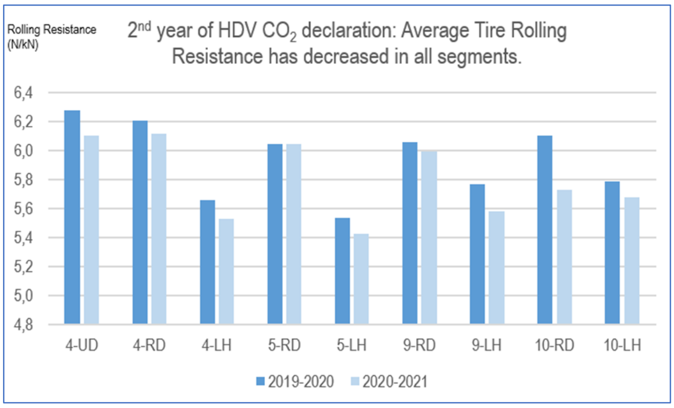
The Vecto scheme set up a monitoring period of 2019-2020 during which the truck manufacturers had to report the Vecto simulation result for each truck sold. This reporting period was needed to give the baseline for reduction targets for each OEM depending on their vehicle type portfolio. A second reporting period covering 2020-2021 is now available, and it is interesting to see how the tire RRC distribution has changed in one year. Tire RRC in the database are summarized in their RRC labelling class as on the right:



Label class	Energy efficiency RRC in kg/t
A	≤ 4
B	> 4 ≤ 5
C	> 5 ≤ 6
D	> 6 ≤ 7
E	> 7 ≤ 8
F	> 8
G	empty

With the engine, aerodynamic drag, transmission and axles, the tire is one of the five components used by the VECTO software to characterize a truck and declare its CO2 emissions to the European Commission. Air drag and tire rolling resistance are by far the two largest parts of dissipation among the usable energy produced by the engine.

Tire manufacturers and truck makers have collaborated to introduce new low rolling resistance technologies in the market. As shown in the figure below, significant rolling resistance improvements are visible as of the second year of OEM CO2 declarations. With the help of tire manufacturers, sales forces and field engineers, the truck OEMs started to change the fleets' tire ordering habits, but stronger change is needed to achieve the CO2 reduction targets defined by the Vecto scheme.



A focus on the biggest segment of the market (5-LH: >16 tons 4x2 tractor with sleeper cab and >265kW engine) shows the strong increase of the A label (best efficiency class) in the tire distribution between the first and the second years of declaration. This improvement is the fruit of new tire generation development by the tire manufacturers. It has also been possible thanks to the promotion of these low rolling resistance tires toward the fleets. Despite their lower mileage (compared to C or D label tires), and thanks to the fuel saving they allow, the low rolling resistance tires are providing a better truck cost of ownership.

RR LABELLING DISTRIBUTION

Vehicle Subgroup: 5-LH

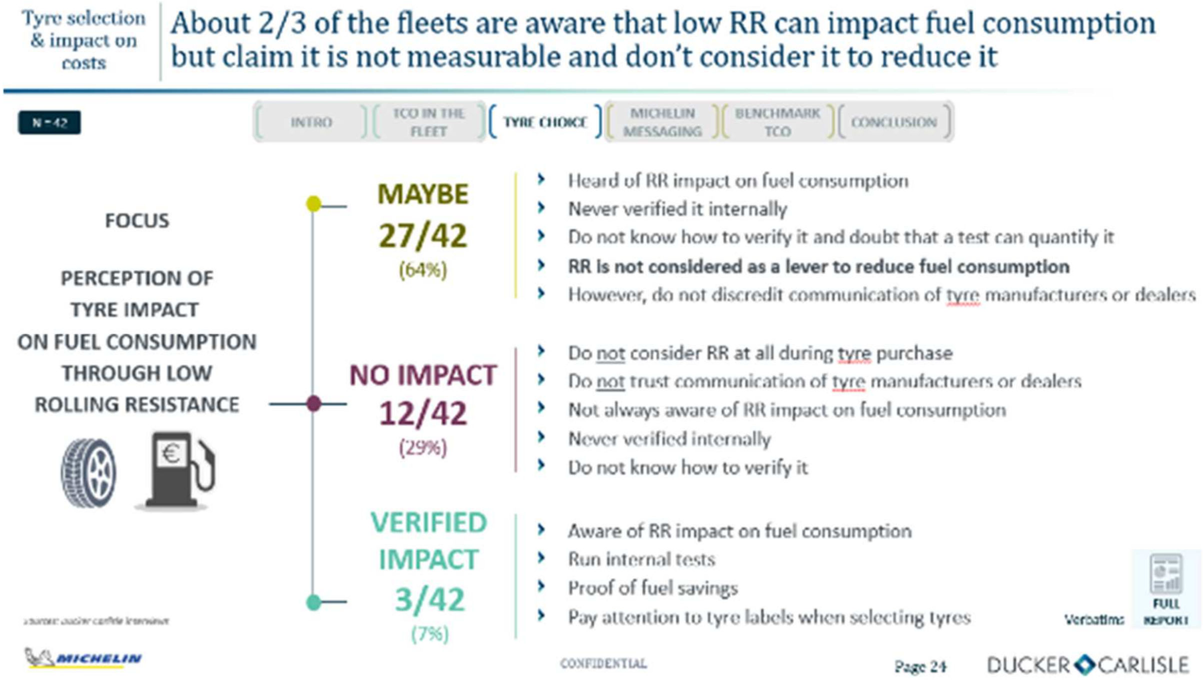
OEM: All

Country: All

4. Real life fuel consumption and rolling resistance coefficient reduction

The fuel consumption of a truck is highly dependent on usage parameters: load is not stable and the magnitude of dispersion can be high, the acceleration pedal usage is not the same between drivers, the elevation profile and the speed profile are dependent on the area where the truck operates. Then, when comparing fuel consumption in real life of a fleet due to a RRC change, there is a big risk to compare mainly the usage differences and not the pure effect of RRC. When a fleet tries to compare the fuel consumption with one tire set then with a second set with better RRC, it is even possible to see a higher fuel consumption due to usage changes.

It leads to a poor adoption of low RRC tires by fleets, as described in this study :



Tyre selection & impact on costs

About 2/3 of the fleets are aware that low RR can impact fuel consumption but claim it is not measurable and don't consider it to reduce it

N = 42

INTRO | TCO IN THE FLEET | TYRE CHOICE | MICHELIN MESSAGING | BENCHMARK TCO | CONCLUSION

FOCUS

PERCEPTION OF TYRE IMPACT ON FUEL CONSUMPTION THROUGH LOW ROLLING RESISTANCE

MAYBE
27/42
(64%)

- Heard of RR impact on fuel consumption
- Never verified it internally
- Do not know how to verify it and doubt that a test can quantify it
- **RR is not considered as a lever to reduce fuel consumption**
- However, do not discredit communication of tyre manufacturers or dealers

NO IMPACT
12/42
(29%)

- Do not consider RR at all during tyre purchase
- Do not trust communication of tyre manufacturers or dealers
- Not always aware of RR impact on fuel consumption
- Never verified internally
- Do not know how to verify it

VERIFIED IMPACT
3/42
(7%)

- Aware of RR impact on fuel consumption
- Run internal tests
- Proof of fuel savings
- Pay attention to tyre labels when selecting tyres

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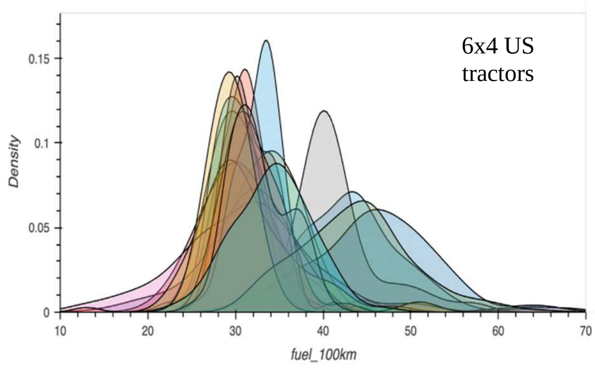
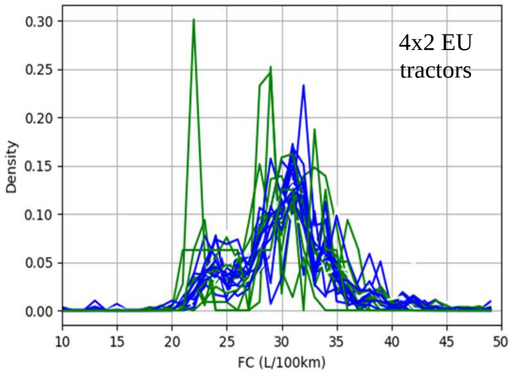
To better know this usage impact on fuel consumption dispersion, we have monitored several trucks with telematic boxes and inductive CAN readers. The time signals are cut in trips based on the ignition key on / off signal. We have analyzed the fuel consumption per trip expressed in L/100km :





The standard deviation of fuel consumption for these trucks is between 2.5 and 6L/100 km!

In more analytical conditions on European 4x2 tractor with a defined road and loading, and only season, driver, and traffic effects, we have measured a standard deviation of 0.7L/100km on 40 repetitions in one analytical test and 1L/100km in another one. This remains a very high dispersion with which a Tire Rolling Resistance effect on Fuel Consumption is too difficult to measure.

For a tractor-semi combination loaded at 40t, the fuel consumption gains with -1kg/t on 12 tires is expected to be 2L/100km.
Statistics theory says that 47 trips of 500km each (23 500km) per tire configuration would be needed to be able to sort 2 configurations on fuel consumption with α1% and β5%.

α risk is the risk that in a statistical test a null hypothesis will be rejected when it is true while β risk represents the probability that a false hypothesis in a statistical test is accepted as true.

During such a long test, tire wear will evolve leading to an evolution in RRC which further complicates an analytical comparison. Furthermore, customers are not ready to accept such a long comparison test. We must therefore find a new approach to demonstrate the fuel consumption gain by RRC reduction. The idea is to normalize the usage bias using truck usage data available on CAN bus, and then extract the part of fuel consumption due to tire rolling resistance only.

5. Real life fuel consumption split

The strategy is to tune some truck model coefficients to align a force model on the actual traction force available on the CAN bus.

The dynamic equation is:

$$(m_v + m_r) \cdot \frac{d}{dt} v(t) = F_t(t) - (F_a(t) + F_r(t) + F_g(t))$$

Where,

Aerodynamic force: $F_a(v) = \frac{1}{2} \cdot \rho_a \cdot A_f \cdot c_d \cdot v(t)^{\ 2}$

Tire rolling resistance force: $F_r(v) = c_{rr} \cdot m_v \cdot g$

Slope force: $F_g(\alpha) = m_v \cdot g \cdot \sin(\alpha)$

Inertia: $m_r = m_{r,w} + m_{r,e} \qquad m_{r,w} = \frac{1}{r_w^2} \cdot I_w \qquad m_{r,e} = \frac{\eta_{gb} \cdot \gamma(t)^2}{r_w^2} \cdot I_e$

Traction force: $F_t(t) = T_e(t) \cdot \gamma(t) \cdot \eta_{gb} \cdot r_w$

The usage data needed to split the various contributors to fuel consumption through this model are almost all available on the CAN BUS which is normalized in the truck domain with the J1939 standard:

- Vehicle speed is given be the wheel speed signal.
- For the load of the convoy, we use the Combination Vehicle Weight signal to define a first guess for the optimization.
- A GPS signal is also needed for local slope identification after map matching, done with the Here database.
- Actual gear ratio is also available on the CAN, and we use the wheel speeds to determine the drive axle ratio. Engine RPM is also used for the gearbox axles' speed calculation.
- Acceleration is better calculated by filtering and differentiating the wheel speed.
- The engine torque is calculated with the actual engine percent torque and friction percent torque.

We used the J1939 CAN bus signals as provided onboard to avoid an expensive new sensors fitment. Then, it is needed to filter, interpolate, and synchronize the signals. The calculation of an accurate acceleration signal is a complex topic and we have defined a specific spatial filter to remove noise in ABS speed signal without affecting the accuracy of signal when acceleration peaks occur. As GPS is not accurate for the local elevation, we moved to a map matching approach with local elevation from Digital Elevation Models on map matched path.

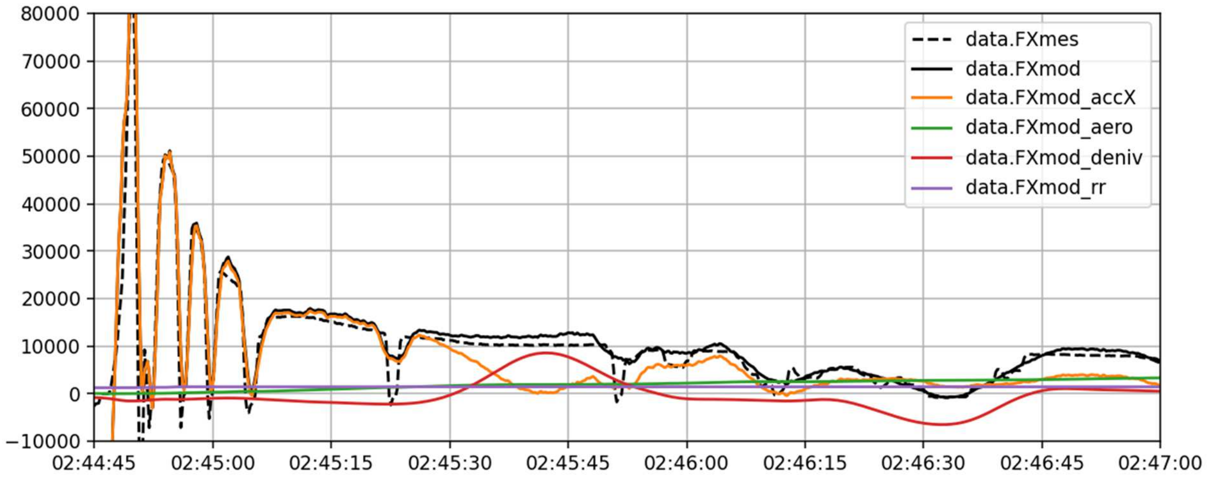
It is then possible to calculate the right part of the equation below and adjust unknown coefficients (🟩) to fit the actual traction force:

$$F_t(t) = \left(\frac{1}{r_w^2}\cdot I_w \frac{\eta_{gb}\cdot \gamma(t)^2}{r_w^2}\cdot I_e + m_r\right)\cdot \frac{d}{dt}v(t) + \frac{1}{2}\cdot \rho_a \cdot A_f \cdot c_d \cdot v(t)^{\,2} + c_{rr}\cdot m_v \cdot g + m_v \cdot g \cdot \sin(\alpha)$$

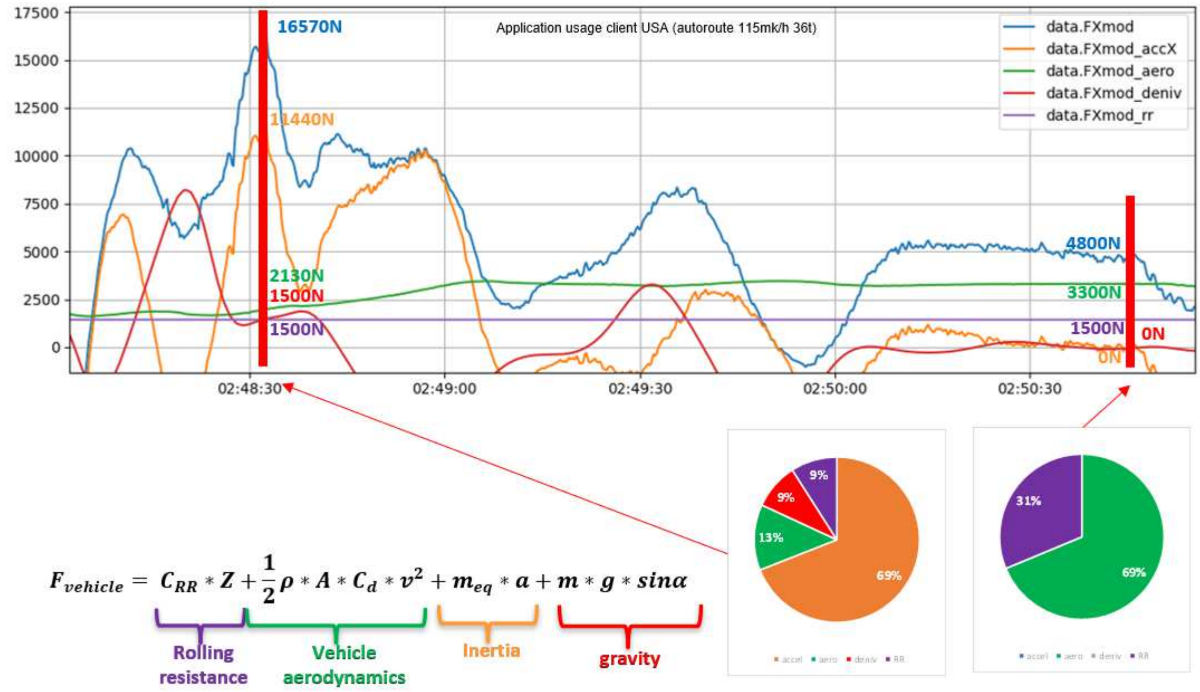
When a suitable fitting is obtained, the force per contribution is determined and the instantaneous fuel consumption is split between these contributors at each time step of the analyzed trip. The sum of each fuel consumption contributor time signal gives at the end the overall fuel consumption from:

- Rolling resistance
- Aerodynamics
- Inertia
- Gravity

The adjustment strategy still needs to be improved since several optima can be reached, not all of which are realistic:

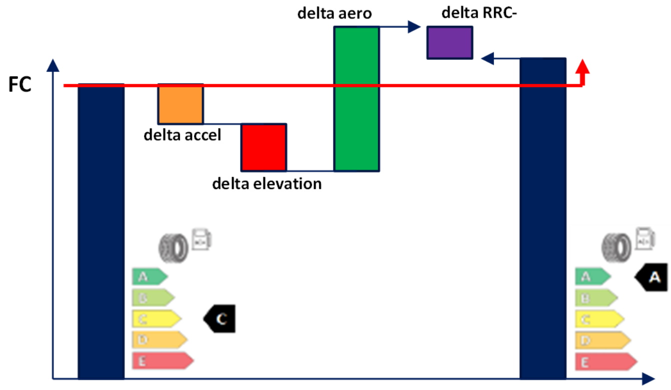


For each time step, we can decompose the force between each contributor and then decompose the instantaneous fuel consumption with this ratio to sum each fuel consumption contributor afterwards:



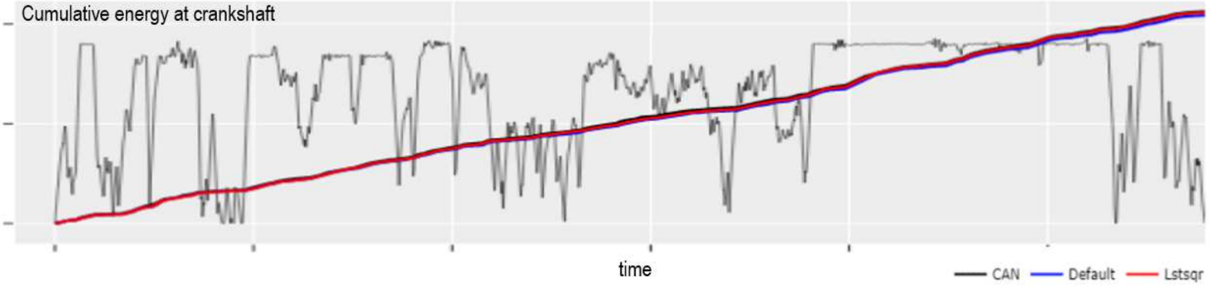
$$F_{vehicle} = \underbrace{C_{RR} * Z}_{\text{Rolling resistance}} + \underbrace{\frac{1}{2}\rho * A * C_d * v^2}_{\text{Vehicle aerodynamics}} + \underbrace{m_{eq} * a}_{\text{Inertia}} + \underbrace{m * g * sin\alpha}_{\text{gravity}}$$

When comparing the fuel consumption between two trucks with a RRC effect and different trips, or one truck with a RRC effect at different times, we can correct the bias of aerodynamics, inertia, and gravity between the 2 trips. Then, even if a lower RRC tire gives a higher fuel consumption due to a change of usage, we can explain the difference with the CAN usage data postprocessing:



This work is still ongoing in partnership with IFPEN, the French research institute for petrol and new energies.

As far as today, the results are promising with less than 2% total energy modelisation comparing to the CAN Bus measurements:



6. Conclusion

This study details the antagonistic expectations from fleets and truck OEMs for tire RRC in a context of strong CO2 reduction driven by the European Commission. To help OEMs to achieve the Vecto targets, tire manufacturers must work in the field to demonstrate to fleets that the low RRC tires are more TCO efficient and are a better choice for them. As the field test demonstration is exposed to several noise with truck usage variations, a fuel consumption decomposition strategy is needed and can make RRC reduction fuel gains measurable.

This objectivation of the fuel consumption gains through RRC reduction is key to get an accurate tire TCO, which is also based on other tire performances like mileage, regroovability and retreadability.

With the deployment of the new battery electric trucks, the stake will remain significant even more. Indeed, the low rolling resistance tires will be selected by OEMs for a better vehicle range (6% range improvement with -1kg/t on all 12 tires of the convoy). Nevertheless, the kinetic energy recovery done by battery electric trucks through the drive axle will increase the drive tire wear. Then, we can except that the RRC/wear antagonist expectations from OEMs and fleets will remain and will need to be reconciliated by tire manufacturers.

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