Evaluating CV tire wear

An evaluation of a tire/road interaction tool for wear on commercial vehicles sees a key research and development cooperation between a manufacturer and a startup

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The automotive tire sector is changing, from a closed environment to an extremely open one where the importance of sharing expertise is a key aspect to consolidating (and in some cases, improving) position in the market. This is something that Prometeon Tyre Group – a company that produces and commercializes Pirelli-branded tires for truck, bus, OTR and agricultural applications – believes strongly.

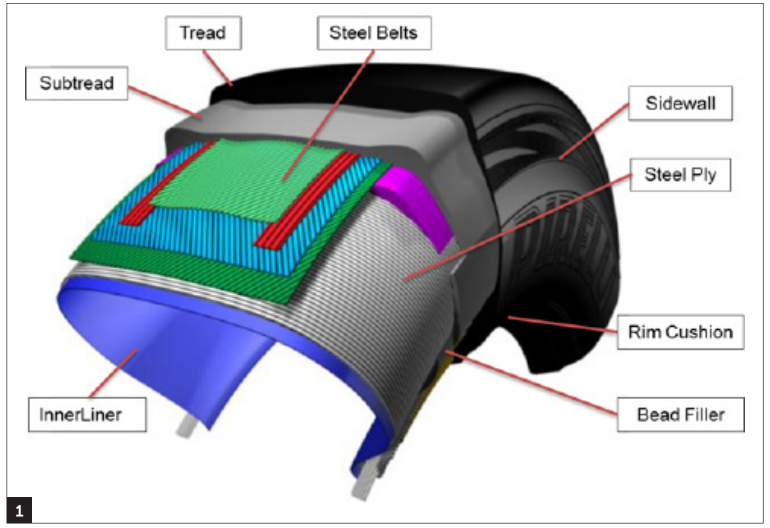
To this end, collaboration with innovative startups such as MegaRide (a company that provides solutions for vehicle performance and safety, working in motorsport, tire development, RT simulations and smart mobility), is a crucial factor in improving expertise in weaker areas. This paper contains the preliminary results of this collaboration.

The understanding and control of tire wear, preventing tread degradation and irregular wear, has long been a challenge for tire product engineers, and is an important issue for fleet management. There is not a simple equation to analyze and predict it. The optimal wear, and consequent mileage performance, depends not only on the tire, but also on its interaction with the vehicle and the road. These vary with operational conditions and, furthermore, with vehicle and tire maintenance.

A predictive tool is important for tire manufacturers and final customers: the advantage for tire manufacturer is the possibility to drastically reduce time to market and have reliable and controlled results; for OEMs, the possibility to receive tire models based on outdoor tests using their own vehicle as a moving lab; for final customers, the advantage of having smart tires able to predict wear performances, generating valuable advice for maintenance and fleet control.

Vehicle suspension system and, generally speaking, vehicle dynamics have a fundamental influence on the tire contact patch forces and, as a result, tire characteristics can be seen as having an important effect on vehicle behavior. The emphasis on research in the field of vehicle systems analysis and modeling comes, of course, from the improvement of tire technological development, mainly in the motorsport and automotive industries. This, albeit with a certain delay, is also happening in the industrial tire business (truck and bus, OTR, and agricultural). The definition of a standard testing activity able to estimate tire forces and slip indices is a crucial task, and is one of the pillars (together with thermic and adherence studies) needed to reach the final goal: a tool to predict wear.

Figure 1: The structure of a pneumatic tire



The pneumatic tire is subjected to large deflections and deformations. It is constructed of non-linear anisotropic composite materials. The tread compound (Figure 1) is the primary external material that covers the belts, and where grooves are stamped to form the tread pattern. The tread compound must satisfy different requisites: grip on wet and dry pavements, abrasion and cut resistance, comfort, and high mileage. For these reasons, it is natural to focus the attention on the tread compounds when studying tire wear.

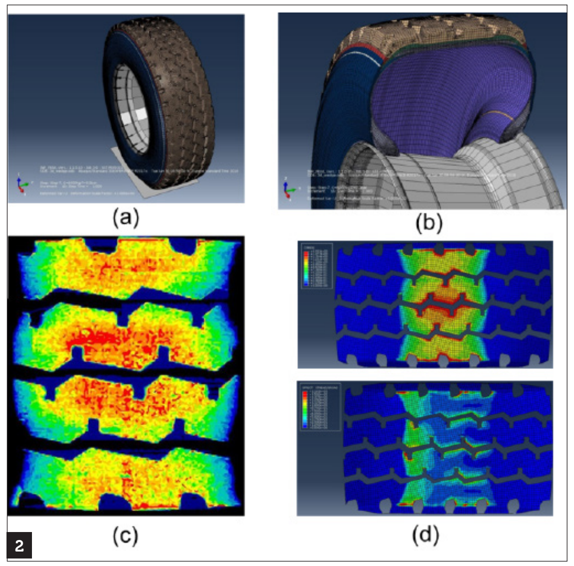
The tread pattern is the most important part of the tire when considering wear performance. Each part of the tread pattern design – its shape, how grooves and lugs have been designed, void ratio, rib proportioning – is studied to obtain the best rolling resistance, wet grip, and wear resistance balance.

Pressure distribution

All the dynamic forces acting on the commercial vehicles during maneuvers have to be supported by the contact patch of tire, a small area not larger than the size of a notebook. The contact pressure distribution and the resulting footprint shape will depend on the operational conditions, tire loads, acceleration, tire inflation pressure and vehicle suspension. The pavement interaction will also be influenced by the temperature, pavement roughness, and wet or dry conditions.

When the local shear forces at each point of the tire contact patch exceed the limit of the frictional coefficient, local sliding will start, resulting in abrasion and tread wear. The level of the contact forces and disposition of local slips will determine if the tire tread will be submitted to a homogeneous wear or uneven wear. Higher contact pressure prevents slippage and abrasion, but if the contact pressures are too high, the thermomechanical degradation of the rubber compounds will also result in irregular wear. To optimize the tread wear, a finite element model is used to evaluate the footprint shape and the respective forces (Figure 2). The boundary conditions for the tire wear simulation are obtained by the tools proposed below.

Figure 2: Finite element simulation of tread wear in (a, b) the tire model; (c) experimental contact pressure; (d) simulated contact pressure and frictional energy



The tool

All the analysis and results explained in this paper have been obtained using TRICK4Truck, a software developed by MegaRide. Prometeon began working with MegaRide in the past year. The software is a version of the TRICK (Tyre/Road Interaction Characterization and Knowledge) tool, customized for industrial application. It features a vehicle model that processes experimental signals acquired from a vehicle CANbus or from dedicated instrumentation. The output of the tool is several extra virtual telemetry channels, containing force and slip estimations, useful for providing tire interaction characteristics. The results coming from the tool are integrated with other physical models for the prediction and the simulation of specific performances.

Input parameters

For correct employment of TRICK4Truck, a reliable description of the vehicle is essential together with information about the vehicle under test (Table 1).

Table 1: Data necessary for the vehicle characterization

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Vehicle data	Symb.	Unit
Sidewall markings of front tire to be characterized		
Sidewall markings of rear tire to be characterized		
Tire unloaded radius	R_{0F}	[m]
Tire effective rolling radius	R_{rF}	[m]
Dry vehicle mass	m	[kg]
Liquids mass – full tanks	M_L	[kg]
Front wheel + tire mass	M_{wF}	[kg]
Rear wheel + tire mass	M_{wR}	[kg]
Vehicle moment of inertia about z-axis	J_z	[kg m^2]
Front wheel moment of inertia about rotation axis	I_{wF}	[kg m^2]
Rear wheel moment of inertia about rotation axis	I_{wR}	[kg m^2]
Wheelbase	l	[m]
Front wheelbase	a	[m]
Rear wheelbase	b	[m]
Front track	t_F	[m]
Rear track	t_R	[m]
Center of gravity height	h	[m]
Front axle roll stiffness	$K_{\Phi F}$	[N/rad]
Rear axle roll stiffness	$K_{\Phi R}$	[N/rad]
Nominal steering ratio	τ_S	[-]
Vehicle master section	A_V	[m^2]
Cx	C_X	[-]
Cz front	C_{ZF}	[-]
Cz rear	C_{ZR}	[-]
Roll center height at center of gravity abscissa	d	[m]
Roll center height at front axle abscissa	d_F	[m]
Roll center height at rear axle abscissa	d_R	[m]
Static camber angle front	γ_{0F}	[rad]
Static camber angle rear	γ_{0R}	[rad]
Static toe angle front	χ_{0F}	[rad]
Static toe angle rear	χ_{0R}	[rad]
Real/geometric maximum available Ackermann angle	ack%	[-]
Datron distances from CG (x, y, z)	b_X,b_y,b_Z	[m,m,m]
Rolling resistance curves		
Elasto-kinematic suspensions characterization		
Axle compliances characterization		

Test procedure

All the data for the identification of tire interactions has to be acquired during dedicated test sessions: the aim is to have a test routine to investigate tire behavior in the widest possible range of working conditions. In particular, the tire road interactions to be highlighted are:

- Pure longitudinal: start maneuver with high wheel-spin and braking maneuver with (if possible) wheel blocked on straight road;
- Pure lateral: curves performed at null longitudinal forces;
- Combined: a series of tests able to keep tires at high exertion levels, adopting an aggressive driving style (high sliding and high slip angle values).

The first stage of testing was performed in December 2017 at Nardò Technical Center. Considering the space available on the truck dynamic platform, it was decided to proceed with the testing maneuvers which are indicated in Table 2.


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Figure 3: The study test vehicle

Figure 4: Front and rear were fitted with dynamometric wheels

Table 2: The test procedures selected for the experiment

Table 3: Loaded vehicle conditions

First results

The results showed here will focus on longitudinal interaction. Furthermore, in this Phase 0, some additional hypotheses have been added because of the unavailability of vehicle input. In particular:

- Suspension system has been considered rigid;
- Cx, Cz has been neglected;
- Camber/toe has been considered constant during acceleration/braking maneuver;
- Center of gravity position has been estimated since the information is missing from the vehicle manufacturer.

The vehicle used is an Iveco Stralis 500 MY 2011 (Figure 3). This vehicle (from the Prometeon test fleet) was chosen for its ease of loading/unloading. When trying to analyze the range of working conditions, three sets of load have been tested (Table 3).

Input parameters

The channels needed for TRICK have been acquired through Dewesoft. In detail, these are:

Table 2: Test procedures

5 sec standing vehicle
5 sec at constant speed
Braking maneuver from 100km/h (62mph)
Full throttle acceleration (0-100km/h) + braking (100-0km/h)
Full throttle acceleration (0-100km/h) + braking (100-0km/h)
Circle clockwise at 15km/h (9mph)
Circle clockwise at 30km/h (18mph)
Circle clockwise at max. speed
Circle counter-clockwise at 15km/h
Circle counter-clockwise at 30km/h
Circle counter-clockwise at max. speed
8 circuit at 15km/h
8 circuit at 30km/h
8 circuit at max. speed
Full throttle acceleration (0-100km/h) + braking (100-0km/h)

Table 3: Loaded condition

	Front axle	Rear axle
Unloaded	5500	3450
Loaded	6100	5850
Overloaded	6850	8500

- δ*: driver's steering angle – analogical output [rad];
- ay*: vehicle lateral acceleration – IMU output [m/s^2];
- ax*: vehicle longitudinal acceleration – IMU output [m/s^2];
- Ω*LF: left front wheel speed – CANbus output [m/s];
- Ω*RF: right front wheel speed – CANbus output [m/s];
- Ω*LR: left rear wheel speed – CANbus output [m/s];
- Ω*RR: right rear wheel speed - CANbus output [m/s];
- r*: vehicle yaw rate – IMU output [rad/s].

To validate the output, two Kistler dynamometric wheels were mounted. IMU was mounted behind the driver cabin (Figure 4).

Center of gravity

For estimating the position of center of gravity in the various loading condition, two maneuvers have been evaluated. For front and rear wheelbase, the values can be easily estimated starting from a zero static test. Weighing the front and rear axle, the formulation to be used is a force balance (Figure 5).

For the evaluation of center of gravity height, signals used come from a braking maneuver from 100km/h (62mph). Acceleration in braking maneuver has the shape shown below. For the calculation of center of gravity height, it is necessary to evaluate the vehicle in a stationary phase, otherwise it is not possible to evaluate the center of gravity with a simple rotational equilibrium around one of the two centers of tire/road contact.

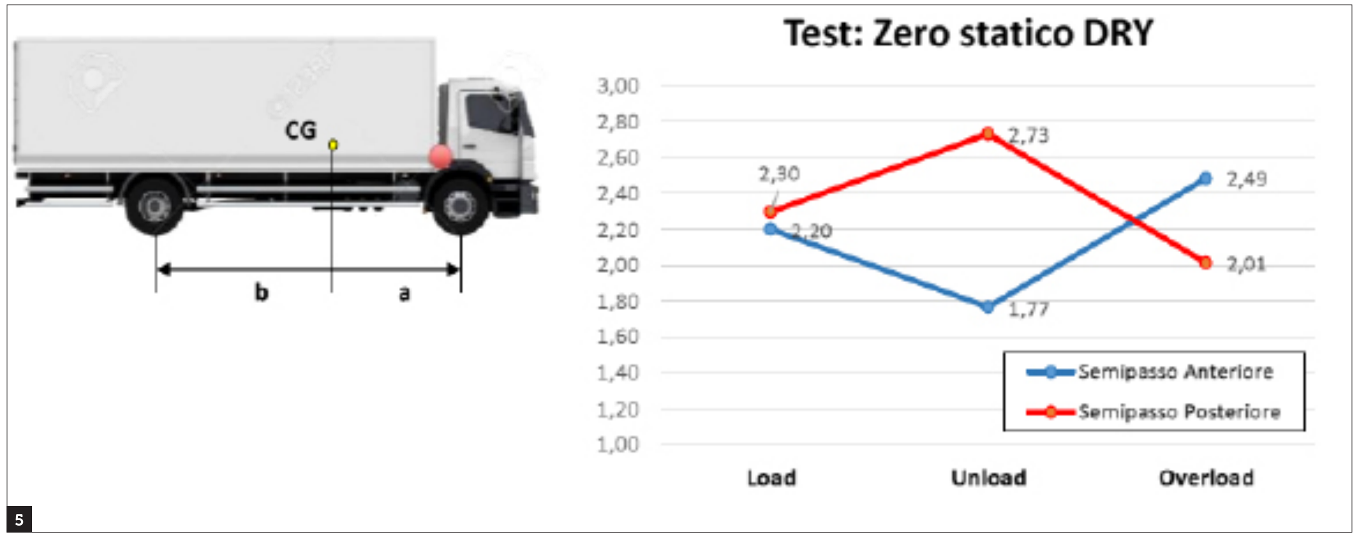
$$h_{CG} = (W_1 - F_{z1}) \cdot \frac{l}{m} \cdot \frac{1}{a_x}$$

Where W_1 is static load front axle; F_{Z1} is vertical load (from front dynamometric wheel); m is vehicle weight; a_X is long. acceleration from the IMU; l is wheelbase.

The results of this estimation are in line with expectations (Figure 6).

Rolling radius

A constant speed test was used to evaluate rolling radius. To do this,



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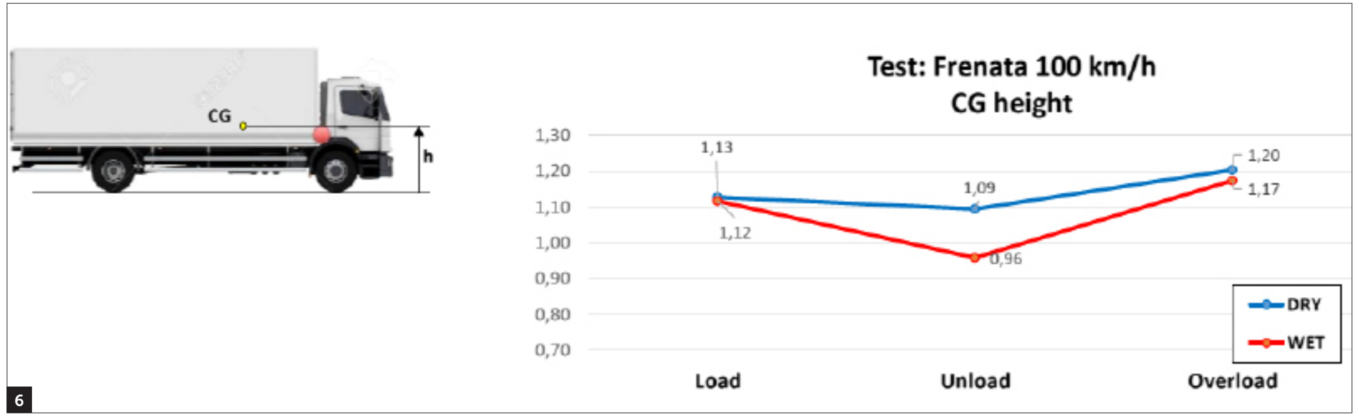

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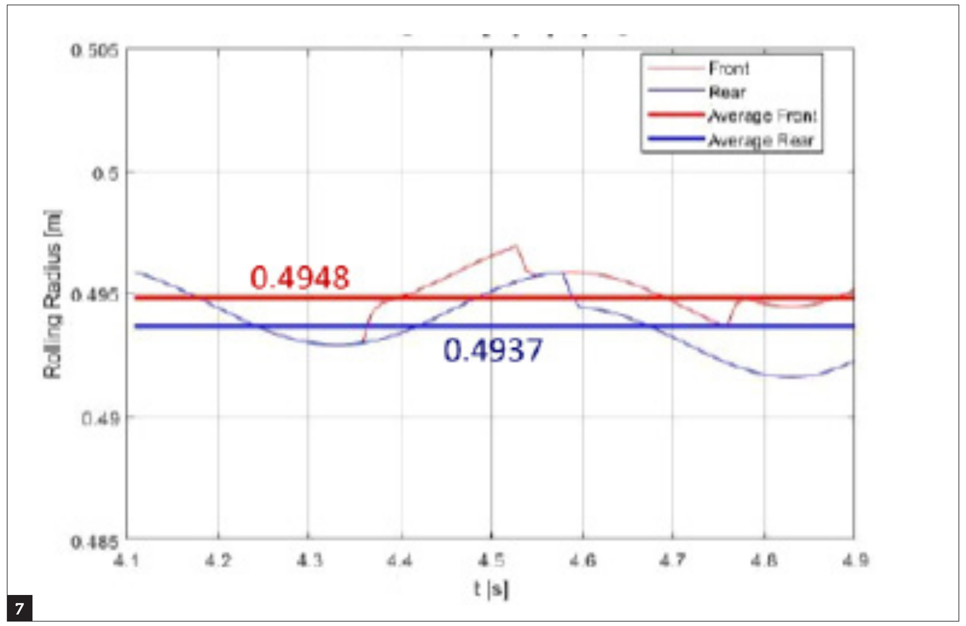
slip angle has to be the smallest and constant. A constant speed test was chosen because of its constant longitudinal acceleration close to zero. Five seconds have been extracted to evaluate rolling radius (the most constant part). Knowing that slip ratio is almost zero (a consequence of the maneuver), the speed and the angular speed from instrumentation and the CANbus, it is possible to evaluate the rolling radius.

Figure 5: Results of a force balance to estimate front and rear wheelbase

Figure 6: Estimation of center of gravity

Figure 7: Reference tire, unloaded condition

$$Slip\ Ratio = \frac{V_{GPS} - \omega * R}{V_{GPS}}$$



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In the figure, rolling radius of tires has been calculated as an average value of ratio between the speed acquired by GPS and angular speed of front-right and rear-right tires (Figure 7).

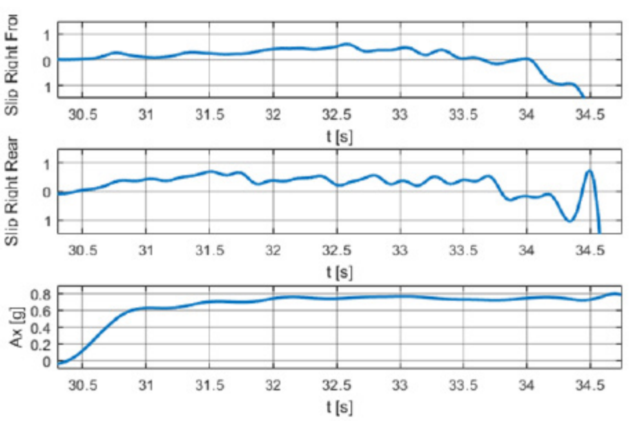
Slip ratio

Slip ratio has been evaluated either in the braking or the acceleration phase. It is necessary to highlight that the best method to evaluate tire/road interaction is through a blocked wheel maneuver and a high slip acceleration. While acceleration with high slip is almost impossible since torque power and the weight of the commercial vehicle make this type of maneuver almost impossible, blocked wheel braking would be possible after some modification of the braking system. In the first test, the vehicle did not receive any modification.

Starting from braking from 100km/h, slip ratio used is:

$$Slip\ Ratio = \frac{V_{GPS} - \omega * R}{V_{GPS}}$$

Where V_{GPS} is the speed acquired by GPS; ω is the angular speed acquired by CANbus; R is the rolling



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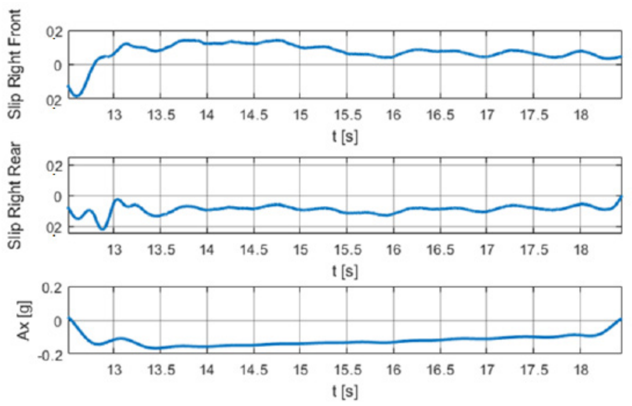

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Figure 8: Slip ratio and longitudinal braking

Figure 9: Slip ratio and longitudinal acceleration

radius measured during constant speed test. Results can be seen in Figure 8.

In the slip ratio of the right-front tire, there is an area (the last part of the graph from 33.5 seconds) where slip becomes negative. This is something unexpected and not feasible considering the formulation used. The reason for this is under investigation.

For acceleration, the formula used for slip ratio is:

$$Slip\ Ratio = \frac{V_{GPS} - \omega * R}{\omega * R}$$

The slip is plotted in Figure 9. In this case, the slip ratio of the front tire is less than zero. This is expected, because the front tire in an acceleration maneuver is a free-rolling tire where rolling resistance has to be considered. The rear wheel has, of course, a positive slip ratio. This is in line with expectations considering that the rear axle is the tractive axle.

Dynamometric wheel output

When TRICK was launched and first results became available, it became necessary to compare results with forces measured. Instrumenting the vehicle with Kistler's dynamometric wheel has enabled the force versus slip ratio graph in Figure 10. It is clear the weight transfer from rear to front affects the longitudinal characteristics (Figure 11).

Conclusions

Part of the starting evaluation for the customization of the TRICK tool for commercial vehicles has been described. The final aim is to have a tool able to process all the information obtained from specific testing sessions, using more vehicles as moving labs. This would make it possible to predict extremely time-consuming performances, without the need for expensive, complex, and often not fully representative benches.

At the present time, Prometeon has evaluated the outputs summarized in the following paragraphs.

Center of gravity position and vehicle information: the estimation of CoG was needed since there was no information from the OEM. Furthermore, it has been necessary to take into account some additional simplification regarding suspension compliances. This critical aspect can be easily solved if collaboration with vehicle manufactures becomes standard in future tire/vehicle development.

Rolling radius: the values are consistent and in line with expectations, considering also indoor bench testing previously undertaken. It is very interesting (and could be a further development) to evaluate how rolling radius changes in real time during various maneuvers at various speeds. For the ongoing development, it is not mandatory to have a real-time rolling radius.

Slip ratio: results obtained in the preliminary analysis are in line with expectations and with past experience.

Dynamometric wheel output: the analysis of dynamometric wheel measurement as a check for the TRICK output is one of the key aspects for the correct implementation of the tool in the commercial business. Results shown in the paper are consistent with previous experience (indoor). **tire**

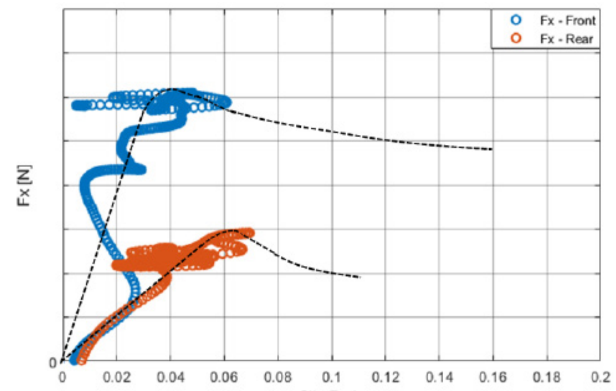

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Figure 10: Longitudinal characteristics versus slip ratio

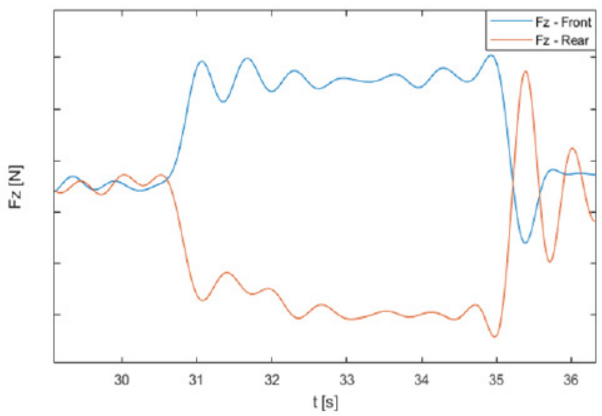

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Figure 11: Forces measured by the Kistler dynamometric wheel during the braking maneuvers