On field demonstration of fuel reduction with low rolling resistance tireS

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Abstract

The tire rolling resistance is considered as a lever to reduce trucks' fuel consumption (FC) in almost all schemes targeting to limit CO2 emissions. Truck OEMs can run simulations, well correlated to real life FC, then they are convinced about the relation between a low rolling resistance tire (LRRT) and FC reduction. Furthermore, the OEMs are pushing truck purchasers to fit their truck with LRRT to lower the CO2 emission score, constrained to decrease following a strong roadmap. At the same time, the fleet is not convinced that a LRRT is a good choice since mileage is reduced and FC improvements are impossible to monitor without a scientific study and retrofitted telematic boxes.
Michelin has developed a method to monitor FC improvement enabled by a LRRT, because tire manufacturers are torn between diverging expectations from OEMs and fleets. The theory has already been presented in HVTT17 and the purpose of this paper is to detail the achieved results. Four different fleets have been equipped for 1 year with data loggers and different rolling resistance tires on steer and drive axles. The FC and the usage parameters are read on the CAN Bus, the standard protocol J1939 giving access to almost all the required signals. We present here a statistical approach as an extension of the study carried out by XiaoXiang Na and David Cebon in 2022.
The fitted tires in our field experience are expected to improve by 1L/100km the FC between normal tires and LRRT. When comparing the FC of the 2 populations of trucks (normal tire and LRRT), it is not possible to sort them with good confidence. With the statistical approach, when selecting similar trips by their usage descriptors, we manage to make the FC improvement visible. The interest of this method is limited since it processes FC values different from what the fleet can measure when refueling. With the physical modelling approach, it is possible not only to extract the FC improvement but also to give the fleet an explanation of the reasons why the FC improvement was not visible on refueling data.
The study is carried out on a wide range of truck brands and usage, with nearly 50 trucks being analyzed. The trucks are used in real business operations. The target is to deploy this method to fleets who are not convinced by the fuel cost reductions given by LRRT to reconcile climate change and fleets' cost expectations.

Keywords: truck, tire, heavy vehicles, fuel consumption, rolling resistance.

1. Background

In the context of road transport, the freight transport sector accounted for 15% of CO_2 emissions in 2019. This highlights the significant role played by heavy trucks in contributing to the overall emissions profile of the transport sector. Consequently, truck manufacturers are compelled to reduce the fuel consumption of the vehicles they market. This is achieved through various regulatory measures, such as the VECTO scheme in Europe, which requires truck manufacturers to report simulated CO_2 emissions for each truck sold in the European market using the VECTO (Vehicle Energy Consumption Tool) software. This simulation considers the main features of the truck impacting fuel consumption, including the tire rolling resistance coefficient (RRC), the aerodynamic performance, vehicle mass and engine efficiency. As OEMs are obligated to adhere to a prescribed roadmap in order to reduce the CO_2 emissions of their products, they are inclined to equip their trucks with ultra-low rolling resistance tires for original equipment, as this represents a highly effective solution for decreasing CO_2 emissions.

The utilization of a truck is subject to variation in operations (loading, route, driving style), with a consequent impact on fuel consumption. Consequently, it proves challenging for truck end users to accurately measure the fuel consumption improvements provided by low RRC tires. Indeed, the fuel consumption reduction offered by low RRC tires is less significant than the dispersion resulting from usage variations, and the monitoring means are not always available. However, the cost impact of mileage reduction can be more readily measured by comparing the distance travelled with the tires before and after removal. Demonstrations of the gains provided by low RRC tires can be conducted in controlled conditions, such as on a track with a stable speed and maximum load. However, this type of demonstration is not well accepted by fleets since it differs from the real usage of freight operations.
The design of low RRC tires may involve a trade-off in terms of mileage, given that the tread area is the most dissipative part of the tire. Consequently, many end users opt to equip their trucks with high-mileage, high-RRC tires, believing this is the optimal choice for their Total Cost of Ownership (TCO).

Consequently, tire manufacturers must take into account these diverging expectations: low rolling resistance coefficient (RRC) for original equipment manufacturers (OEM) but high mileage for fleets. It may be possible to align the needs of both by persuading fleets that low RRC tires are beneficial for their total cost of ownership by developing methods to demonstrate the improvements.
This paper describes a fleet demonstration study in which Michelin analyzed usage data, fuel consumption and tire wear performance to demonstrate the improvements with low rolling resistance tires and the impact on the TCO.

2. Use case and fleet description

The analysis presented in this paper is based on a survey in a fleet who wanted to compare the TCO between two tire sets A (regional delivery low rolling resistance tire) and B (regional delivery tire). The fleet in question stated that it was unable to quantify the fuel consumption difference between these tire sets. In response, a field survey was proposed to demonstrate the improvements.

This fleet is organized by agencies that are geographically dispersed throughout the country. The business of each agency is dependent on the proximity of its customer base, and each is required to report on its efficiency through the use of KPIs. The fuel performance of each agency is subject to global monitoring, with the monthly fuel invoice and distance travelled (€fuel/1000km) serving as the primary metrics. The tire performance is also a global indicator, considering all the costs related to the tire (purchasing, maintenance, regrooving, retreading) and the monthly distance (€tire/1000km). In these conditions, it is evident that without an analytical comparison between two trucks with a pure effect on the tire, it is difficult to demonstrate fuel consumption gains.

The first measure implemented for the demonstration was to fit two trucks of the same brand, same technical definition, same agency, almost the same road, with different tires (steer and drive position). The tractor does not pull always the same semi-trailer, and we monitor the usage with a telematic box fitted on the tractor. Then, we won't know which semi-trailer is pulled by the tractor: This will be considered as noise in the fuel consumption measurement.

This approach has been deployed in four different agencies in France with 16 trucks equipped with low RRC tires that are compared to 16 trucks equipped with conventional tires.
Three different brands of trucks (Renault T520, MAN TGX, Iveco Stralys) have been equipped with the two types of tires by duo.
The tire fitment is on steer and drive axles and the RRC difference is 1.1kg/t when homogenised with common steer/drive load balance.

The survey has been carried for 4 months for fuel consumption analysis (not to compare tires with different wear levels) and 1 year for the wear performance.

Figure 1 :Location of 4 sites where survey has been done

3. Data monitoring

The telematic box used in this study is 'C4 Dongle' by Munic car data™ with GPS and additional sensors like accelerometer, altimeter, meteorology. It is equipped with wireless vehicle CAN information reading and 4G connectivity.
The time data are sent in real-time to servers where it is stored in time signals database. We can request the time signals on a defined duration to do the accurate processing, filtering, averaging, etc.

Figure 2:C4 by Munic Car data

The main time signals useful for a fuel consumption study are the followings:

- GPS (latitude, longitude, speed), that are enhanced with the local slope from a digital elevation model and mapmatching processing.

- CAN signal available on J1939
  - EngFuelRate
  - HighResolutionTripDistance
  - GrossCombinationVehicleWeight
  - FrontAxleSpeed
  - ActualEngPercentTorque, EngSpeed
  - TransCurrentGear
  - NominalFrictionPercentTorque
  - ActualRetarderPercentTorque

Time signals have a high sampling rate (10 to 40 Hz), then the time window to load the data for processing must be limited, but the survey for fuel consumption needs 4 months recordings. A time window defined by days is not suitable since the truck can be in a trip at midnight. Some criteria have been defined to cut the total time signal in several trips on which the processing is done: In one trip the truck must be moving, not idling parked, the payload is stable, starting point à zero speed, ending point at zero speed.

4. First fuel consumption comparison and usage comparison

If we assume that the usage is comparable between two truck populations (tire A and tire B), the statistical distribution of fuel consumption (FC) per trip for both trucks' populations is in Fig.3:

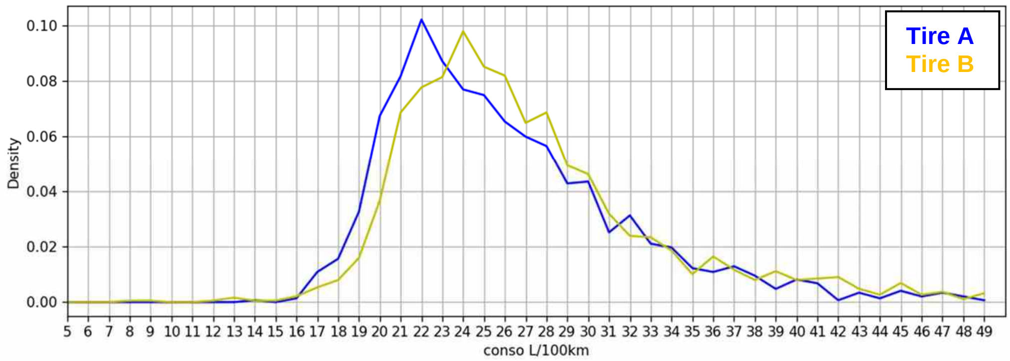

Figure 3:statistical distribution of FC (L/100km) per trip between trucks fittd with Tire A and B

Firstly, it is evident that the FC is highly dispersed. Secondly, it is observed that tire A trucks appear to consume less fuel than tire B trucks, as evidenced by the slight shift of the blue distribution to the left in comparison to the yellow distribution. However, given the high standard deviation of the distribution, it is challenging to persuade the end user that the FC shift between the two truck populations is solely attributable to the tire RRC. It is also important to note that this distribution was obtained over a period of four months and a large number of trips.If a fleet operator were to conduct a test, the testing time would be shorter and the number of equipped trucks would be reduced, leading to the probability of comparing fuel consumption on a few trips and resulting in an inverse ranking.

With the actual engine percent torque available on CAN BUS, we can compare the quantiles 25, 50 and 75 of engine torque usage. It shows that the trucks equipped with tire B use less torque than the trucks equipped with tire A, low rolling resistance, what is not consistent with the fuel consumption results:

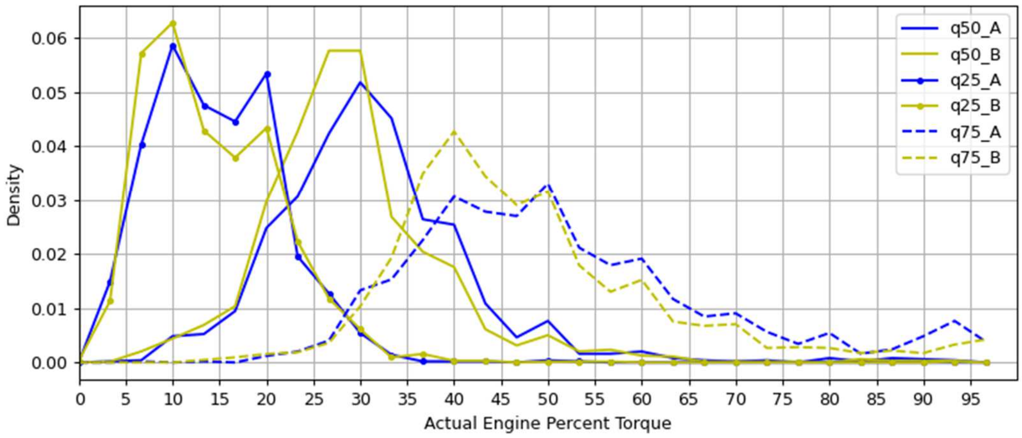

Figure 4: Quantiles distribution of actual engine percent torque

A comparison of the combined weight of the two truck populations is also required. Preliminary findings suggest that the B-tire trucks have a lower payload and should therefore be favored with regard to fuel consumption:

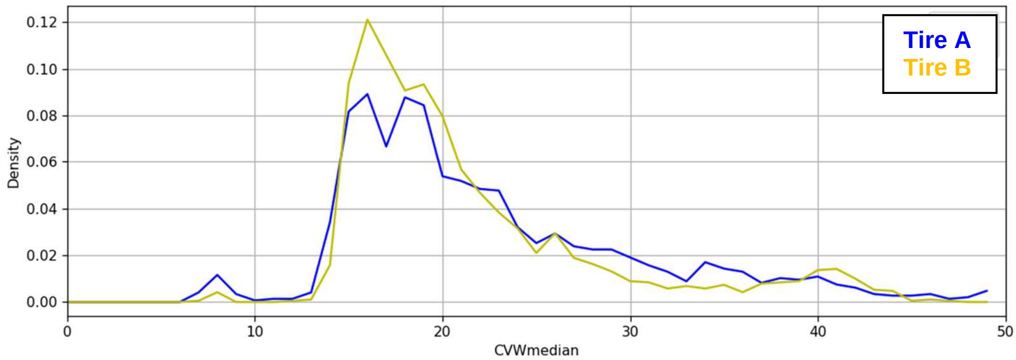

Figure 5: statistical distribution of combination Vehicule Weight

Differences in average speed can result in different aerodynamic drag and subsequent effects on fuel consumption. B-truck trucks are observed to exhibit reduced aerodynamic drag:

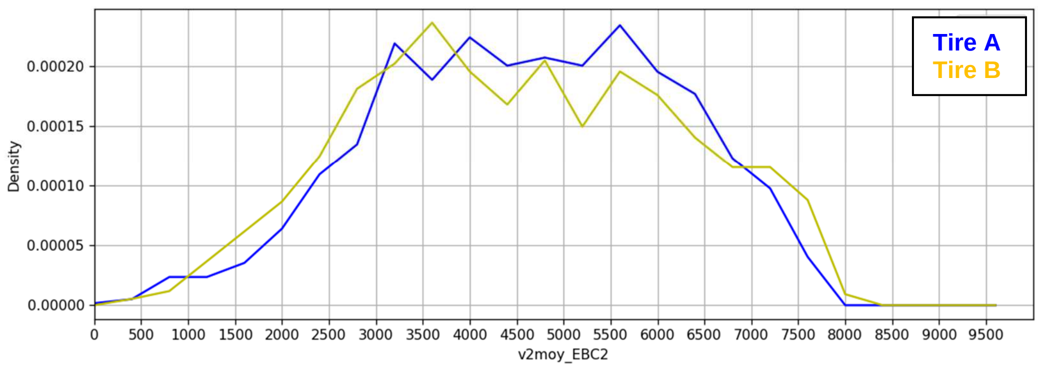

Figure 6: statistical distribution of average speed²

The same observation applies on the average slope of trips. The B tires trucks have used roads with less gradient:

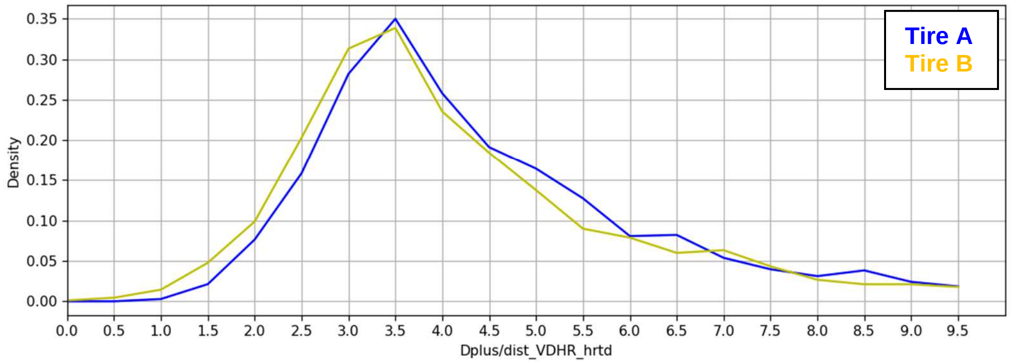

Figure 7:statistical distribution of average slope per trip

The topography of the road during the journey exerts a significant influence on the FC. Subsequently, the methodology for storing usage data in the database has been refined. This now incorporates the road segment reference at each timestamp. The position is tagged to denote the section of road on which the GPS point is measured and mapmatched. Consequently, it is now feasible to extract usage data by selecting portions of the journeys common to two trucks, thereby facilitating the creation of new, more analytical trips.

5. Fuel consuption analysis with analytical routes

This selection of sub-trips with same route between 2 trucks same brand equipped with different tire reduces the length of trips and the number of trips considered in the database since we had another criterion to select the usage.

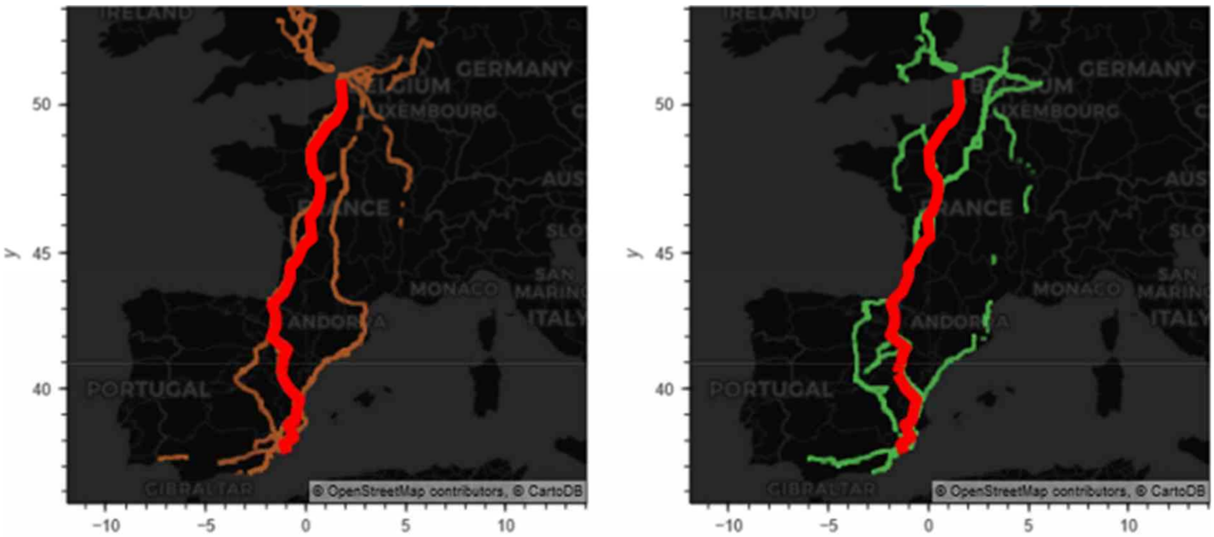

Figure 8: common routes selection

When we plot the FC statistical distribution on the sub-trips database, we find a lower average FC and a lower standard deviation of fuel consumption since the route matching selection will probably extract portions on frequently used roads and not on parking areas where trip starts with accelerations:

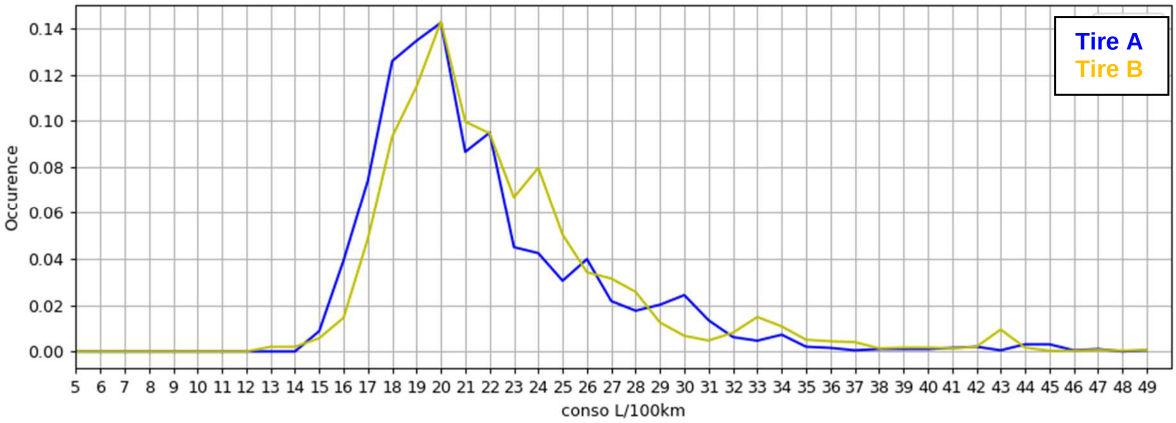

Figure 9: statistical distribution of FC on sub selection of trips with common routes

At that stage of the analysis, we can plot the distribution of fuel consumption delta between 2 trucks with different tire sets since the routes are similar between 2 compared trucks:

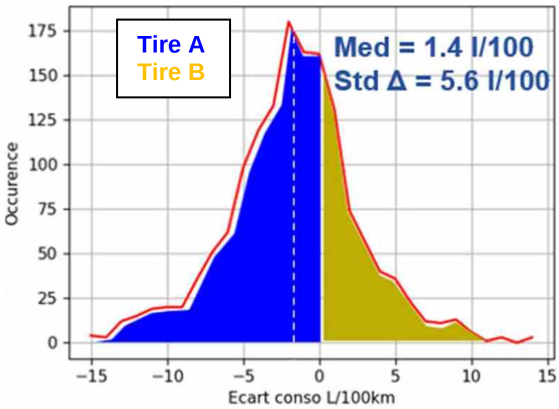

Figure 10:statistical distribution of FC difference between 2 trucks on same route and different tires BEFORE CVW and slope correction

In the left part of the plot, the blue occurrences represent instances where the truck equipped with tire A, low RRC, exhibits a lower FC compared to the one equipped with tire B. Conversely, on the right side, the reverse is observed.

On average, at a given route, low RRC trucks consume 1.4L/100km less fuel than their normal tire counterparts. However, this statistical difference is only evident in a substantial proportion of the data. The blue area represents only 69% of the comparisons. When selecting a random pair of trips, there is a 69% probability of obtaining a favorable ranking (A > B). This comparison at a similar route is insufficient to reliably demonstrate the fuel consumption improvements. The CVW of tire A truck versus the CVW of tire B truck on the same route is plotted here, with the color scale representing the FC in L/100km.

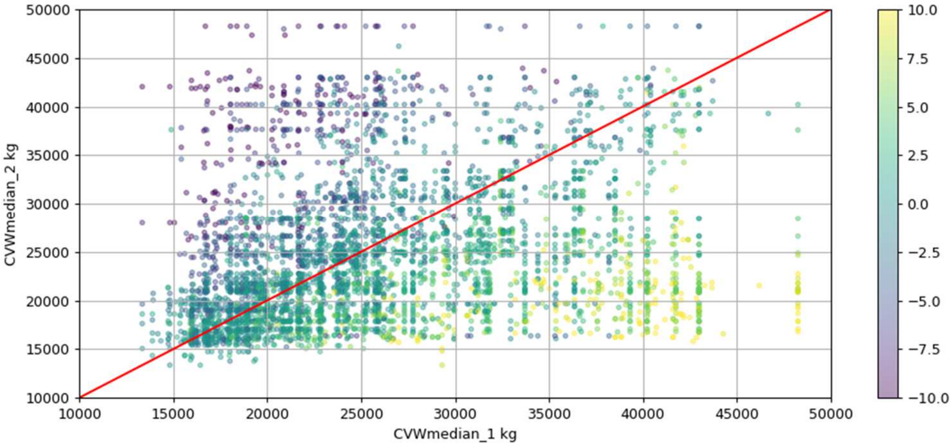

Figure 11:Correlation between Combination Vehicle Weight difference and FC difference on same route

The FC difference is correlated with the CVW differences when the routes are identical. Furthermore, several truck couples possess significantly different CVWs, thereby rendering the FC comparison contingent on CVW rather than RRC. It is imperative to rectify this bias, and we have adjusted a mathematical function to link FC (L/100km), CVW (kg) and the average slope (cumulative positive altitude delta/distance, m/km):

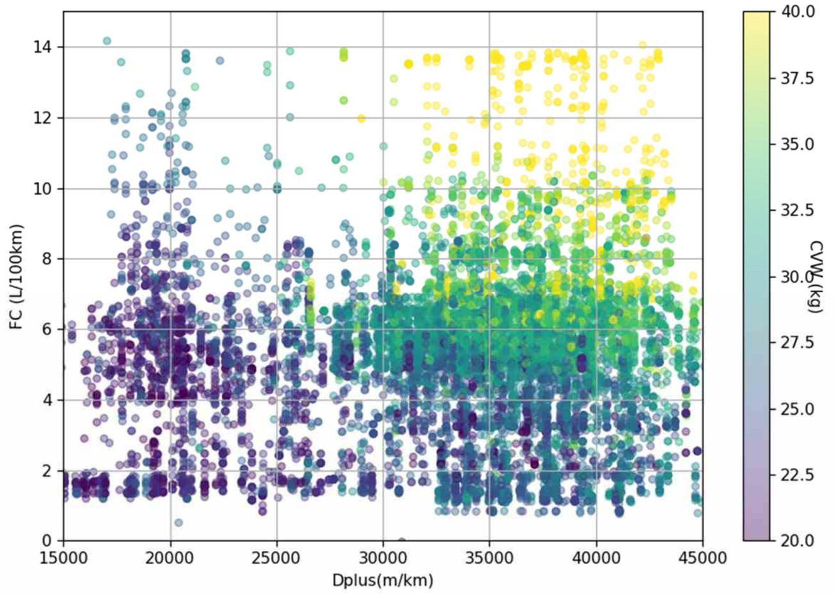

Figure 12:correlation between average positive slope, CVW and FC

The function to represent the correlation between these parameters is:

$$\mathrm{FC} = a.CVW + b.slope + c.CVW.slope + d$$

a, b, c, d are adjusted to minimize the difference with experimental point of Fig.12.

It is possible to correct each FC value with the statistical fitting on the surface presented in Fig.12. This approach leads to a reduction in the dispersion of FC differences between two trucks travelling along the same route, thereby enhancing the sorting power:

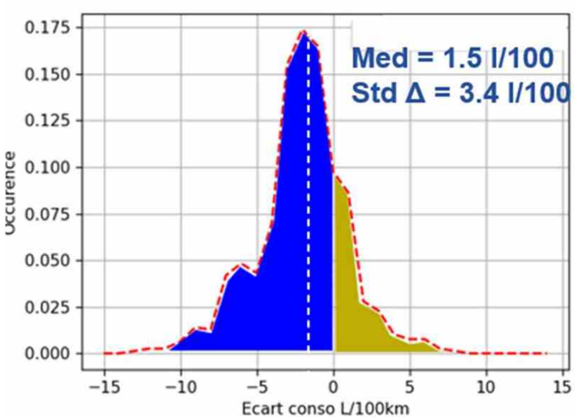

Figure 13; statistical distribution of FC difference between 2 trucks on same route and different tires AFTER CVW and slope correction

The risk of erroneously sorting the FC between two trucks equipped with different tires has been reduced to 18%, which, while still high, is an improvement on the pre-correction figure of 31%.
The average FC improvement was not expected to change, and the calculated mean is 1.5 L/100 km as opposed to the previous average of 1.4 L/100 km. The standard deviation is reduced from 5.6 L/100 km to 3.4 L/100 km, what explains the better sorting power.

It is acknowledged that further enhancements could be realized through the rectification of residual bias. The current study acknowledges the challenges associated with the incorporation of semi-trailer loadings during travel, and the RRC of tires, which remains a challenging area to manage at this time.

This study demonstrates the complexity of demonstrating FC enhancements through RRC in field tests, given the inherent variability in usage patterns and the instability of usage per truck.

Some truck manufacturers propose FC monitoring tools based on aggregated data at the week level. An attempt was made to reproduce this approach with the data under review, but it was found that the FC improvements were not fully visible due to the averaging window being too long to account for all the usage variations that occur over the course of a week. It is evident that time signals are required to analyze each trip separately, given that fuel consumption is the result of usage on the trip in question.

6. Wear performance and TCO

The FC analysis has been conducted on the first 4 months of the survey, but it was necessary to monitor the tire wear rate regularly on a longer duration. The wear rate has been followed by remaining tread depth measurements while one year and despite this long time, the tire wear level was not sufficient to predict an accurate tire end of life (trucks have not done the forecasted distance). The tire tread depth has been measured regularly on the trucks.
Nevertheless, the wear study concludes to a removal mileage reduction by 10% on steer position and 20% on drive position due to the fact that there is a strong antagonism between the RRC and the wear mileage.

With the figures gathered on this real-life experience, it is possible to estimate the impact of FC reduction and tire mileage on total cost of ownership. We consider an average mileage reduction by 15% on tires purchased 600€ each. The tires are worn in 2 years. The truck is considered to do 100 000km/year, with a diesel cost at 1.5€/L, and a reference FC of 27L/100km.

€ / year / truck	Tire cost	Fuel cost	Total
Tire B	1 800	40 500	42 300
Tire A	2 070	38 250	40 320
Difference	+270 (wear+)	-2 250 (FC-)	**-1980**

Figure 14: TCO comparison between low RRC and conventionnal tires

It has been demonstrated that the tire wear counter's performance is not compensating for the fuel cost savings (FC) since the tire cost is very low. It can thus be concluded that a cost improvement of €1980 per truck per year can be expected, which is significant with respect to the operational margin created by a truck.

7. Conclusion

This paper presents an approach studied at Michelin to demonstrate to fleets how low RRC tires can help them reduce their costs. Other methods have been developed, and the choice of method is guided by the CAN Bus data availability and quality, the number of trucks fitted, the RRC delta and the usage stability. It is challenging to decouple all the usage features from their impact on FC. Given the significant impact of truck CVW on FC, the most appropriate granularity for analyzing the impact of RRC is the trip without stops. Georeferenced usage databases facilitate analytical FC comparisons with RRC changes in real-life fleet data.
Despite a decline in tire mileage, low RRC tires have been shown to reduce the total cost of ownership, thereby incentivizing fleets to select these tires, which in turn contributes to a reduction in CO2 emissions from freight transport.

8. References

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