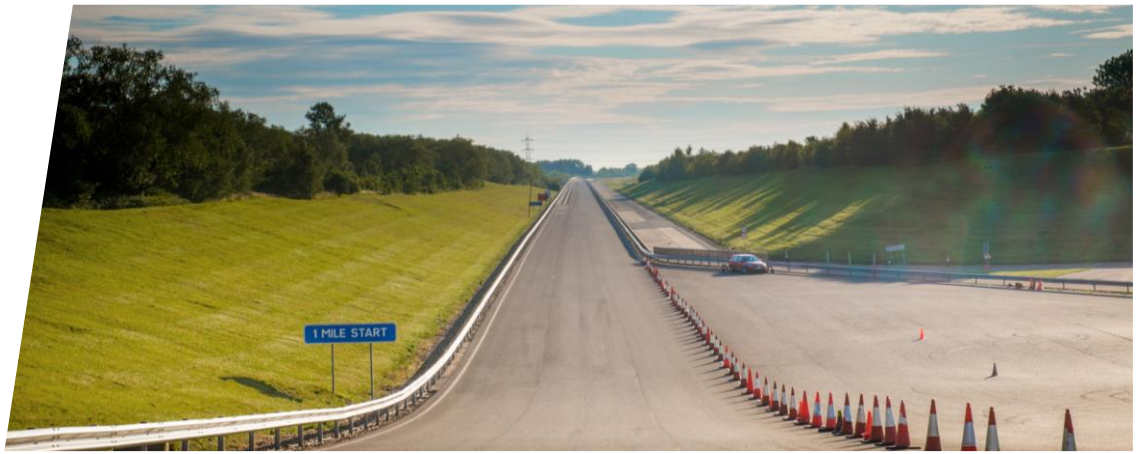
Tyre Abrasion Study for ACEA

Maëlle Dodu – Tyre Expert

GRBP TF TA Session 19



CONTENTS

- Tyre Abrasion Study Overview
- WP3 – Real Life Testing
- WP4 – Statistical Analysis
- Conclusions & Next Steps

TYRE ABRASION STUDY OVERVIEW

- Scope:
  - Theoretical and experimental study of influencing factors on tyre wear / abrasion.
- Objectives:
  - Review GRBP TF TA tyre abrasion requirements proposal: test method, interdependency evaluations, etc,
  - Quantify differences in tyre wear / abrasion in relation to vehicle type (ICE vs BEV),
  - Quantify possible differences between OE and Aftermarket tyres by testing tyres with different label values.
- Work Packages & Timing:

Work Packages		Updated Timing
WP1	Literature Review	Jun-23 (completed)
WP2	EPREL Tyre Database Analysis	Aug-23 (completed)
WP3	Real Life Testing	Aug-23 (completed)
WP4	Test Results Analysis	Initial Analysis: Oct-23 (completed) Analysis update following additional testing: Jan-24
WP5	Presentations to GRBP/GRPE:	Interim report: GRBP 78th session (completed) Final report: GRPE 90th session / GRBP 79th session

WP3 – REAL LIFE TESTING

- Objectives:
  - Quantify differences in tyre wear / abrasion in relation to:
    - Vehicle type: ICE vs BEV,
    - Tyre type: OE vs aftermarket tyres with different label values.
- Vehicles selection:
  - Scope: BEV & ICE vehicles from same model platform,
  - Vehicles: 1 x BMW iX1 xDrive (BEV) vs 5 x BMW X1 (ICE).
- Tyres selection:
  - Scope: C1 summer tyres,
  - Tyre size: 245/45R19 102 Y,
  - Tyre labels (rolling resistance / wet grip):
    - AA (aftermarket, best label combination available, eco tyre for EV),
    - AB (OE homologated, eco tyre),
    - BA (OE homologated, comfort tyre),
    - CA (aftermarket, best-selling based on analysis of French tyre distributors websites, High Performance tyre),
    - DB (aftermarket, worst label combination available, High Performance tyre),
  - Tyres tested before tyre wear test to check wet grip and rolling noise label values.
  - Start of Production: between 23/20 and 29/22
  - DOT: between 20/22 and 19/23

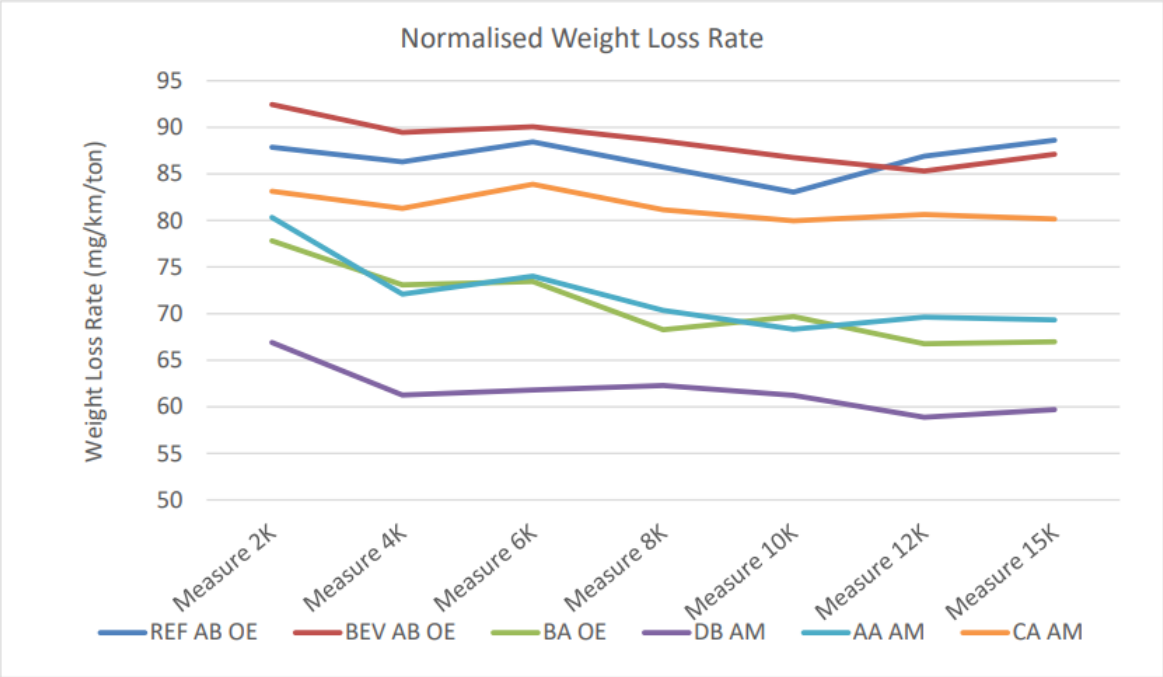
WP3 – REAL LIFE TESTING

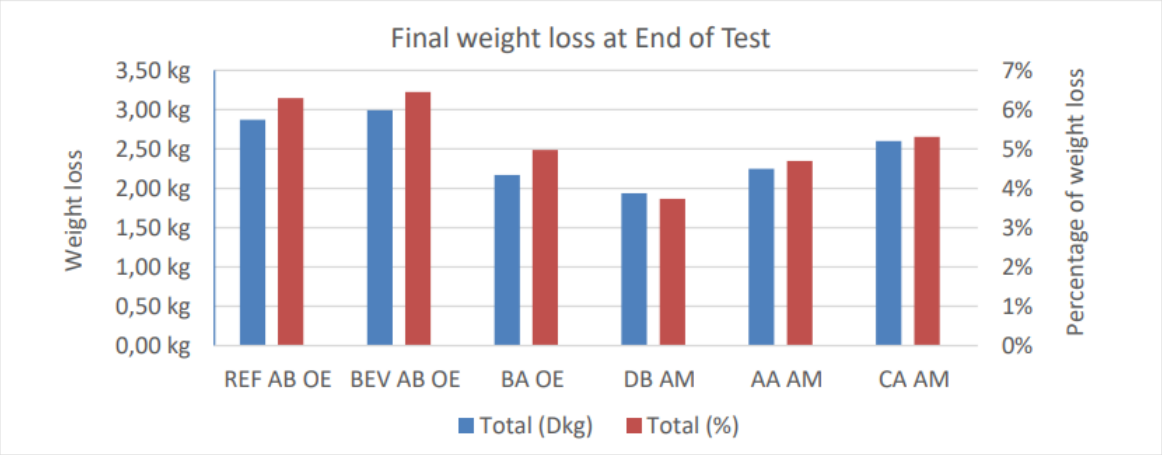
- Circuit:
  - Specifications as close as possible to TADG-ORV Test Method proposal,
  - Open road circuit around UTAC Mortefontaine site (Northern France),
  - Compatible with BEV range & charging constraints.
  - *Note: acceleration levels being checked vs calculation method in TADG-ORV Test Method proposal.*
- Test Method:
  - Test procedure as close as possible to TA DG-ORV Test Method proposal,
  - Main differences with TADG-ORV Test Method proposal:
    - 1 double convoy: 3 + 3 vehicles mixing ICE and BEV to limit test time & cost,
    - Reference (REF): BMW X1 (ICE) fitted with AB OE homologated Tyre,
    - Total running distance: 15,000km (8 weeks),
    - Measurement parameters: tyre tread depth and mass loss.
  - Intermediate measurements every 2,000km.
- Timing: July – August 2023
- Note: RL tyre on REF replaced after 6,000km due puncture.

Circuit characteristics	
Length (km)	390
City (km / %)	59 km / 15 %
Road (km / %)	195 km / 50 %
Highway (km / %)	137 km / 35 %
Average speed (km/h)	93,13
Standard deviation speed	32
Standard deviation longi accel (m/s^2)	0,68
Standard deviation lat accel (m/s^2)	0,87

WP3 – REAL LIFE TESTING

- Average weight loss rate per vehicle normalised by vehicle load:

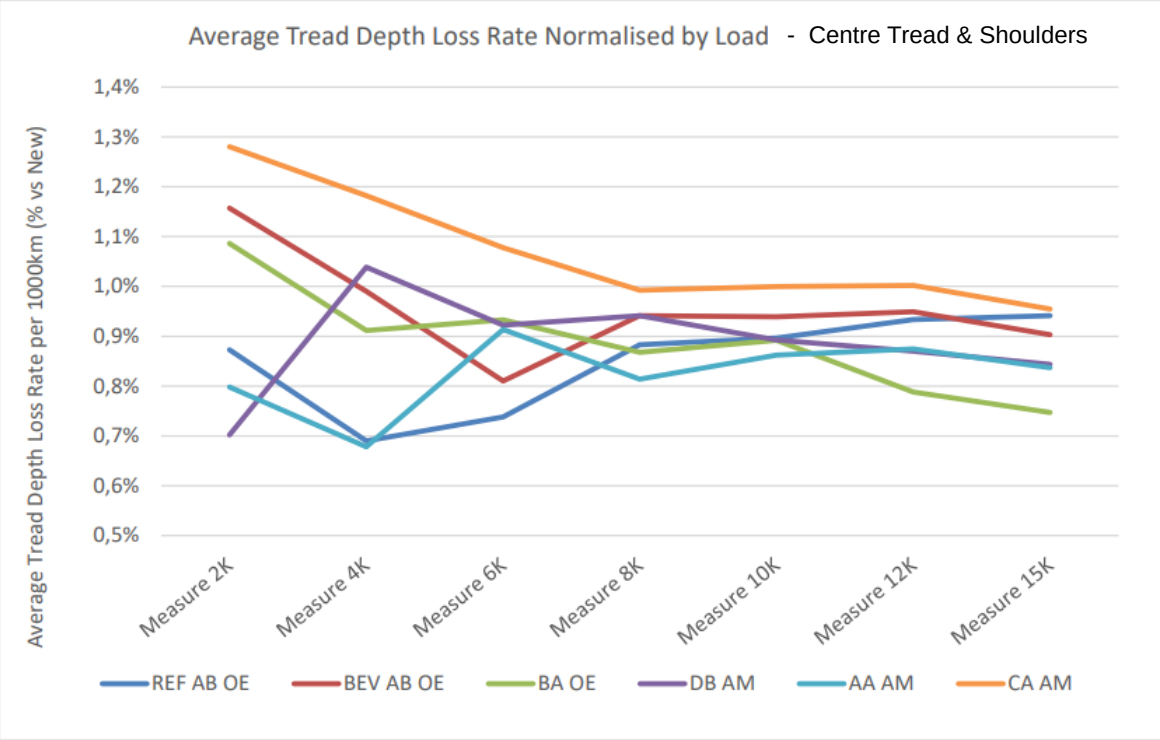


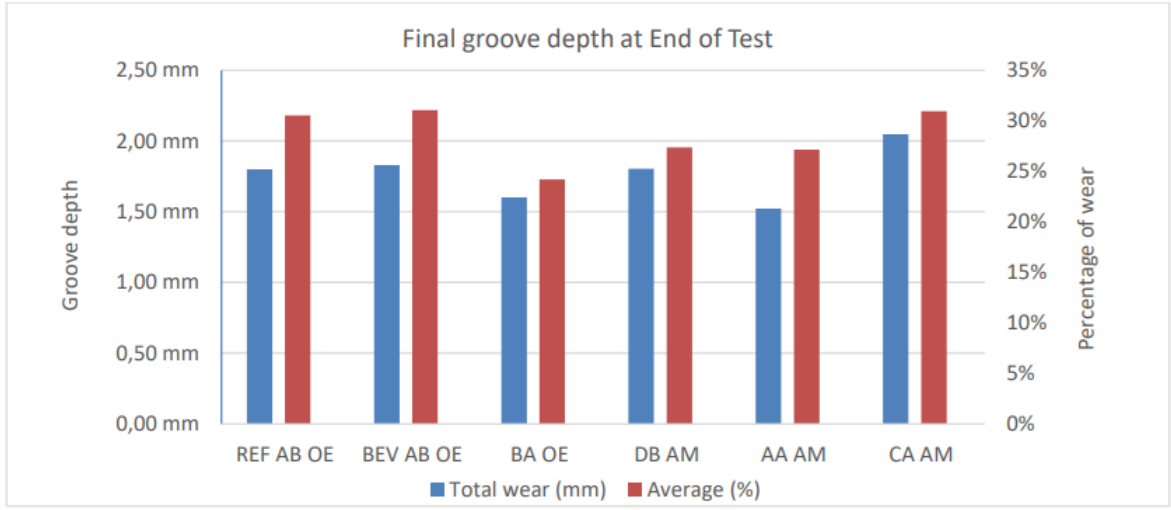


- REF AB OE: RR tyre counted twice due to RL tyre replacement during testing,
- Vehicle weight influence on weight loss rate observed → Change in test results when normalised by vehicle load,
- Similar weight loss rate between ICE and BEV when tested in same convoy and results normalised by vehicle weight.

WP3 – REAL LIFE TESTING

- Average tread depth loss rate per vehicle normalised by vehicle load 15,000km:





- Vehicle weight influence on tread depth loss rate observed → Change in test results when normalised by vehicle load,
- Longer test distance required to get stabilized tread depth loss rate compared to weight loss rate.

WP4 – Statistical Analysis – Data Exploration

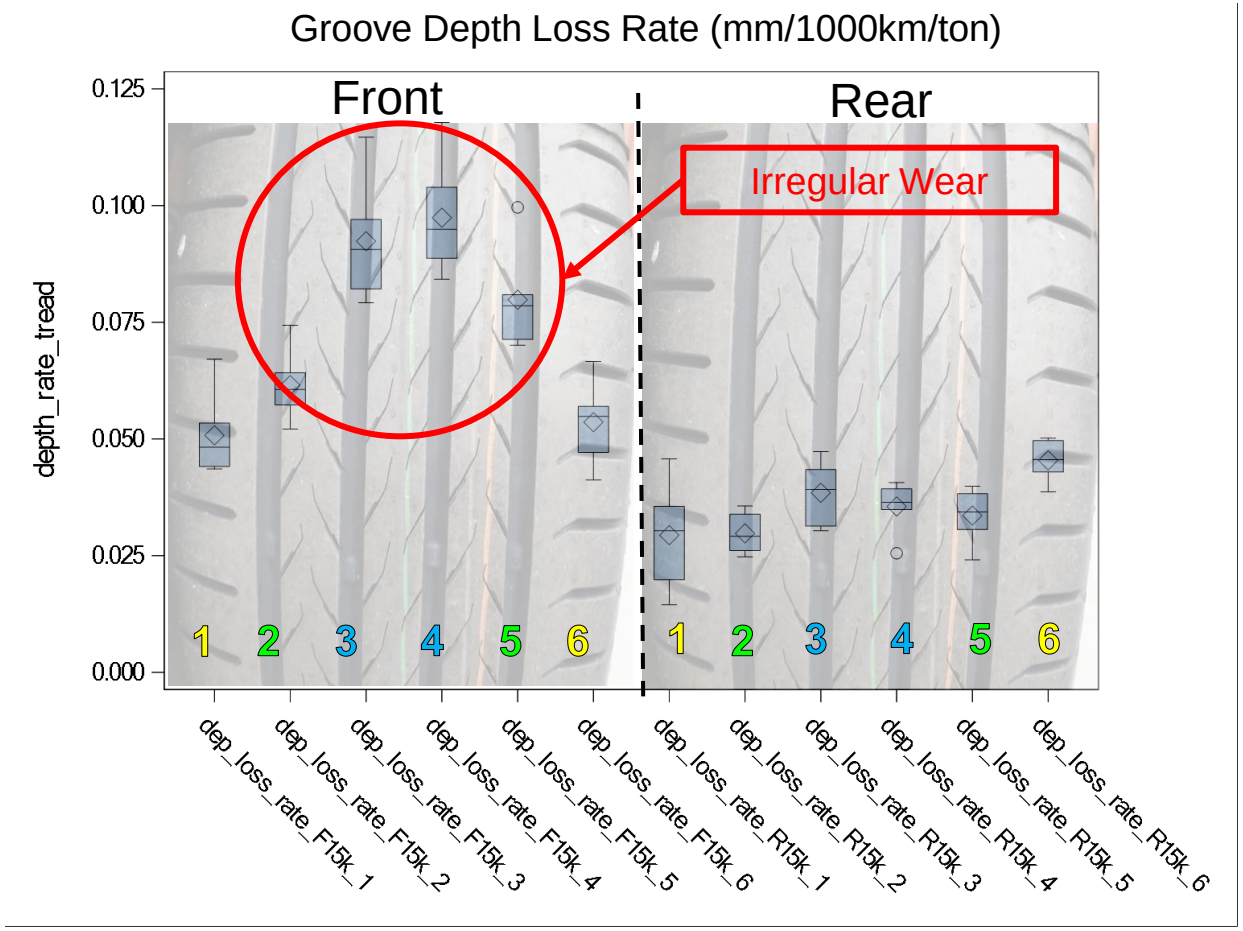
- Tyre Labels Value and Tyre Test Results:

Tyre	RR Label	WG Label	Noise Label	WG Index (1)	Sound Level (dB(A)) (2)	Weight Loss Rate (mg/km/ton) (3)	Tread Depth Loss Rate (mm/1000km/ton) (4)
AA - AM	A	A	A (69dB)	1,56	70,25	69,321	0,047
REF AB – OE (5)	A	B	A (69dB)	1,48	71,20 (B)	88,620	0,055
BEV AB – OE (6)	A	B	A (69dB)	1,48	71,20 (B)	87,110	0,053
BA – OE	B	A	B (70dB)	1,70	72,52	66,974	0,049
CA – AM	C	A	B (72dB)	1,56	73,82	80,161	0,063
DB – AM	D	B	B (70dB)	1,58 (A)	72,11	58,704	0,056

- Notes:
  - (1) Wet Grip Index in new state as per Annex 5 to UNR117.
  - (2) Sound Level only after temperature correction according to §4.3 of Annex 3 to UNR117.
  - (3) Average Weight Loss Rate per vehicle normalised by vehicle load after 15,000km.
  - (4) Average Tread Depth Loss rate (centre tread and shoulders) per vehicle normalised by vehicle load after 15,000km.
  - (5) AB – OE tyre fitted to reference Internal Combustion Engine (ICE) vehicle for tyre abrasion / wear testing.
  - (6) AB – OE tyre fitted to Battery Electric Vehicle (BEV) for tyre abrasion / wear testing.

WP4 – Statistical Analysis – Data Exploration

- Tyre Tread Wear Profile – Box Plots:

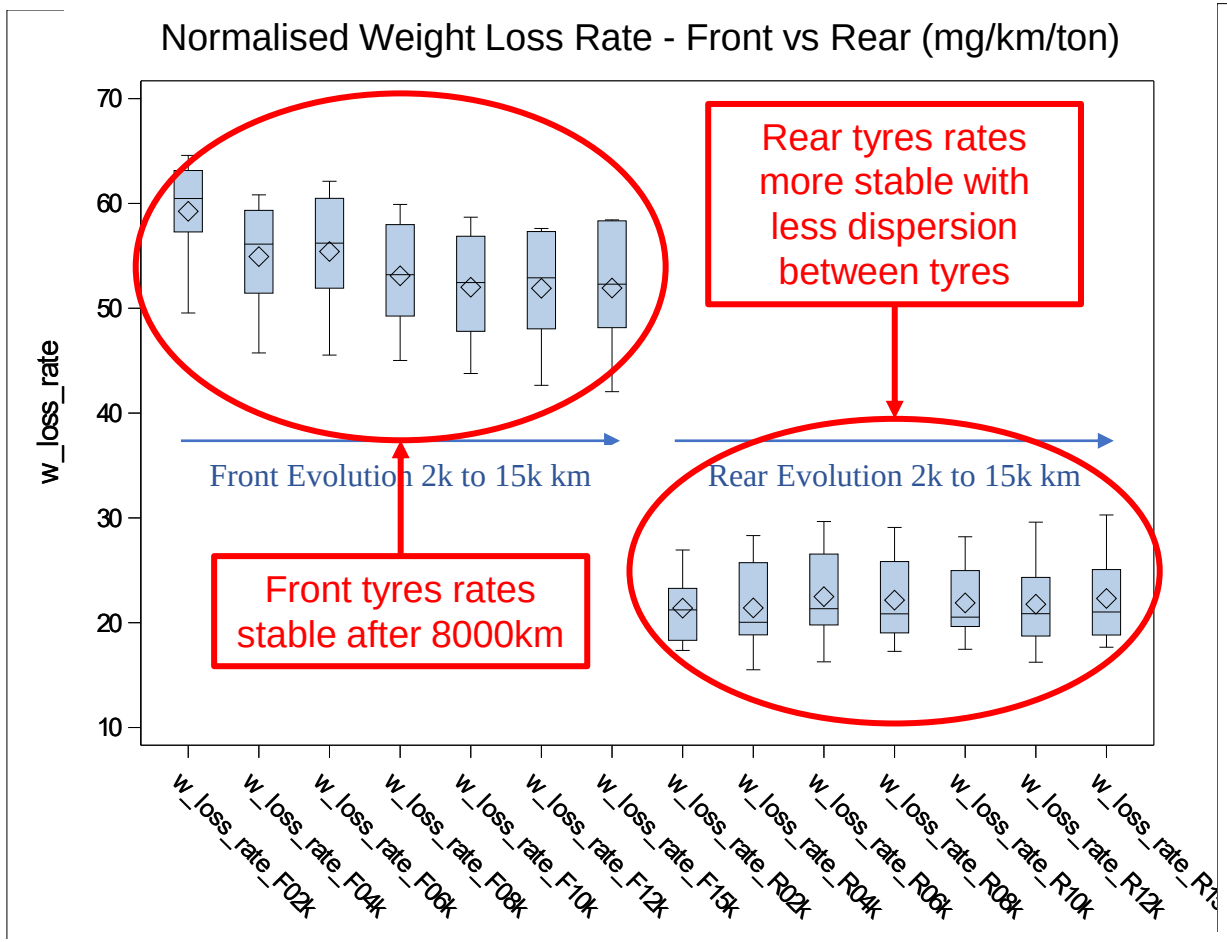


12 measures per box (2 tyres – 6 vehicles)

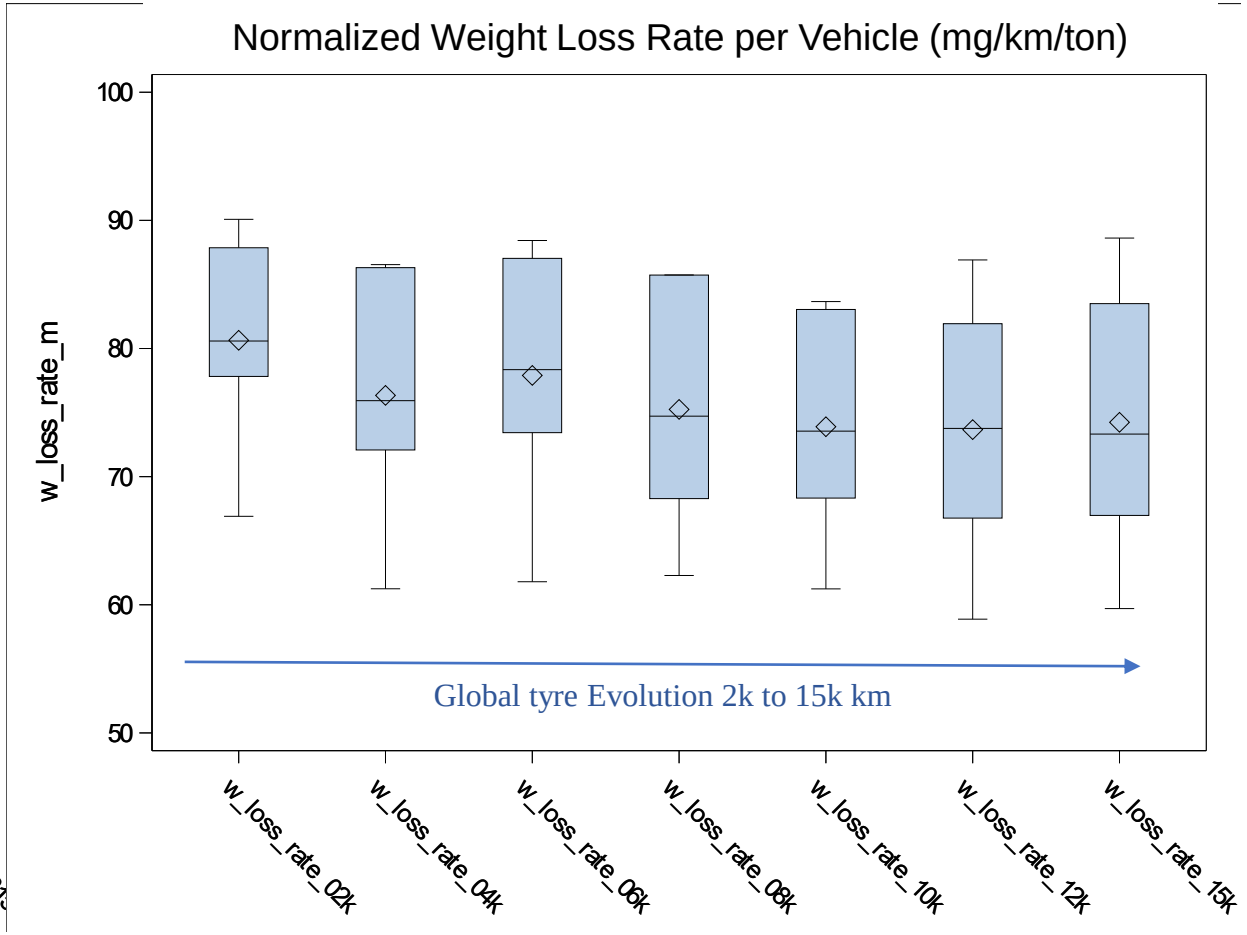
- Higher wear rates on Front than on Rear tyres.
- Irregular wear profile on Front tyres with higher wear in the centre tread.
- Front / Rear inflation pressure: 2,9b, as per TADG-ORV Test Method proposal.
- Static tyre load within 67% ± 7% of total tyre load capacity as per TADG-ORV Test Method proposal.
- ICE vehicle: FWD / BEV: AWD.
- Wheel alignment set up according to vehicle manufacturer nominal specifications to avoid vehicle instability.
- Vehicle manufacturer wheel alignment spec for FWD ICE vehicles and AWD BEV within TADG-ORV Test Method proposal for FWD candidate vehicle.

WP4 – Statistical Analysis – Data Exploration

- Tyre Weight Loss Rate Evolution – Box Plots:



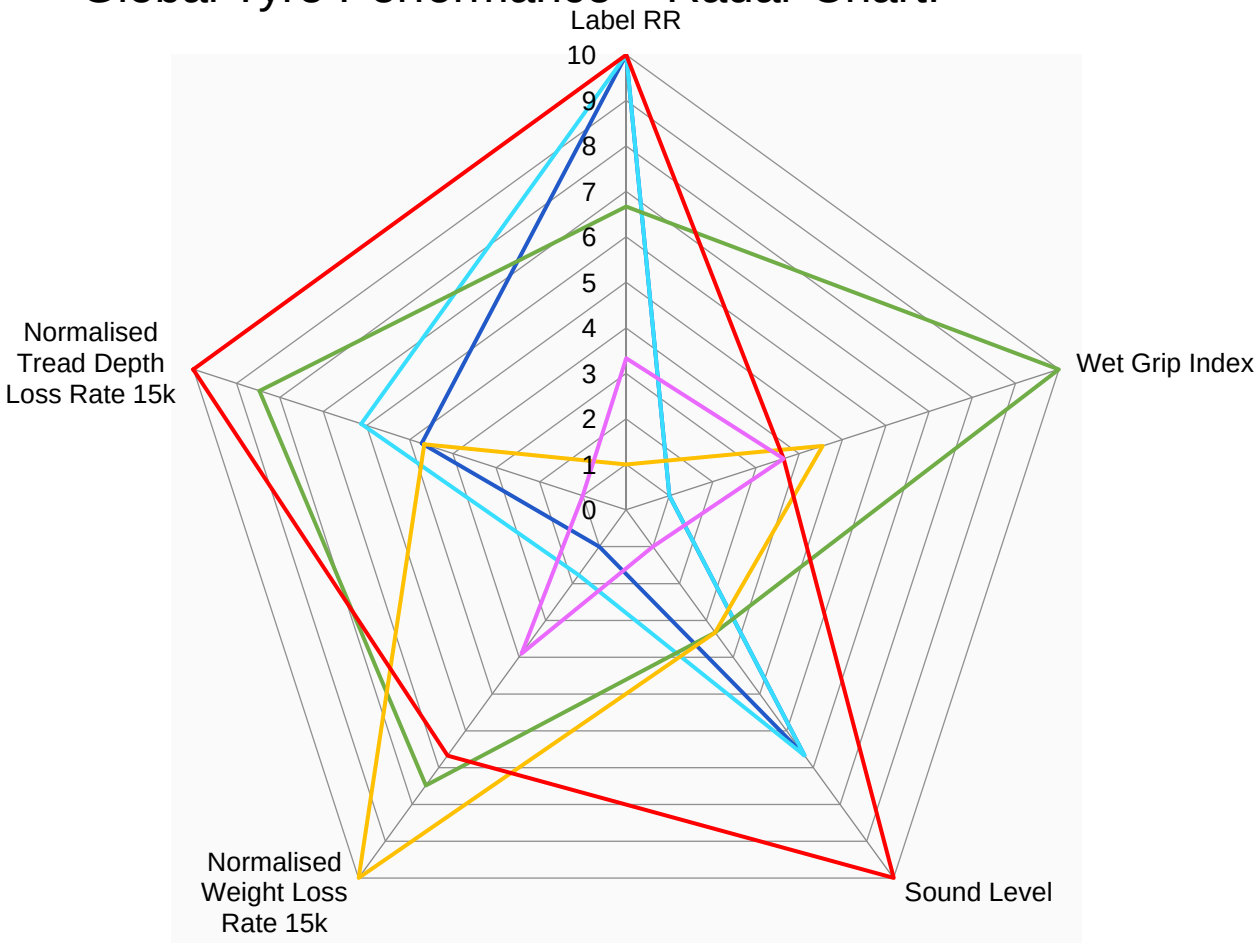
12 measures per box (2 tyres – 6 vehicles)



24 measures per box (4 tyres – 6 vehicles)

WP4 – Statistical Analysis – Data Exploration

- Global Tyre Performance – Radar Chart:



REF AB OE — Eco
BEV AB OE — Eco
BA OE — Comfort
DB AM — High perf
AA AM — Eco
CA AM — High perf

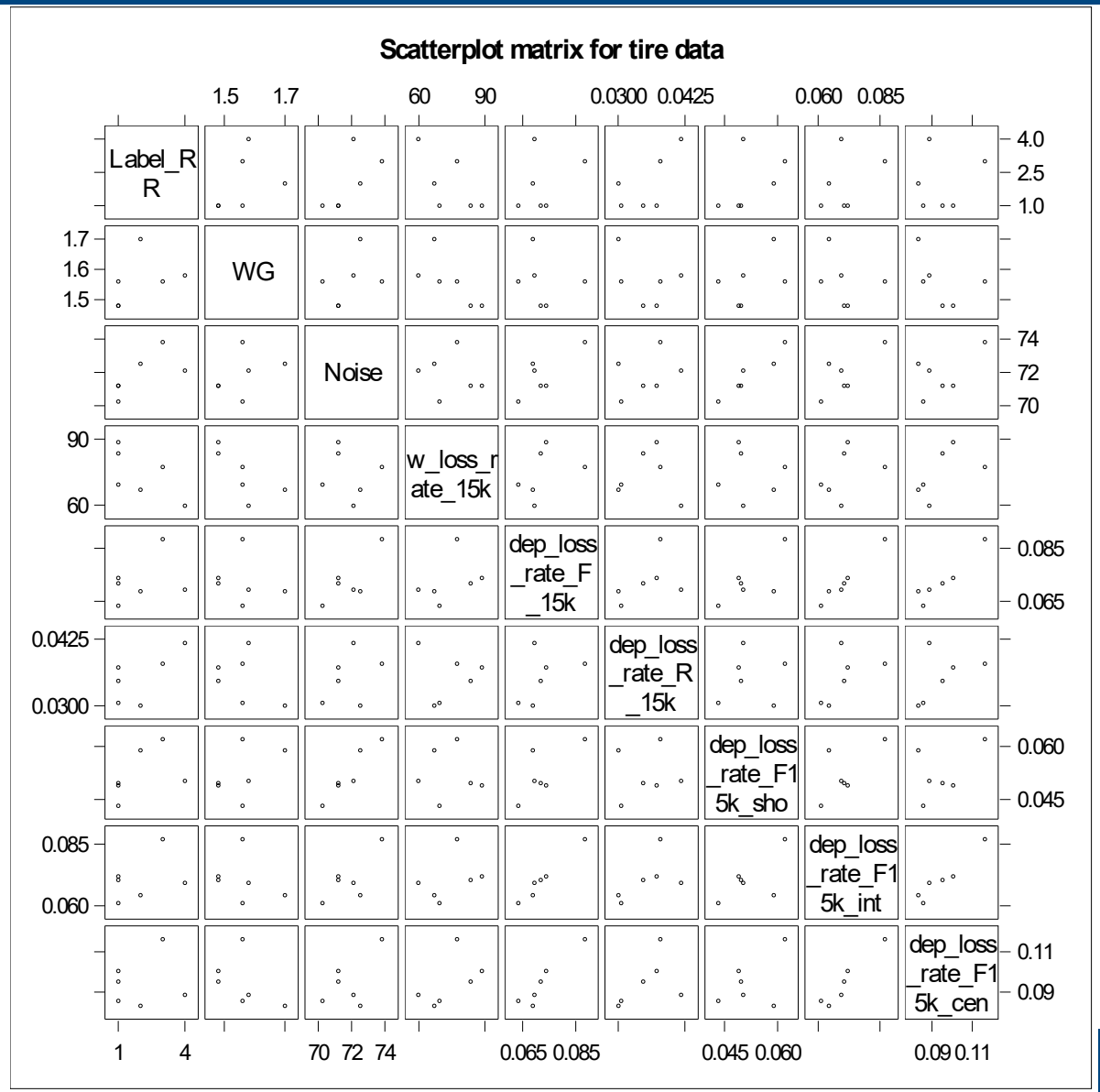
10 : Defined by the best tyre of the sample

1 : Defined by the worst tyre of the sample

- Observations aligned with WP1 – Literature Review Findings:
  - No clear correlation highlighted with weight loss rate or tread depth loss rate.
  - Good tyre in RR can be good for tread depth loss rate.
  - Good tyre in Noise can be good for tread depth loss rate.
  - Good tyre in Wet Grip can be good for tread depth loss rate and weight loss rate.
  - Weight loss rate and tread depth loss rate not correlated.
- No clear picture to be drawn between:
  - OE vs AM tyres.
  - Eco vs Comfort vs High Performance tyres.
- Tyres cornering stiffness to be measured to confirm tyres type and influence of handling performance on global tyre performance.

WP4 – Statistical Analysis – Correlation Analysis

- Significant Relationship between variables:
  - Correlation between 2 characteristics if Pearson correlation coefficient is significant (probability value, p-value < 0,05).
- Variables considered:
  - RR label,
  - Wet Grip label,
  - Noise label,
  - RR / Wet Grip / Noise label,
  - Wet Grip Index,
  - Sound Level,
  - Normalised Weight Loss Rate:
    - per Vehicle / Front / Rear,
    - after 2k / 4k / 6k / 8k / 10k / 12k / 15k km,
  - Normalised Tread Depth Loss Rate:
    - per Vehicle / Front / Rear,
    - after 2k / 4k / 6k / 8k / 10k / 12k / 15k km,
    - Centre tread grooves (3 & 4) / Intermediate tread grooves (2 & 5) / shoulders (1 & 6).



WP4 – Statistical Analysis – Correlation Analysis

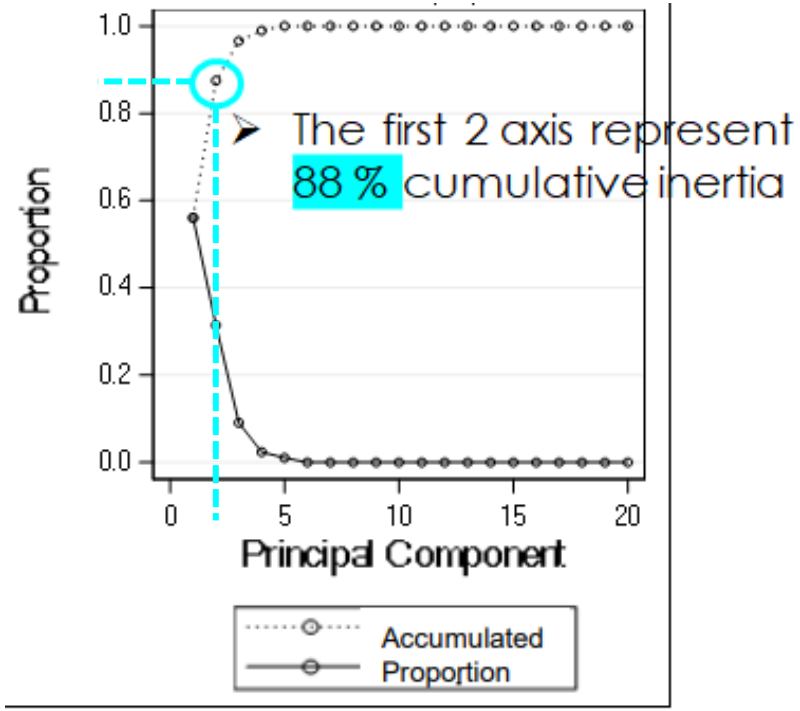
- Significant Relationship with weight loss rate or tread depth loss rate:

	Variable 1	Variable 2	Pearson Correlation coefficient example	P-value example
1	Noise	Tread depth loss rate (2k/4k/6k/8k/10k/12k, Front 15k shoulder)	Front 15k shoulder: 0.95	Front 15k shoulder: 0.003
2	Label (RR + WG + Noise) (AAA:3, AAB =4,…)	Tread depth loss rate (2k / 8k, Rear 15k shoulder)	Rear 15k shoulder: 0.93	Rear 15k shoulder: 0.008
3	Label Noise (A=1, B=2 ….)	Weight loss rate (Rear 2k / 6k)	Rear 2k: -0.89	Rear 2k: 0.017
4	Label Noise (A=1, B=2 ….)	Tread depth loss rate (2k / 4k / 6k / 8k / 10k, Rear 15k shoulder)	6k: 0.85	6k: 0.031
5	Label RR (A=1, B=2 ….)	Weight loss rate (2k, Rear 2k / 6k)	Rear 2k: -0.87	Rear 2k: 0.026
6	Label RR (A=1, B=2 ….)	Tread depth loss rate (2k, Rear 15k shoulder)	2k: 0.87	2k: 0.026

- Correlation between RR label and weight loss rate to be confirmed with RR measurements as per R117.
- No correlation found between Noise measurement and weight loss rate.
- No correlation found between Wet Grip and weight loss rate or tread depth loss rate.

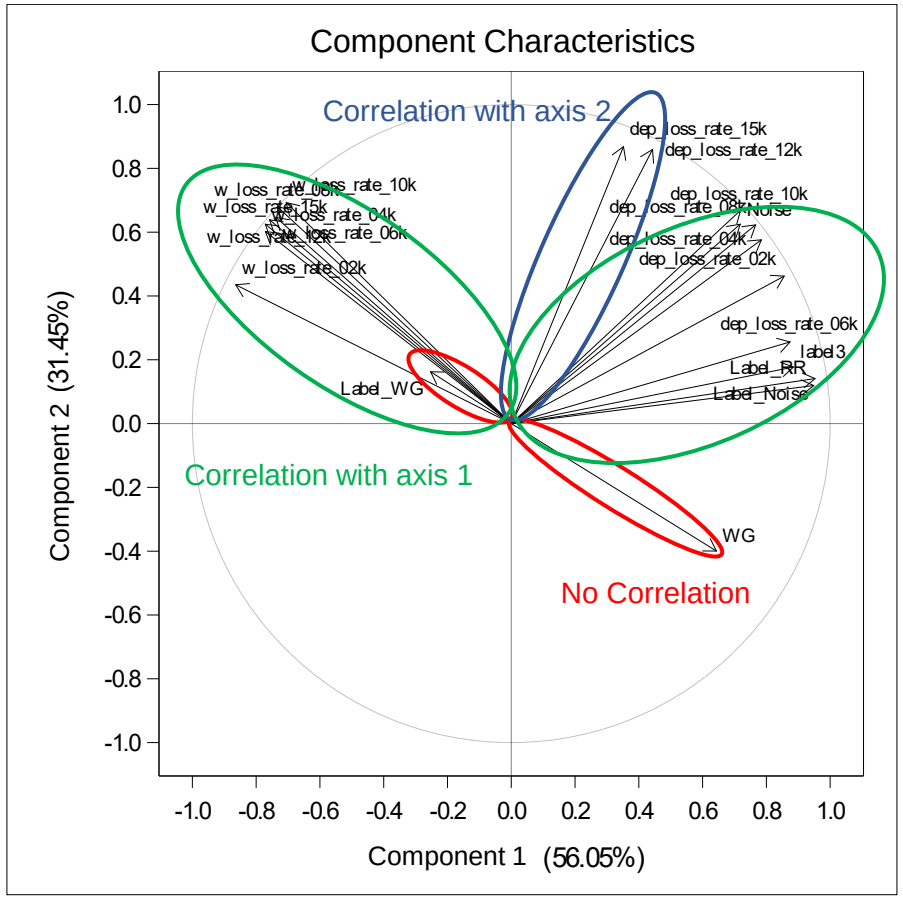
WP4 – Statistical Analysis – Principal Component Analysis

- Principal Component Analysis (PCA):
  - Mathematical procedure used to convert a set of possibly correlated variables into a smaller set of uncorrelated variables called principal components.
  - PCA used here to reduce a set of 20 characteristics (label, RR, Wet Grip, Noise, Tread Depth Loss Rate (after 2k / 4k / 6k / 8k / 10k / 12k / 15k km), Weight Loss Rate (after 2k / 4k / 6k / 8k / 10k / 12k / 15k km) to 2 variables.
- PCA results:
  - Inertia of the first dimensions:
    - Shows if strong relationships between variables,
    - Suggests the number of dimensions to be studied.
  - First 2 components of PCA express 88% of the total dataset inertia → 1st plane well represents data variability.



WP4 – Statistical Analysis – Principal Component Analysis

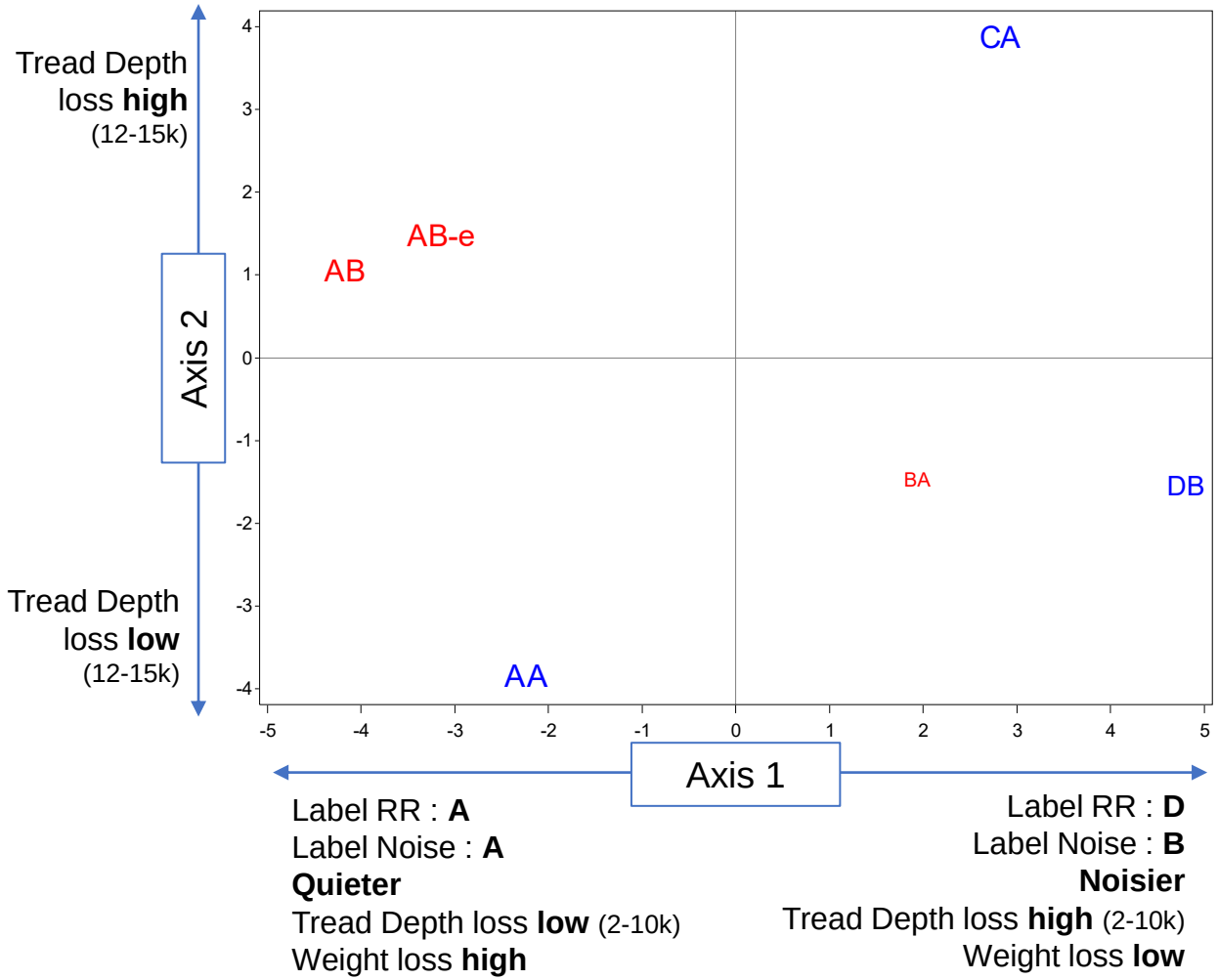
- PCA Results:
  - Circle of correlations: projection of the cloud of variables on the level of the main components.
  - The variables close to the circle are well represented, those close to the origin are poorly represented.



Part of inertia	56%	31%	9%
	Axis 1	**Axis 2**	**Axis 3**
Depth loss rate (2-10k)	~ 0.85	~ 0.46	~ -0.08
Depth loss rate (12-15k)	~ 0.44	~ 0.85	~ -0.08
Weight loss rate (2-15k)	~ -0.86	~ 0.43	~ 0.20
label3	0.88502	0.17721	-0.41404
Label RR	0.94854	0.11917	-0.27238
Label WG	-0.25291	0.16245	-0.90412
Label Noise	0.95283	0.14110	0.18091
WG	0.64342	-0.39953	0.55614
Noise	0.71800	0.62501	0.27369

WP4 – Statistical Analysis – Principal Component Analysis

- PCA Visualisation and Explanation:
  - Trend between Rolling Noise and Tread Depth Loss Rate,
  - Opposition trend between Rolling Noise and Weigh Loss Rate,
  - Opposition trend between Weight Loss Rate and Tread Depth Loss Rate,
  - Different Tread Depth Loss Rate evolution for some tyres after 10,000km.
- Comments on PCA Results Representativeness:
  - PCA can be considered as descriptive method: it summarises the information but does not explain it,
  - Recommended to have a relatively large sample to ensure an optimal statistical power of the analysis: at least a ratio of 10 subjects per variable.
  - With a sample of 6 tyres, trends shown maybe valid for this sample but necessary to remain cautious regarding generalization of interpretations given the representativeness of the tyres' population.



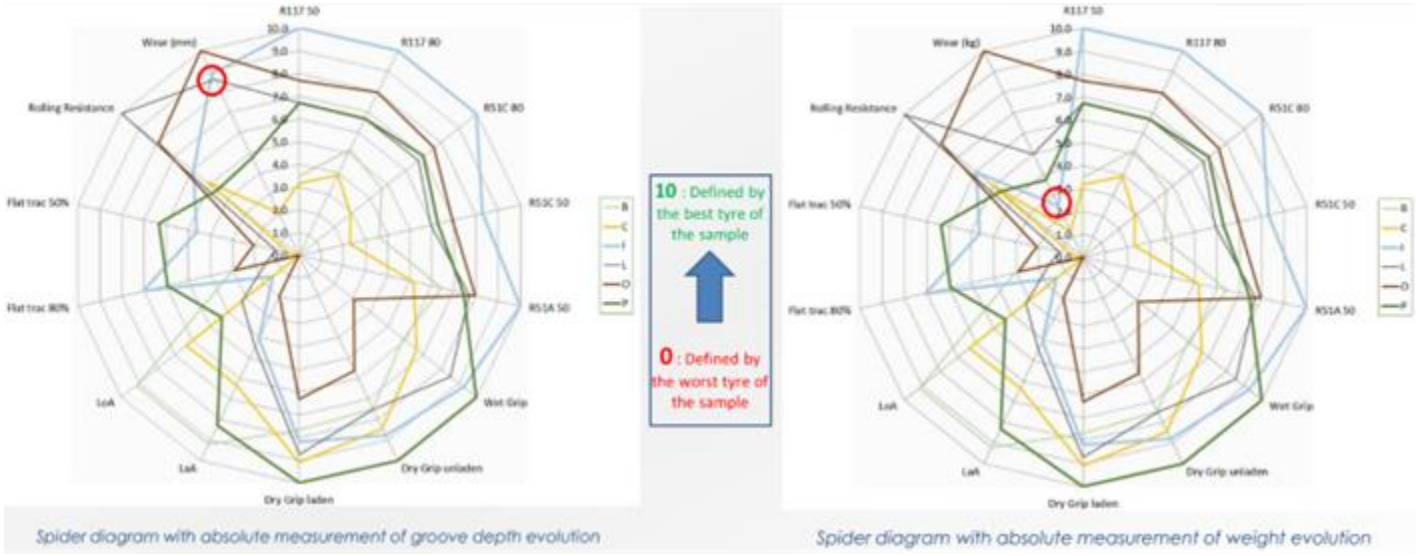
CONCLUSIONS AND NEXT STEPS

- Conclusions:
  - Correlation found between Rolling Noise and Tread Depth Loss Rate after up to 10,000km confirmed by trend shown by PCA,
  - Trends shown by PCA:
    - Quieter Tyre ↔ Higher Weight Loss Rate,
    - Higher Rolling Resistance Label ↔ Higher Weight Loss Rate,
    - Higher Weight Loss Rate ↔ Lower Tread Depth Loss Rate after up to 10,000km.
  - No correlation found between Wet Grip and Weight Loss Rate or Tread Depth Loss Rate.
  - Different tyre tread depth loss rate evolution for some tyres after 10,000km.
  - Analysis based on label values only not conclusive → Need for tyre performance measurements for robust tyre performances interdependency analysis.
  - No clear picture between OE and AM tyres in terms of tyre performances interdependency.
- Next Steps:
  - PCA to be applied to larger set of data available to confirm trends from sample of 6 tyres: Jan-24,
  - Tyres Rolling Resistance to be measured as per R117 to confirm correlation found with RR label: Jan-24,
  - Tyre Cornering Stiffness to be measured to confirm tyre types and influence of handling performance: Jan-24,
  - Statistical Analysis update: Jan-24 (to be confirmed vs additional tyre measurements timing),
  - Conclusions to be included in study final report presentation to GRPE 90th session / GRBP 79th session.

www.utac.com

ANNEX - WP1 – LITERATURE REVIEW - FINDINGS

- Tyre performances interdependency:
  - Tyre wear / abrasion vs rolling resistance: good level can be achieved for both performances, depending on:
    - Strategy chosen during tyre development,
    - Type of tyre considered (ie: eco vs high performance / sport).
  - Tyre wear / abrasion vs rolling noise: good level can be achieved for both performances, depending on:
    - Strategy chosen during tyre development,
    - Type of tyre considered (ie: eco vs high performance / sport).
  - Tyre wear / abrasion vs safety: challenging to achieve good level for both performances:
    - Investments required in development and implementation of innovative technical solutions.



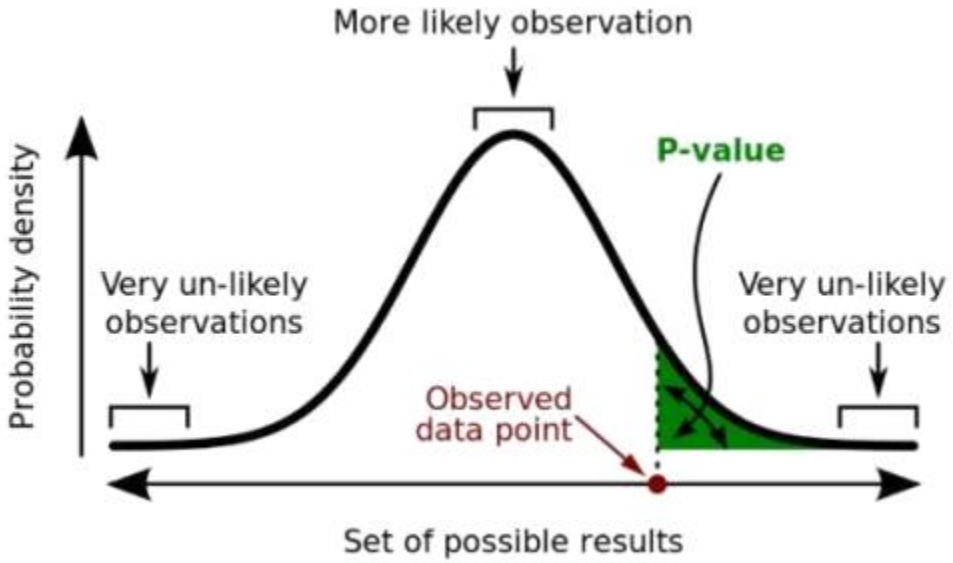
Spider diagram with absolute measurement of groove depth evolution

Spider diagram with absolute measurement of weight evolution

(UTAC, TA-03-04 OICA GRBP-75-19-Rev.1)

ANNEX – CORRELATION ANALYSIS

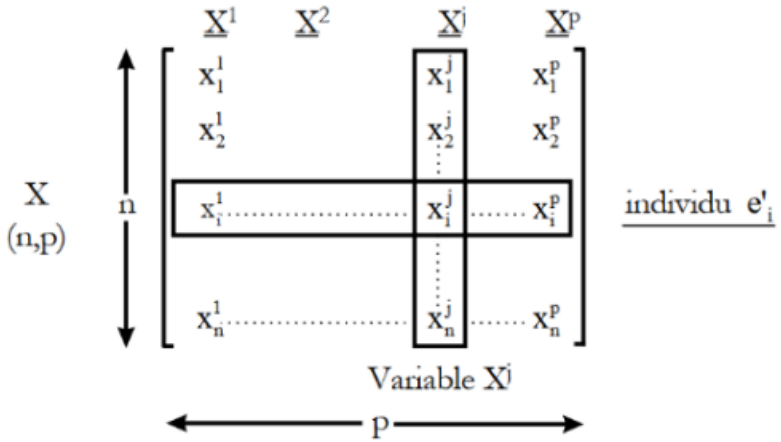
- P-Value:
  - The **p-value or probability value** is, for a given statistical model, **the probability that, when the null hypothesis is true, the statistical summary would be greater than or equal to the actual observed results**.
  - In the present case, the null hypothesis is: "**there is no correlation between characteristics**".
  - In other words, if **p-value is low then the null hypothesis is false** and **it can be concluded that there is a correlation**. The admitted threshold value is: 5%.



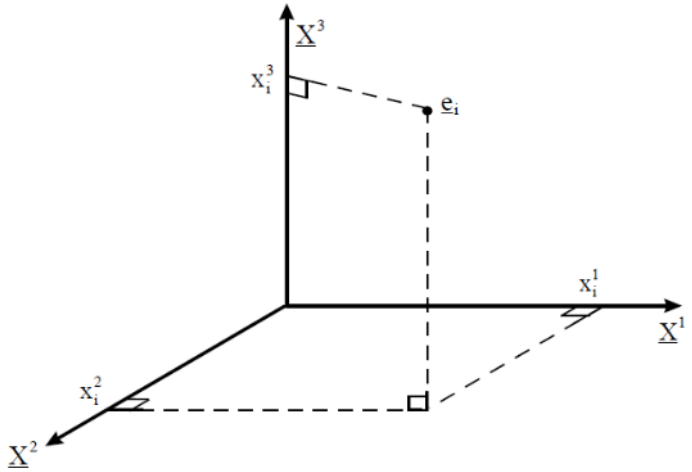
A **p-value** (shaded green area) is the probability of an observed (or more extreme) result assuming that the null hypothesis is true.

ANNEX – PRINCIPAL COMPONENT ANALYSIS

- Data:
  - n individuals observed on p quantitative variables
  - Individual: element of R^p
  - Variable: element of R^n



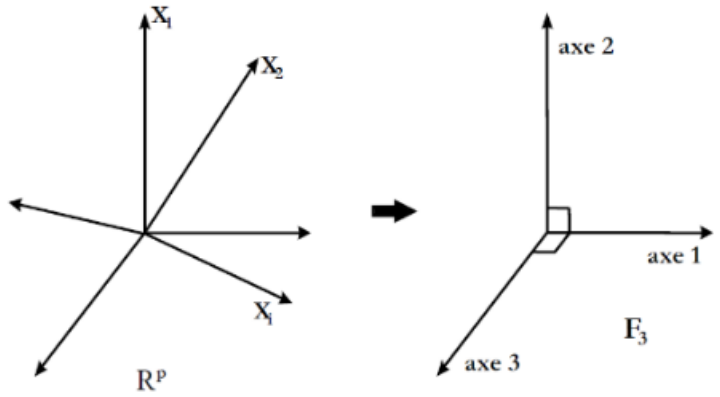
- Cloud of individual representation:
  - To each individual noted e_i, a point can be associated in R^p
  - Each variable in table X is associated with an axis of R^p.



ANNEX – PRINCIPAL COMPONENT ANALYSIS

- Cloud of individual representation:
  - Looking for a representation of the n individuals, in a subspace F_k of R^p of dimension k

  → Trying to define k new variables linear combinations of the p initial variables that will cause as little information loss as possible.



- As little information loss as possible:
  - F_k will have to be "adjusted" as best as possible to the cloud of individuals: the sum of the squares of the distances from individuals to F_k must be minimal.
  - F_k is the subspace such that the projected cloud has a maximum inertia (dispersion).

  → Based on notions of distance and orthogonal projection.