Submitted by the experts of OICA

Informal Document **GRPE-90-20-Rev.1**
90th GRPE, 09-12 January 2024
Agenda Item 7 (c)

# Tyre Abrasion Study for vehicles of category M & N

## Study performed by UTAC on behalf of ACEA / OICA

Informal Document GRPE-90-20-Rev.1
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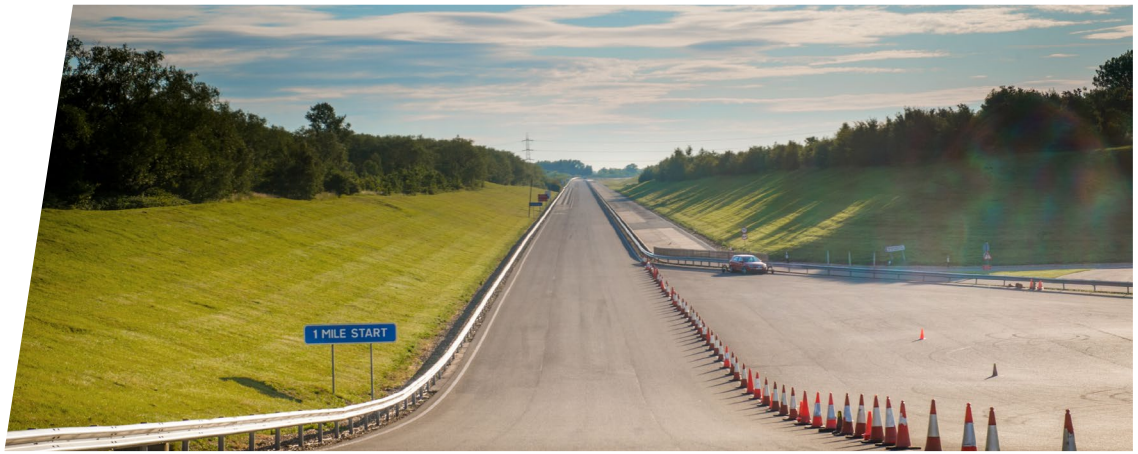



UTAC

# Tyre Abrasion Study for ACEA

*90th GRPE*

# CONTENTS

- Tyre Abrasion Study Overview
- WP1 – Literature Review
- 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:

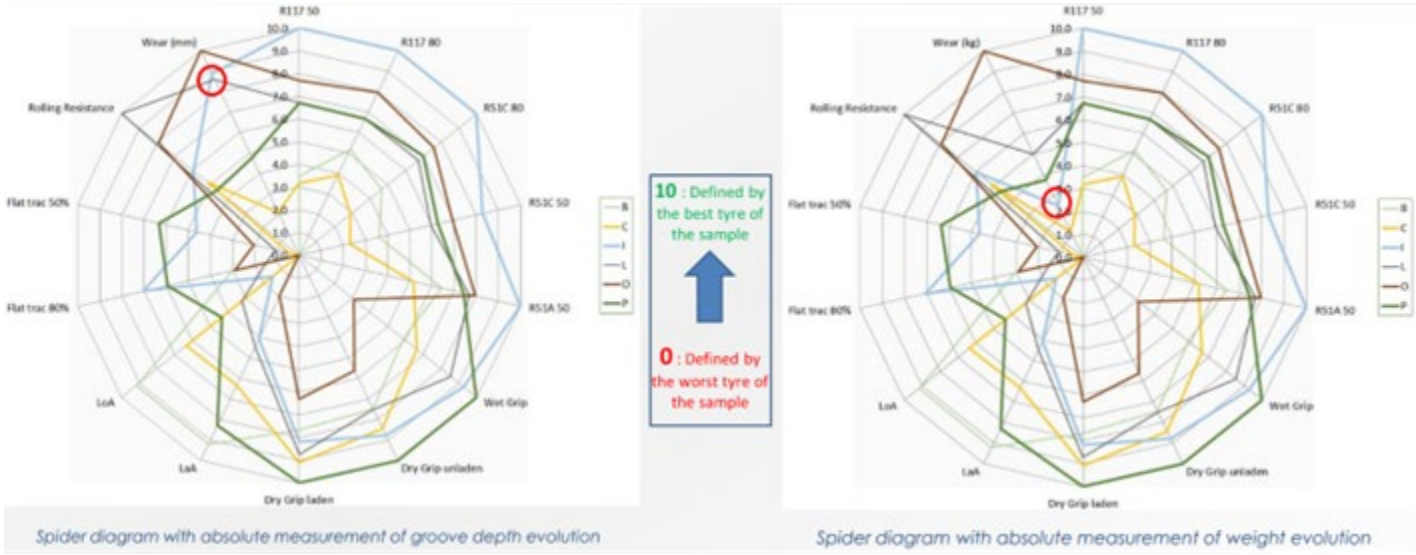
| Work Packages | | Updated Timing |
|---|---|---|
| WP1 | Literature Review | Jun-23 (completed) |
| WP2 | EPREL Tyre Database Analysis | Aug-23 (completed) |
| WP3 | Real Life Testing | Aug-23 (completed) |
| WP4 | Test Results Analysis | Initial Analysis: Oct-23 (completed)<br>Analysis update following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

# WP1 – LITERATURE REVIEW - SCOPE

- Tyre abrasion and mileage for:
  - C1, C2 & C3 tyres,
  - Summer & 3PMSF tyres.
- Aspects considered:
  - Driving behaviour influence on tyre wear / abrasion,
  - Vehicle design influence on tyre wear / abrasion,
  - Tyre performances interdependency,
  - Tyre wear / abrasion testing,
  - Tyre & Road Wear Particles (TRWP) emissions.
- Review included, but was not limited to, relevant studies presented in GRBP TF TA.

# 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)

# 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

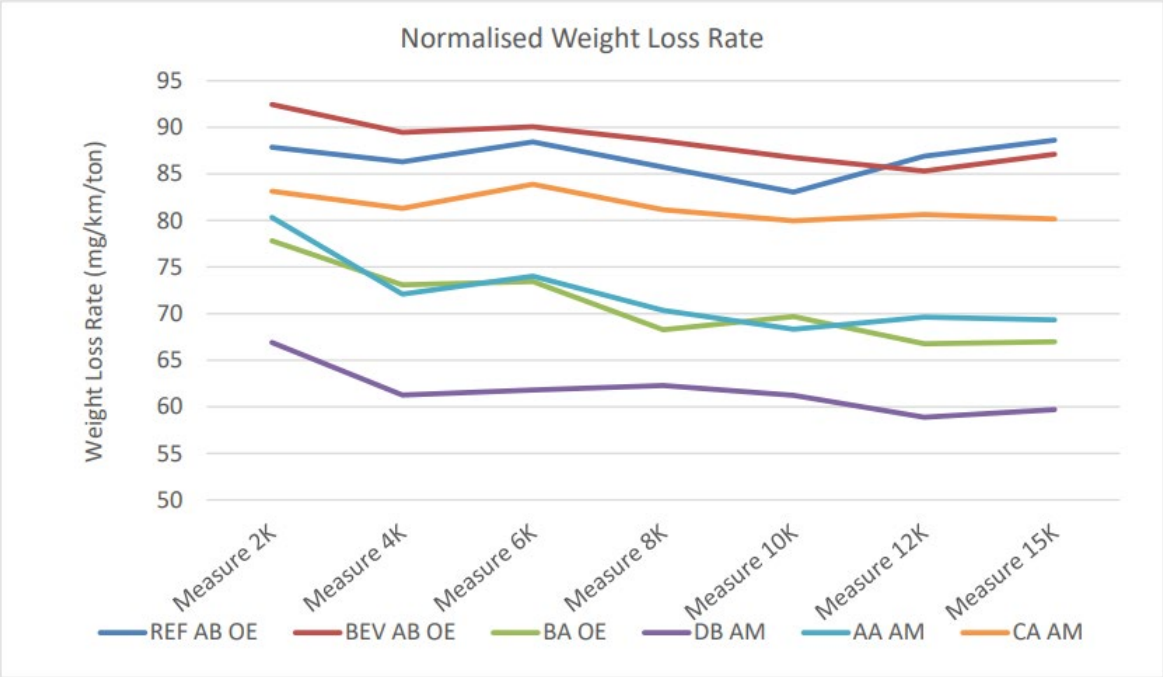
# WP3 – REAL LIFE TESTING

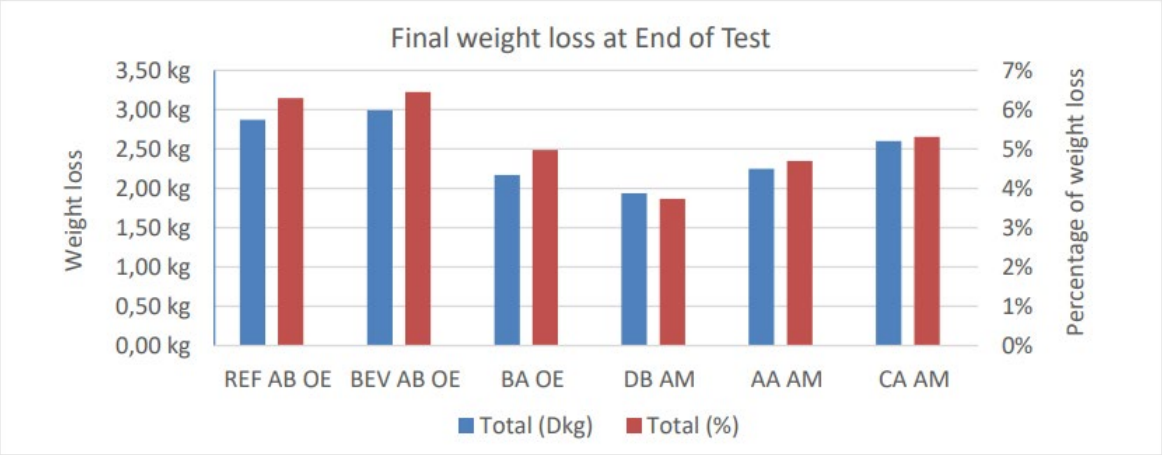
- Circuit:
  - Specifications as close as possible to TADG-ORV Test Method proposal,
  - Open road circuit around UTAC Mortefontaine site (Northern France),
  - Compatible with BEV range & charging constraints.
  - *Note: acceleration levels being checked vs calculation method in TADG-ORV Test Method 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: Rear Left 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:

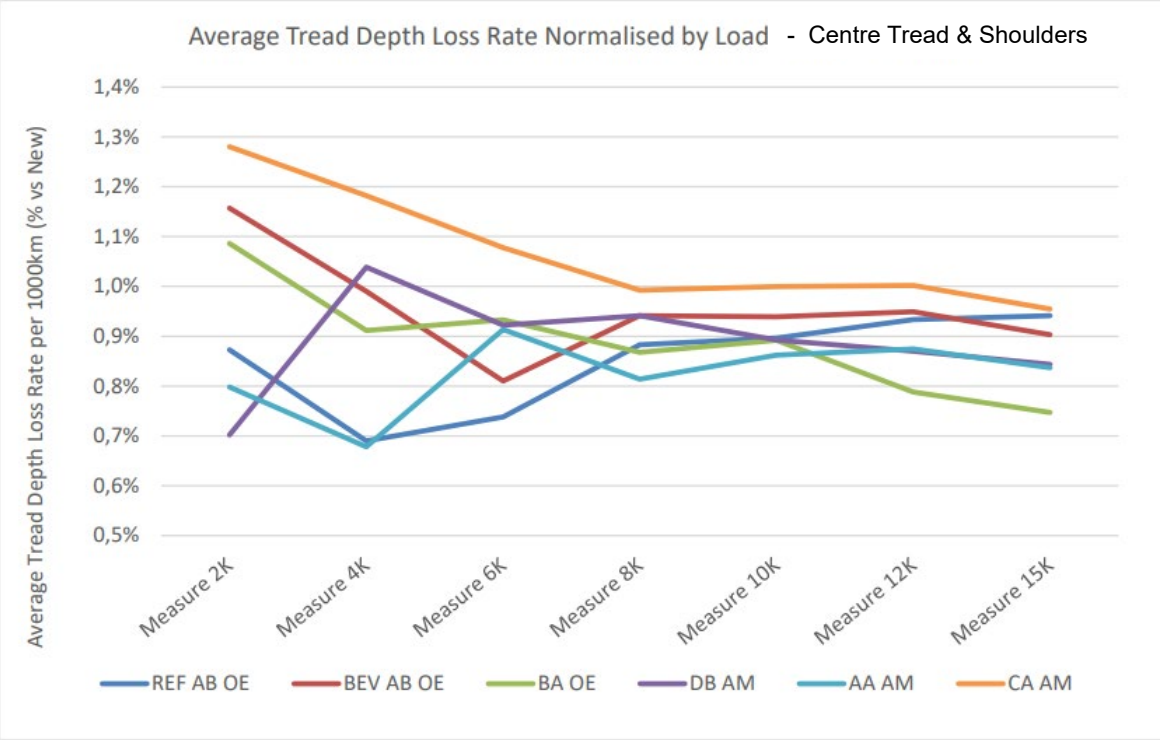


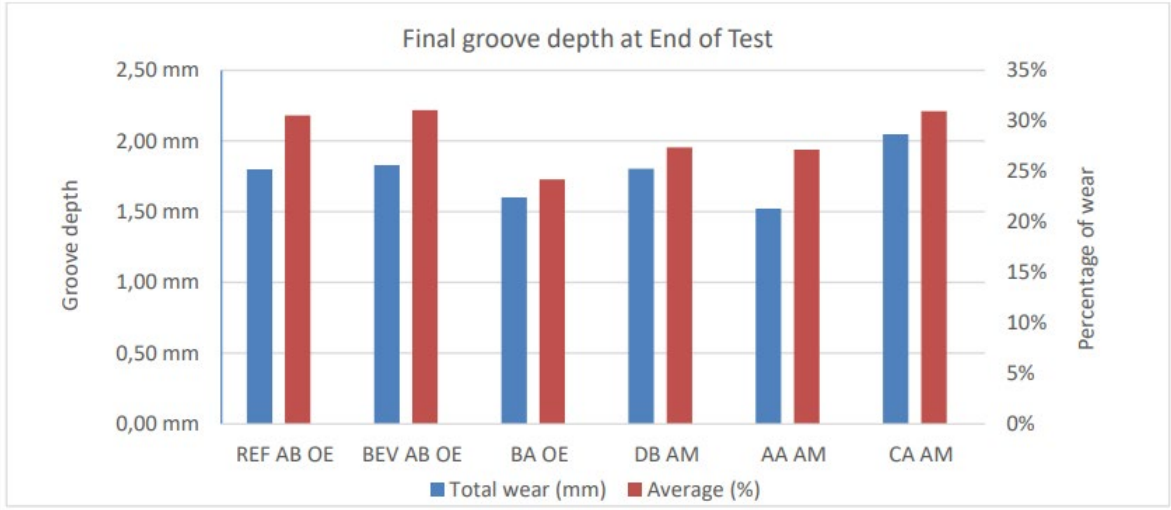




- REF AB OE: Rear Right tyre counted twice due to Rear Left tyre replacement during testing,
- Vehicle weight influence on weight loss rate observed → Change in test results when normalised by vehicle load,
- Similar weight loss rate between ICE and BEV when tested in same convoy and results normalised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

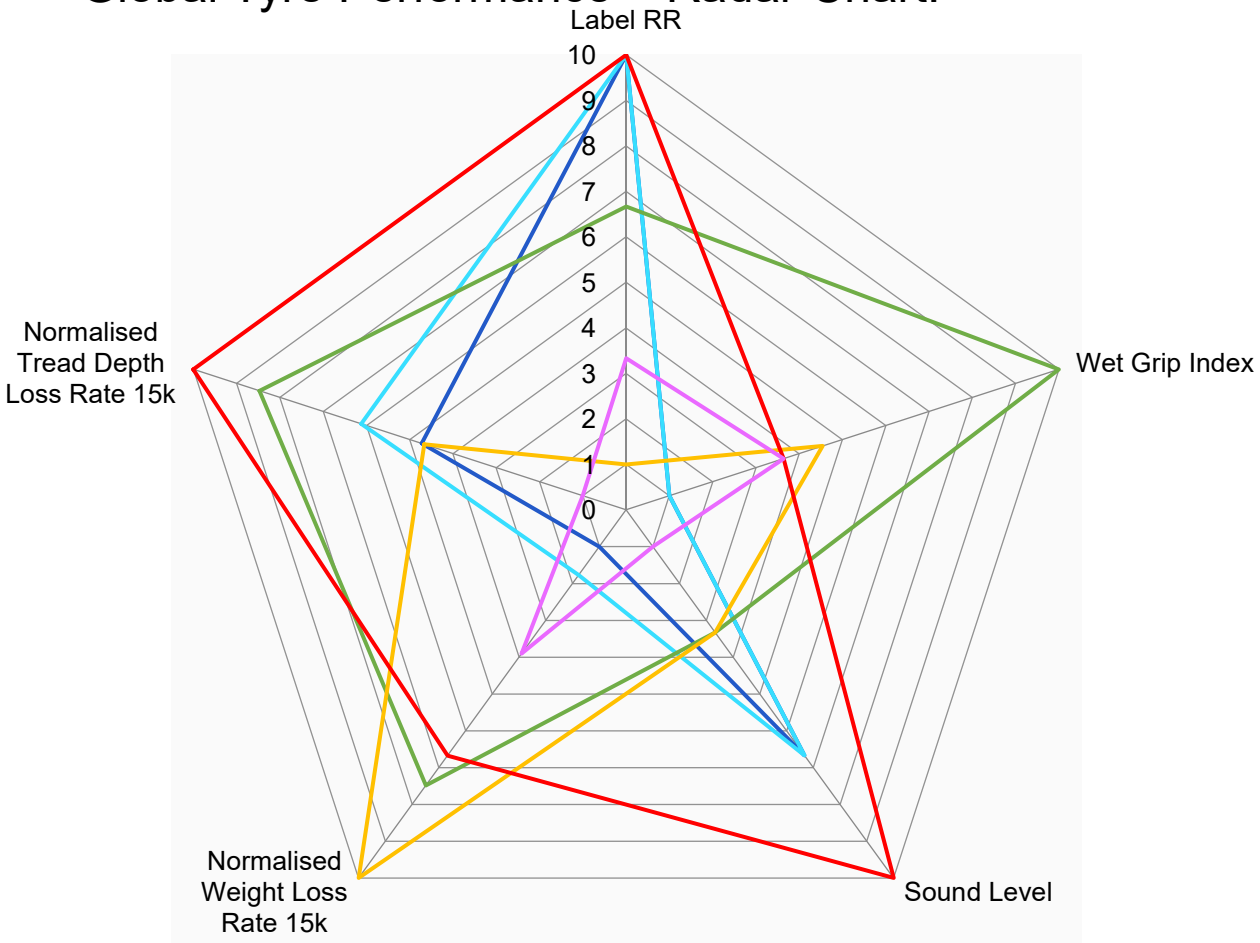
- Tyre Labels Value and Tyre Test Results:

| 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

- 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

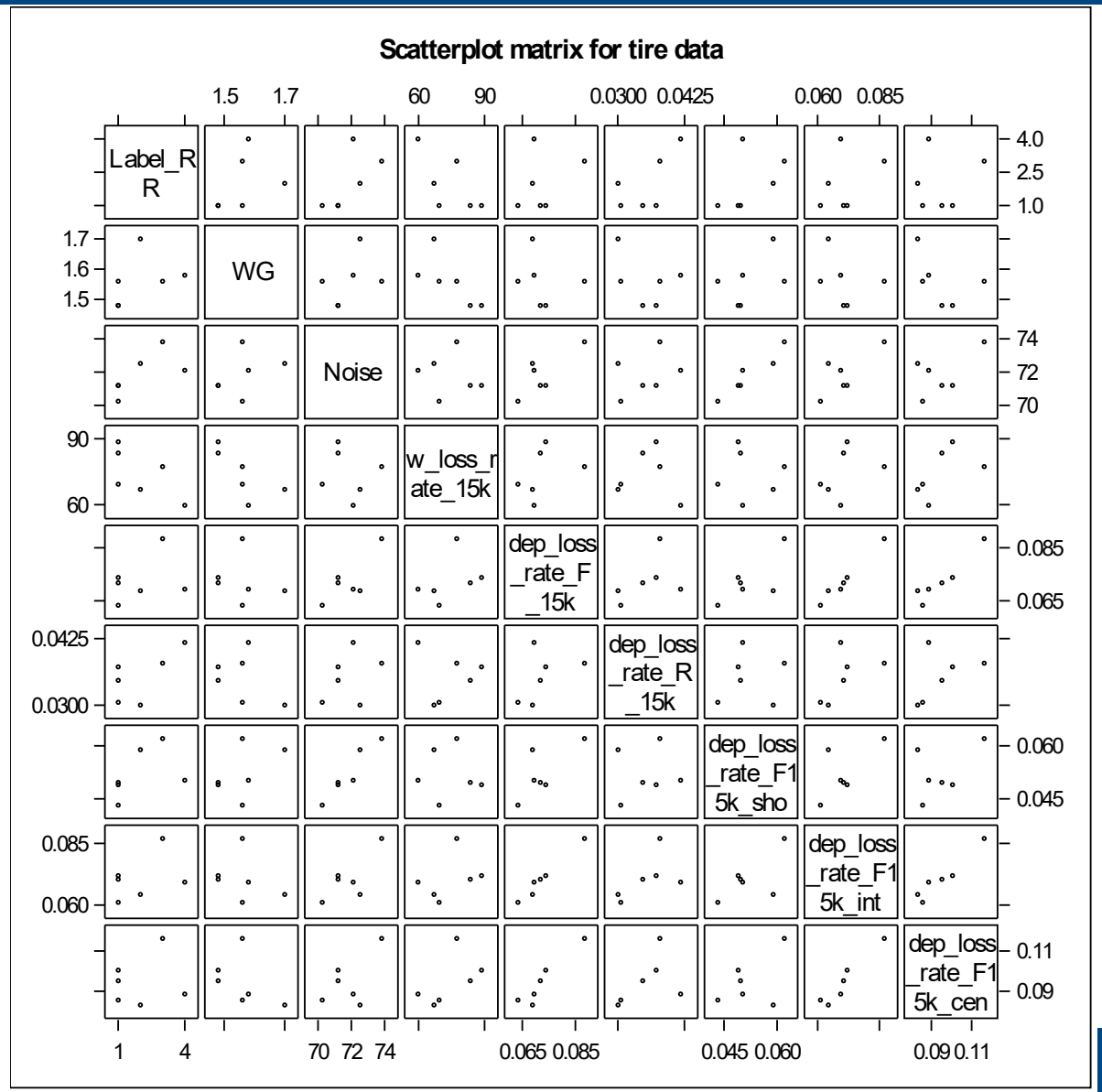
**10** : Defined by the best tyre of the sample

**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

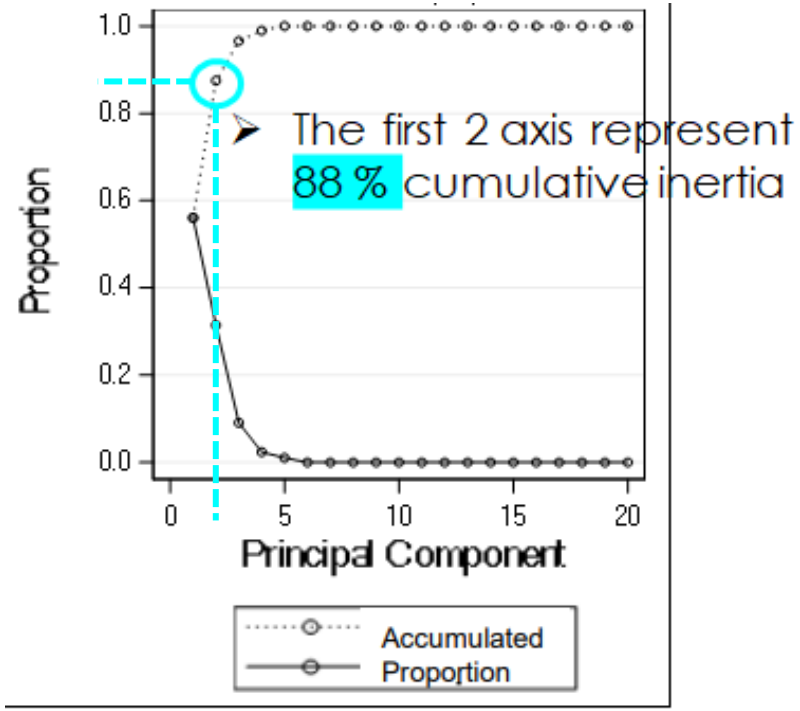
- Significant Relationship with weight loss rate or tread depth loss rate:

| | 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.

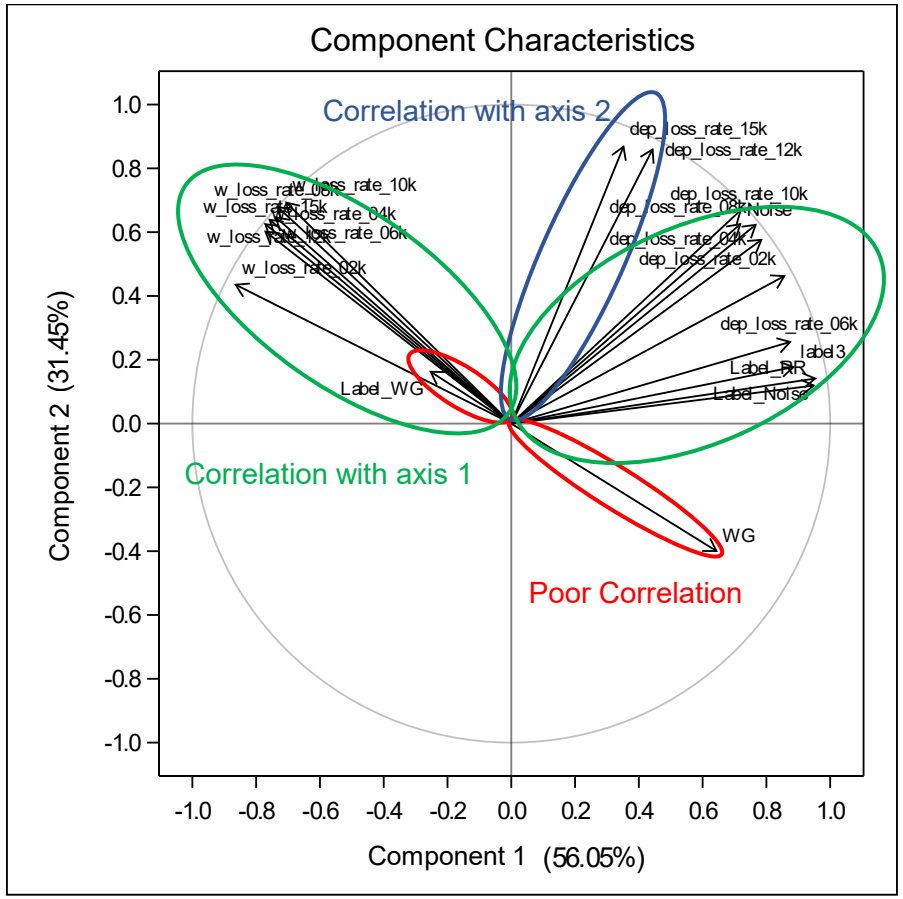
# WP4 – Statistical Analysis – Principal Component Analysis

- 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

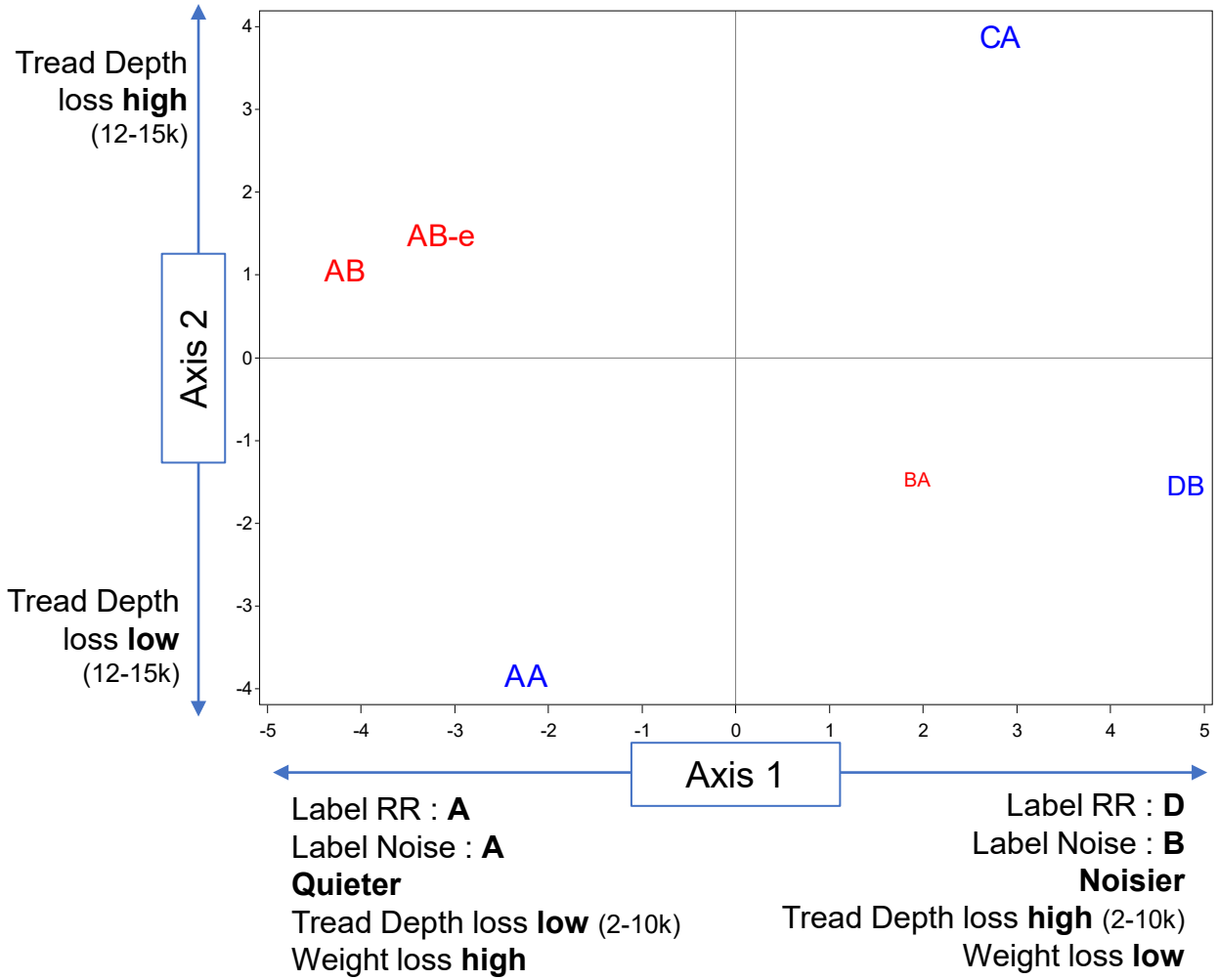
- PCA Results:
  - Circle of correlations: projection of the cloud of variables on the level of the main components.
  - The variables close to the circle are well represented, those close to the origin are poorly represented.




| 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: Feb-24,
  - Conclusions to be included in study final report presentation to GRBP 79$^{th}$ session.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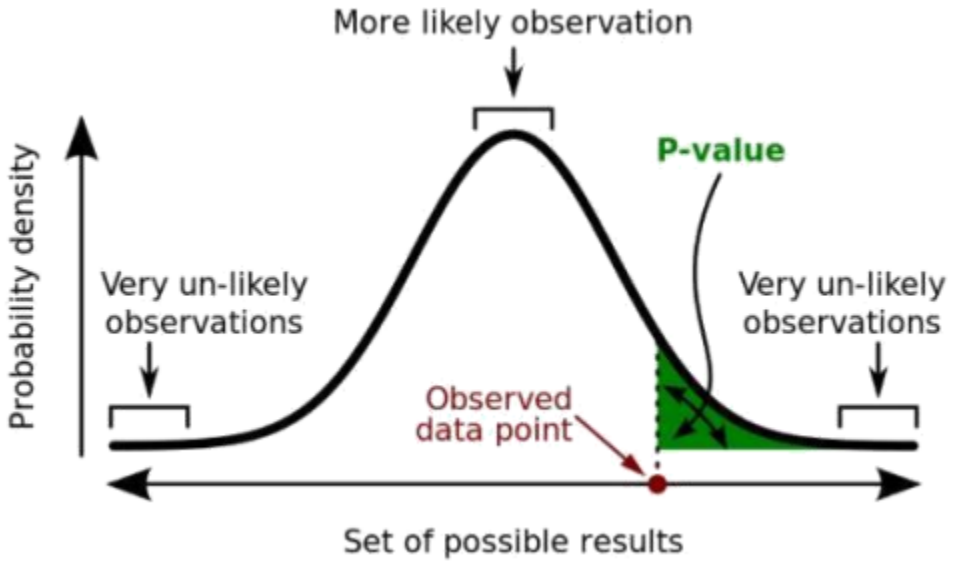
# ANNEX – CORRELATION ANALYSIS

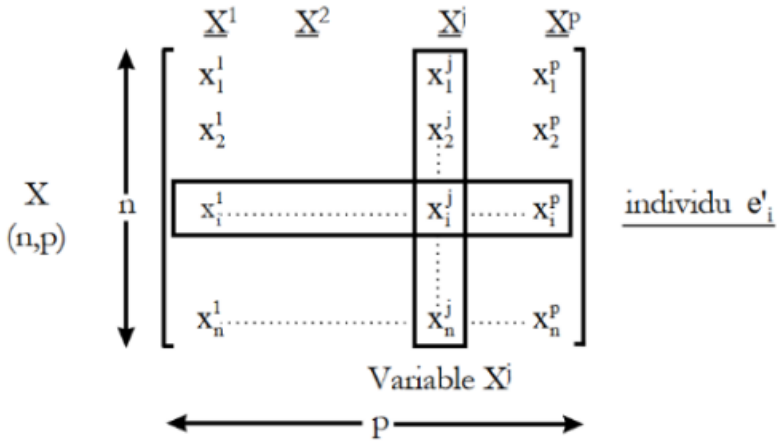
- P-Value:
  - The **p-value or probability value** is, for a given statistical model, **the probability that, when the null hypothesis is true, the statistical summary would be greater than or equal to the actual observed results**.
  - In the present case, the null hypothesis is: "**there is no correlation 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%.



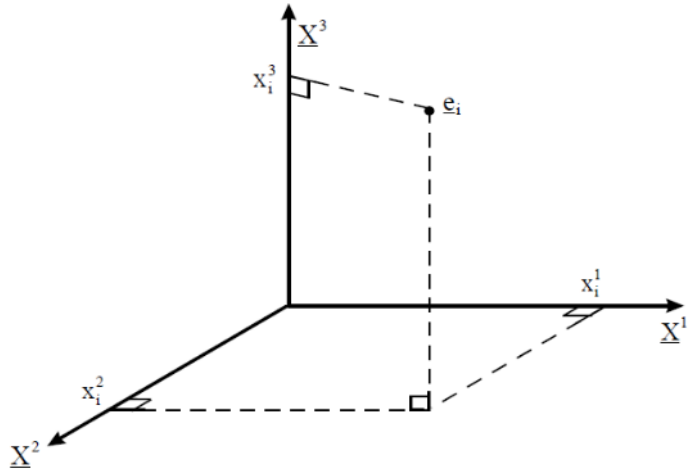

A **p-value** (shaded green area) is the probability of an observed (or more extreme) result assuming that the null hypothesis is true.

# ANNEX – PRINCIPAL COMPONENT ANALYSIS

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



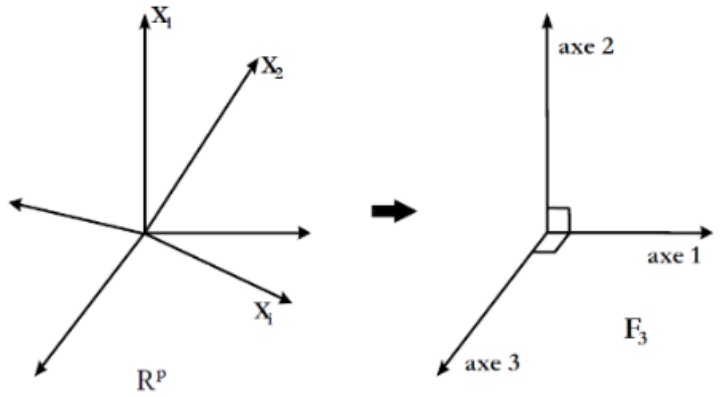

- Cloud of individual representation:
  - To each individual noted $e_i$, a point can be associated in $R^p$
  - Each variable in table X is associated with an axis of $R^p$.



# 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.