Submitted by the experts of OICA

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Informal Document **GRBP-70-25**
70th GRBP, September 11-13, 2019
Agenda item 13

ACEA - Tyre Performance Study
Noise VS other performances

12/09/2019 – GRBP, 70th

Content

1 - Literature Study

Reason for why the literature study was conducted

- **Is it possible to optimize Rolling Sound performance without compromising other parameters essential for vehicle safety and CO2 emission reduction ?**

- **Do performance parameters, i.e. like**
  - Rolling Sound (coast-by) ➔ Health Protection
  - Rolling Resistance ➔ Environmental Protection (CO_2 emission reduction)
  - Wet Grip ➔ Safety (braking distance, handling)

- **…affect other performance parameters like**
  - Longitudinal and Lateral Aquaplaning
  - Rolling Sound during Acceleration
  - Dry Grip
  - Dry Handling
  - Wet Performance
  - Wear Life

Significant studies which have been analysed

- **Journalistic Studies**
  - EVO103_LD (2015)
  - Auto Express Studies (2018)
  - Whichcar Wheels (2017)
- **European Research Organization Studies**
  - GRB-61-03 Study based on TNO 2014 R10735 report (12 June 2014)
  - FEHRL – Study SI2,408210 Tyre/Road Noise (2007)
- **Internal Manufacturer Studies**
  - Noise Technology (Continental - 2011)
  - Noise Trade-offs (Michelin - 2007)
  - Tire-Road Noise (Goodyear - 2018)
  - Noise (Michelin – 2015)
- **Technical University Studies**
  - Inter.noise_HAMBURG 2016
  - Tyre modelling for rolling resistance (MASTER'S THESIS IN AUTOMOTIVE ENGINEERING) 2014

Analysis template

- **Framework**
  - Framework and goal of the studies
- **Content**
  - Description of the content and the parameters of the studies
- **Vehicle type**
  - Information about vehicles used for each tests
- **Tyre types, sizes and dimensions**
  - Description of the sample used for each tests
- **Tracks**
  - Description of the tracks used for each tests
- **Test methods**
  - Description of the tests methods used
  - Description of the tests conditions
  - Description of the tests equipment

Summary of all important information regarding measured parameters and test method used

Study	Wet-Grip	Longitudinal aquaplaning	Aquaplaning in curve	Dry-Grip	Handling	Snow Performance	Rolling Resistance	Rolling Sound	RS during acceleration	Wear
TNO R10735 report (2014)	EU Regulation EC1222/2009	No Information	No Information	No Information	No Information	No Information	EU Regulation EC1222/2009	- EU Regulation EC1222/2009 - VENOLIVA	- EU Regulation EC1222/2009 - VENOLIVA	No Information
FEHRL – Study (2007)	- ECE R117 - 80 to 10km/h ; water depth 1,5mm	- ECE R117 - Water depth 8 mm ; slip of 15% was reach	No Information	No Information	No Information	No Information	- ISO 8767:1992 or 9948:1992 - ISO 18 164 : 2005	ECE R117	No Information	No Information
Continental (2011)	No Information	No Information	No Information	No Information	No Information	No Information	No Information	ECE R117	No Information	No Information
Michelin (2007 & 2015)	- 80 to 10 km/h - on macro rough surface	- Water depth 8mm - 82 to 66km/h	- Water depth 7mm - acceleration 55 to 85km/h	No Information	No Information	No Information	No Information	ISO 10 844	No Information	No Information
GoodYear (2018)	No Information	No Information	No Information	No Information	No Information	No Information	No Information	- ISO 10 844 At 50km/h - ISO 3745	No Information	No Information
Inter-noise HAMBURG (2016)	No Information	No Information	No Information	No Information	No Information	No Information	Trailer method	CPX method nowadays specified ISO/FDIS 11 819-2	No Information	No Information
Tyre modelling for RR (2014)	No Information	No Information	No Information	No Information	No Information	No Information	No Information	No Information	No Information	No Information
EVO103_LD (2015)	No Information	No Information	No Information	No Information	No Information	No Information	No Information	No Information	No Information	No Information
Auto Express Studies (2018)	No Information	No Information	No Information	No Information	No Information	No Information	No Information	No Information	No Information	No Information
Whichcar Wheels (2017)	No Information	No Information	No Information	No Information	No Information	No Information	No Information	No Information	No Information	No Information

➔ No study has information in each cell

Conclusions

- **3 Tyre Manufacturers studies show antagonistic relationship between Noise and Safety (Aquaplaning, Wet Grip and Handling)**
- **2 Tyre Manufacturers studies show relationship between Noise and Rolling Resistance**
- **Test procedures or testing methods are disparate from one study to another**
- **General agreement on the major role of road surface on the noise emission**
- **Due to the purpose of the journalistic studies and the lack of technical information it is difficult to make a statement about the results**
  - The main goal of the journalistic studies is to rank a sample of tyres
  - Test methods are not described precisely and are different from one study to another
  - In some studies, repeatability conditions are questionable
  - Test data are not provided
- **ACEA Tyre Performance Study aims at determining the inter-dependency between rolling sound, rolling resistance and the main safety performances by carrying out tests according to regulatory or standard procedures**

Literature study

- **For detailed information, see Appendix 1**

2 - Test Program

Test Program

Test sample

- 16 different tyre references
  - OEM x4
  - After Market x12
- 2 snow tyres (3PMSF) among the 16
- 205 55 R16 91H, T, V or W
  - Most common size on European after market

Tests Content

- Rolling Resistance
  - Bench test
  - RR Index
- Rolling Sound
  - Vehicle test / VW GOLF 5 & NISSAN LEAF
  - Noise level in different conditions
- Wet Grip
  - Trailer method test on wet surface
  - Wet Grip index
- Dry Grip
  - Vehicle test / PEUGEOT 308
  - Braking performance on dry surface
- Dry handling (Flat) Track
  - Bench test
  - Cornering stiffness
- Aquaplaning
  - Vehicle test / PEUGEOT 308
  - Aquaplaning speed and acceleration under aquaplaning condition

Test Programs

Test Methods

- Rolling Resistance : UN Regulation No.117 procedure
- Rolling Sound : UN Regulation No.117 procedure & UN Regulation No.R51.03
- Wet Grip : UN Regulation No.117 procedure
- Dry Grip : UN Regulation No.R13H procedure Type 0
- Dry handling (Flat Track): Procedure proposed by ETRTO
- Aquaplaning : VDA E08 Longitudinal Aquaplaning & VDA E05 Lateral Aquaplaning

Tests Program

Test Conditions

Rolling Resistance

- UN Regulation No.117 procedure
- Test Speed (km/h): 80
- Load (kg): 482
- Tyre initial reference pressure (kPa) : 210
- Room temperature (°C) : 24<T°C<25

Rolling Sound

- 8 passes @ 50 & 80 kph according to UN Regulation No.117 procedure
- 4 accelerations @ 50 kph & cruising according to UN Regulation No.R51.03 (Acceleration values close to @ 2,0 m/s²)

Wet Grip

- UN Regulation No.117 procedure
- Test Speed (km/h): 65
- Water depth (mm) : 0,9
- Track texture depth (mm) : 1
- Load (kg) : 461

Dry Grip

- UN Regulation No.R13H procedure Type 0
- Test speed (km/h) : 100
- Tyre pressure (kPa) :
  - Unladen : 250 Front and 240 Rear
  - Laden : 260 Front and 340 Rear

Dry handling (Flat Track)

- Procedure proposed by ETRTO
- Test speed (km/h) : 80
- Test duration (min) : 20

Aquaplaning

- VDA E08 Longitudinal Aquaplaning
- VDA E05 Lateral Aquaplaning

Tests Schedule

ACEA Study Schedule	January				Febuary				March				April				May				
	W1902	W1903	W1904	W1905	W1906	W1907	W1908	W1909	W1910	W1911	W1912	W1913	W1914	W1915	W1916	W1917	W1918	W1919	W1920	W1921	W1922
	MEETING										MEETING		MEETING								
SET #1		Recepti	Tire conditionning																		
					Rolling Resistance & Wet Grip tests																
							Rolling Sound cruising & torque influence tests														
															Longitudinal & Lateral Aquaplanning						
SET #2			Tire conditionning																		
					Dry Handling (flat trac)																
											Dry Grip										

2 sets of tyres to avoid influence on each tests

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3 - Statistical Analysis

Interdependence analysis

Results, Explanations & Interpretation

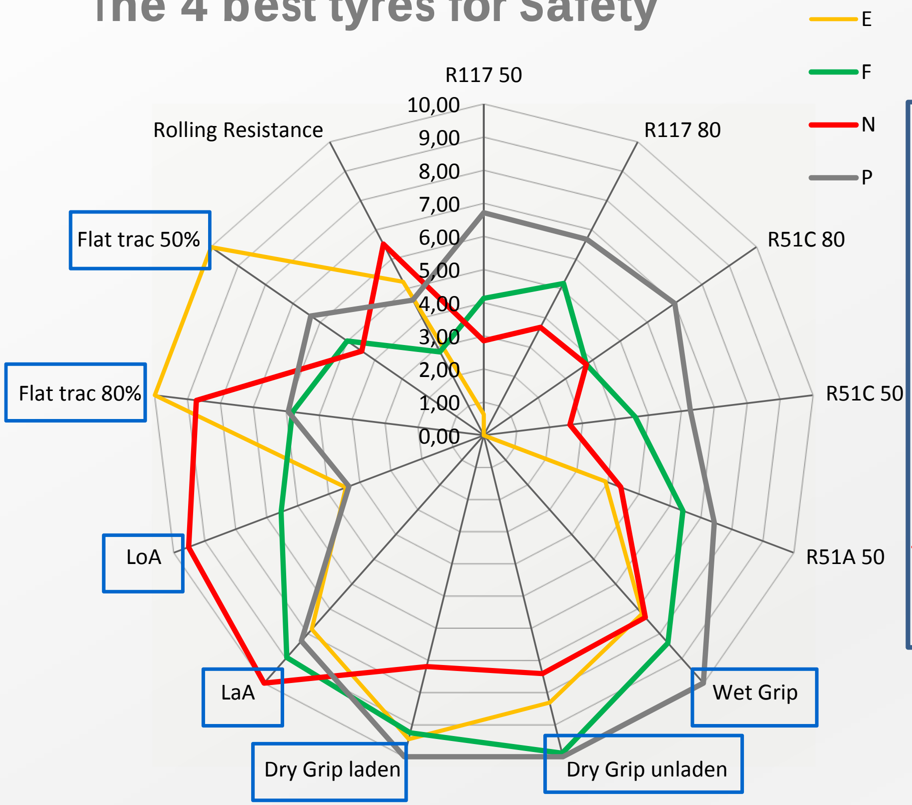
Results Table

	TEST															
	Rolling Resistance	Rolling Sound					Flat Trac		Wet Grip	Dry Grip		Longi. Aqua.	Lateral Aqua.	Weight	Void ratio	Tread Depth
List	RR (index)	R117 50 kph AVG (dB(A))	R117 80 kph Arr LR-1dB (dB(A))	R51A 50 kph (dB(A))	R51C 80 kph T° corr (dB(A))	R51C 50 kph T° corr (dB(A))	80% LI (N/°)	50% LI (N/°)	WG (index)	Ratio unladen (%)	Ratio laden (%)	Ratio LoA (%)	LaA (Integer m/s)	(Kg)	% Void	Mean (mm)
A	8,985	64,8	70,7	66,4	72,4	65,5	1417	1288	1,57	95,52	93,7	103,22	63,96	8,18	36,8	6,87
B	9,949	64,9	70,3	66,3	72,2	65,7	1387	1080	1,46	94,06	94,31	108,76	70,52	9,55	42	7,82
C	8,142	65	70,8	67,1	72,8	66,1	1265	1099	1,51	96,37	97,76	103,67	61,43	7,84	46,2	7,44
D	8,444	65,1	71,1	67,5	73	66,4	1462	1144	1,56	96,58	96,71	103,2	63,29	8,27	24,7	7,13
E	8,117	65,8	72,4	67,4	73,8	66,8	1669	1507	1,55	96,04	98,66	100,18	66,15	8,13	34,3	6,53
F	8,953	64,7	70,3	66,3	72,5	65,4	1500	1294	1,63	99,74	98,18	103,99	69,75	8,86	43,4	7,3
G	9,002	63,6	69,6	65,5	71,7	64,9	1641	1337	1,38	91,89	94,03	102,05	57,49	9,62	23,1	7,83
H	8,454	63,2	68,5	66,6	71,1	64,6	1420	1130	1,43	92,59	90,06	94,96	49,11	9,19	29,9	7,46
I	7,865	62,9	68,4	65	70,4	64,3	1550	1278	1,69	97,14	95,57	94,76	54,18	9,55	31,9	7,01
J	9,760	63	70,1	67,4	71,8	63,8	1479	1090	1,06	76,48	75,54	93,03	41,28	11,8	33	8,18
K	7,075	65,1	71,0	67,5	73	66,6	1351	1232	1,50	97,85	99,02	100,8	59,74	8,14	40,9	6,39
L	6,449	63,9	69,7	65,8	71,5	65	1326	1126	1,64	94,14	96,9	97,92	55,48	8,23	41,8	6,89
M	8,389	66	70,6	69,2	72,6	66,8	1294	1126	1,67	86,53	84,63	110,29	63,39	8,43	39,7	7,92
N	7,666	65,1	70,9	67,3	72,5	66	1618	1271	1,56	93,92	93,14	109,43	73,05	8,83	37,4	7,4
O	7,175	63,6	69,2	66,5	71,2	64,7	1382	1168	1,27	89,69	90,99	92,08	47,52	8,27	40,8	6,87
P	8,336	63,9	69,7	65,9	71,4	64,9	1505	1351	1,74	100	100	100	67,65	8,77	32,3	6,97

*Tyre P is the reference tyre for dry Grip & Longitudinal Aquaplaning.

Spider Diagrams

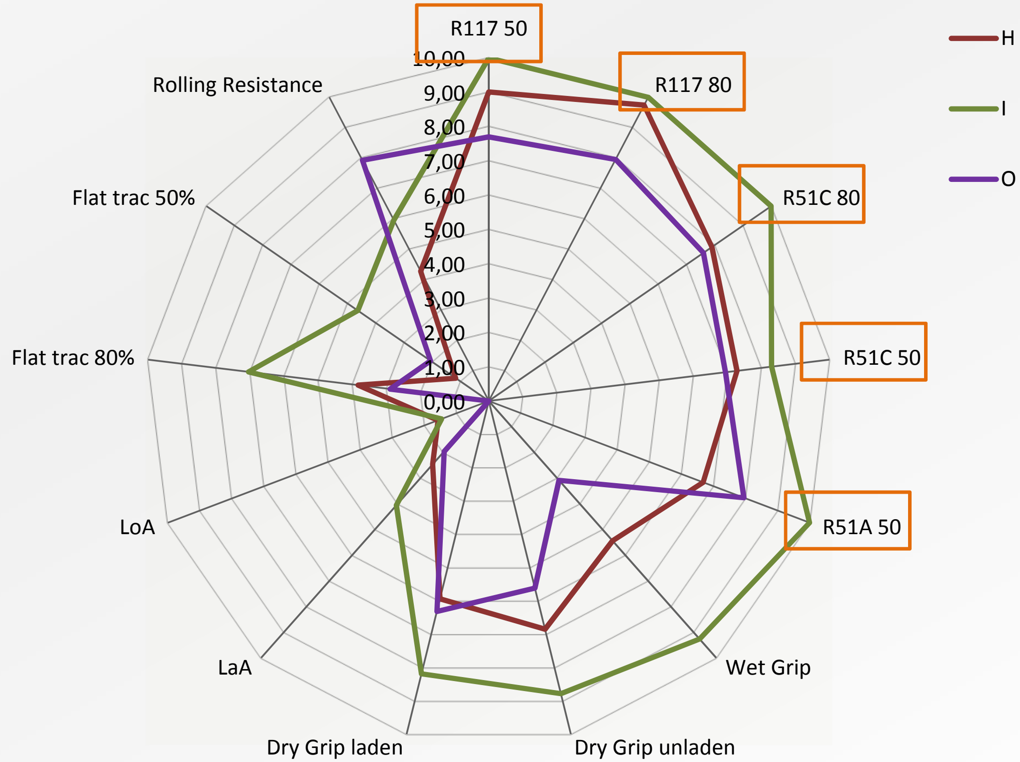
The 4 best tyres for Safety



10 : Defined by the best tyre of the sample

0 : Defined by the worst tyre of the sample

The 3 best tyres for Noise

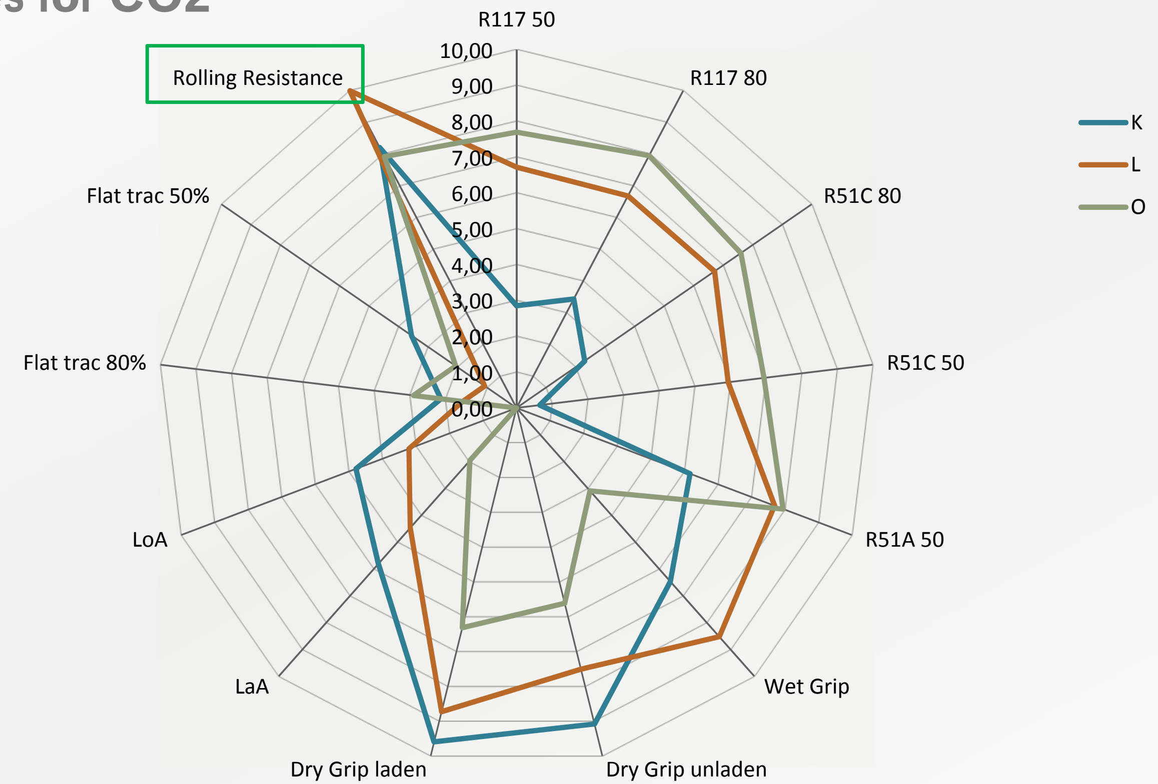


Good in Safety ➔ Less in Noise

Good in Rolling Sound ➔ Less in Aquaplaning

Spider Diagrams

The 3 best tyres for CO2



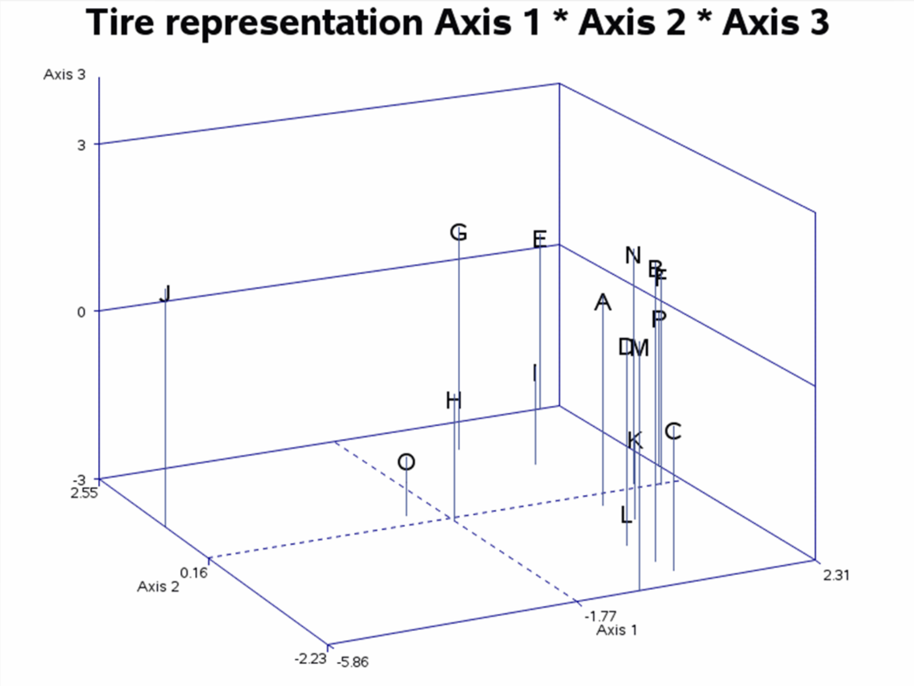
Good in Rolling Resistance → Less in Handling and Aquaplaning

Toolbox

Principal Component Analysis (PCA)

- **“Principal component analysis** (**PCA**) is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables (entities each of which takes on various numerical values) into a set of values of linearly uncorrelated variables called **principal components”**. *Wikipedia*

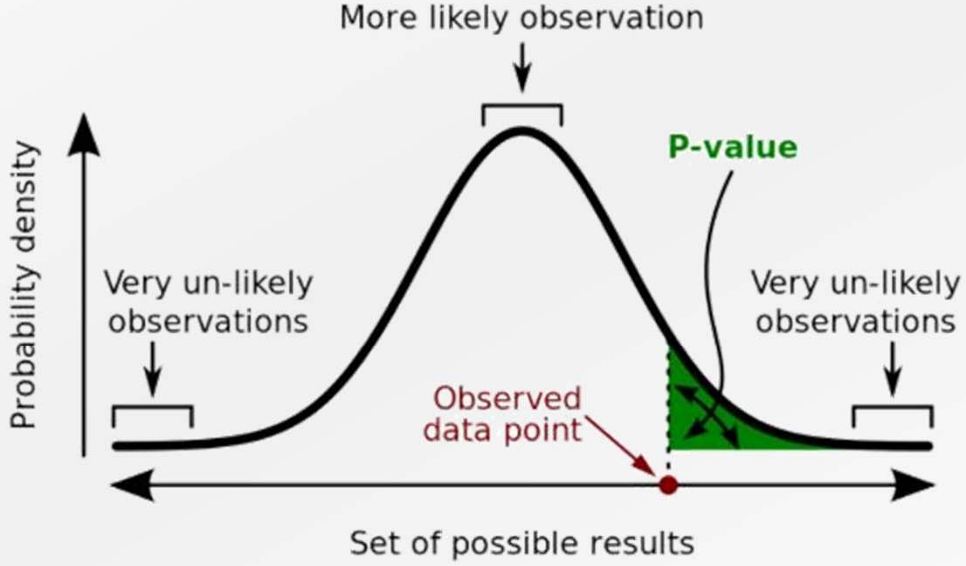
- In our case it is used to **reduce the number of input characteristics** (rolling resistance, dry grip, wet grip and aquaplaning) **from 8 to 3** to allow a 2D or 3D visualization



3D representation
Letters A to P correspond to the 16 tyres tested

Toolbox

- **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 our case the hypothesis is "there is no correlation between characteristics". In other words, if p-value is low then our hypothesis is false and we can conclude 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.

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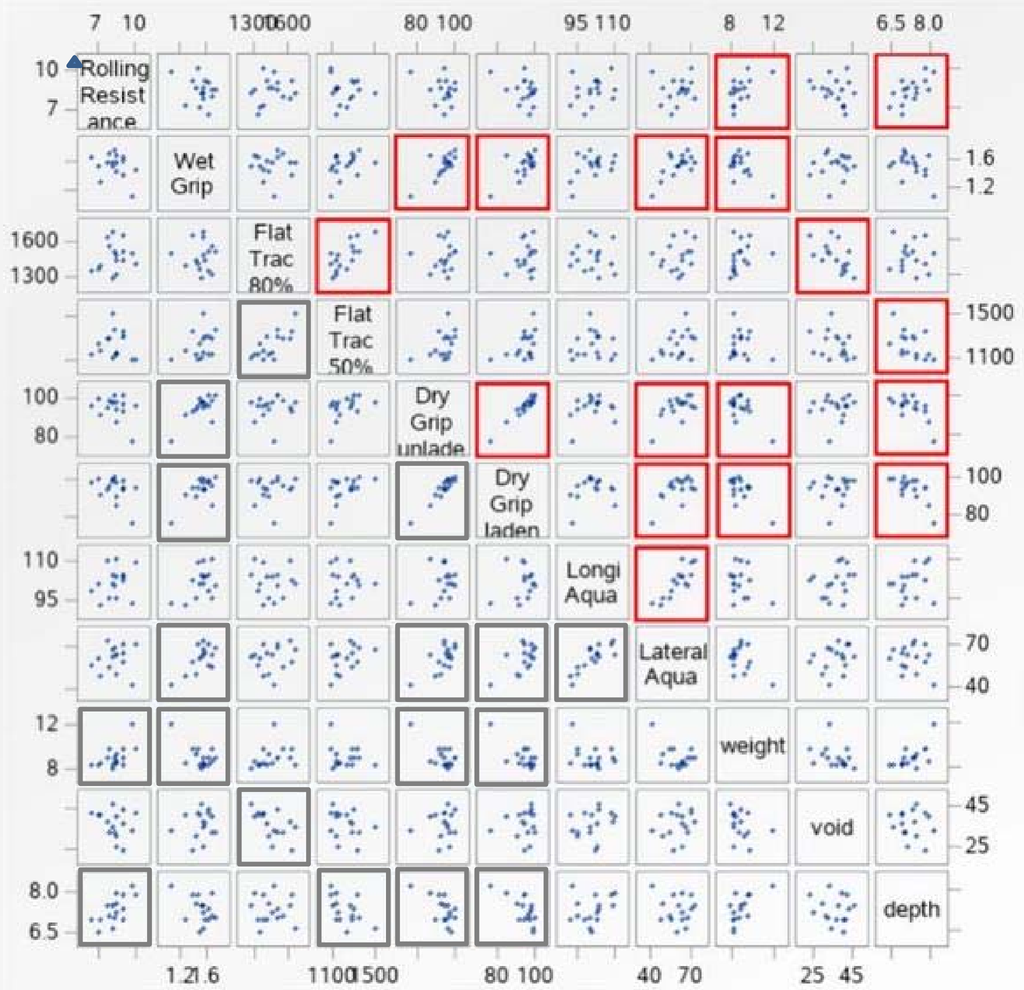
Toolbox

- In **the chart of scatterplots**, Red boxes show strong probability of correlation (**P-value <5%)**
- As the chart is symmetric, we just focus on the right part of it.

Test	Units
Rolling Resistance	RR Index
Wet Grip	WG Index
Flat Track	N/°
Dry Grip	%
Longitudinal Aquaplaning	%
Lateral Aquaplaning	m/s (integer)
Weight	Kg
Void Ratio	%
Tread Depth	mm



Without Rolling Sound

➔ This tool allows us to show direct relationship between the parameters

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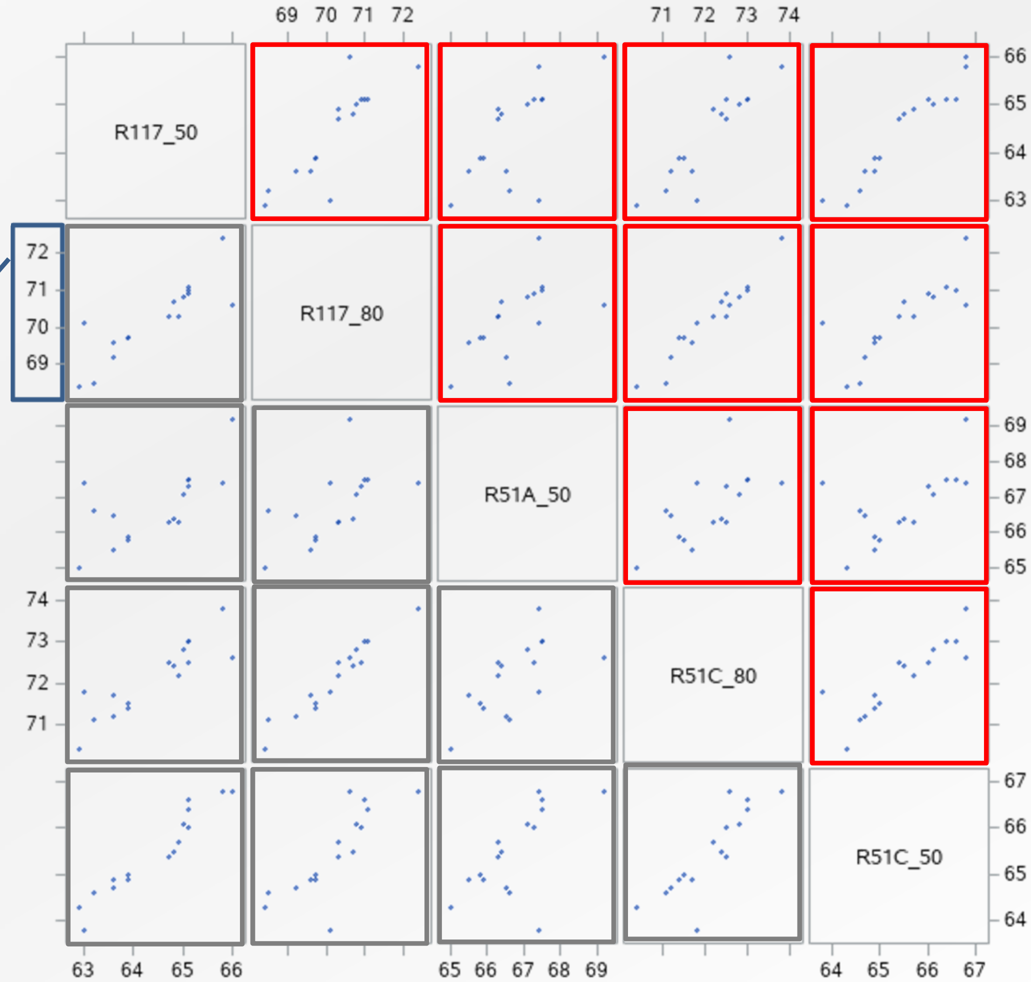
2D charts and Scatterplots for rolling sounds

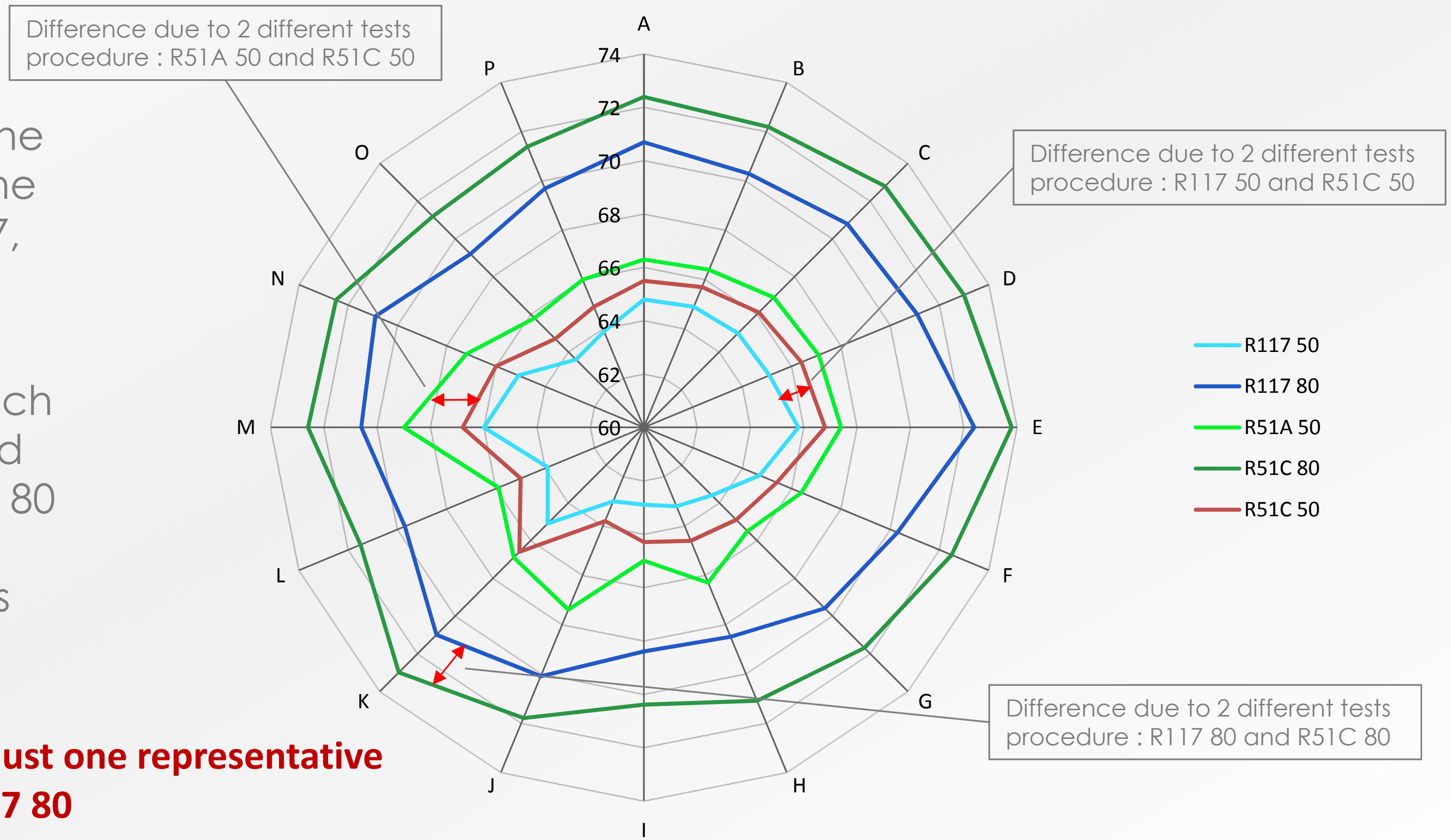
- Comparison between each Rolling Sound tests with **P-value <1%**
- As the P-value is less than 1% we have a top level of probability of correlation

➔ We have the opportunity to state on the Rolling Sound performance only through one noise characteristics e. g. R117



Rolling Sound tests correlation

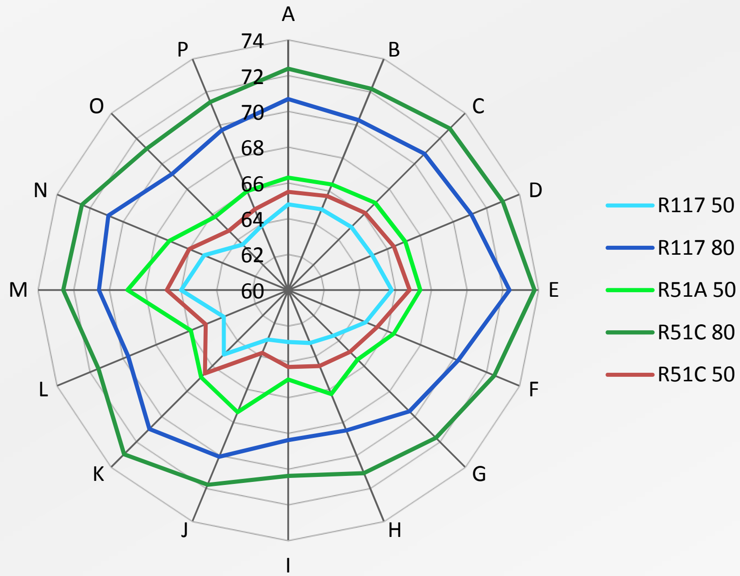
- The tyres are behaving differently depending on the sensitivity of each tyre to the test procedures used (R117, R51C and R51 A).
- In general the shape of each "circle" shows a quite good correlation, better for R117 80 vs R51C 80 and R51A 50 vs R51C 50 than for R117 50 vs R51C 50.

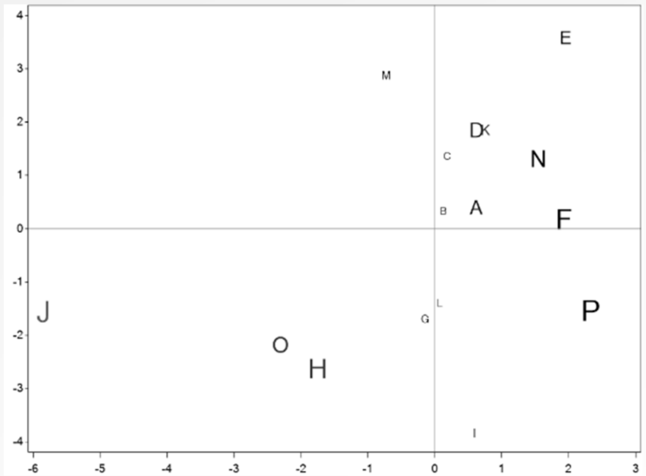


This confirms that we can keep just one representative characteristic among the 5 : R117 80

Representing Rolling Sound

- **5 characteristics for Rolling Sound (R117_50, R117_80, R51A_50, R51C_80 & R51C_50)**
- In results previously shown, measurements for R117_80 were used to represent Rolling Sound among the 5 characteristics. To be noted that an PCA on the 5 characteristics leads to a first axe explaining 84% of sound variability see next slides for details.
- **The chosen option is to keep just one representative characteristic among the 5 : R117 80**





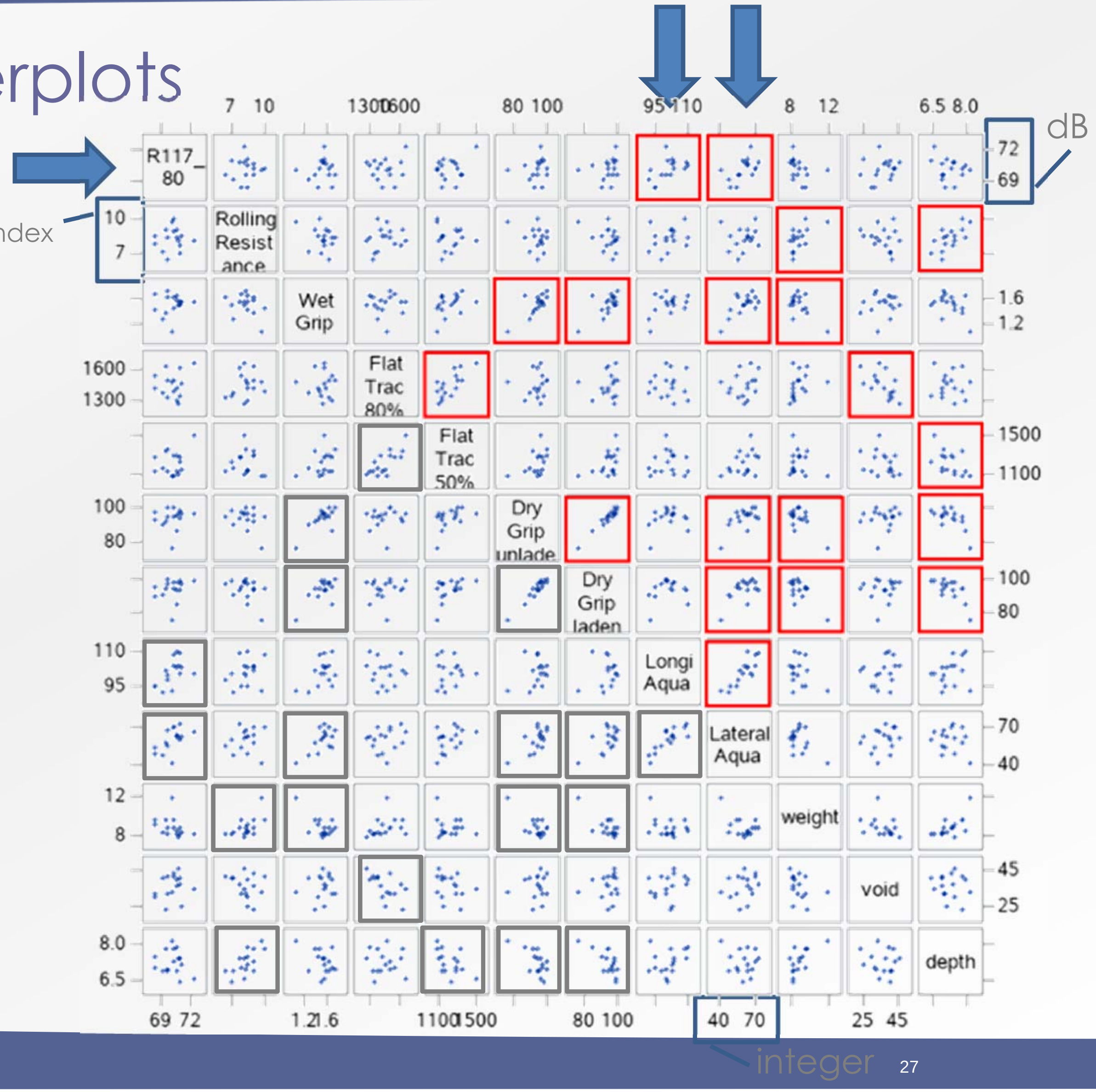
Statistical Analysis

- **For detailed information, see Appendix 2**

2D charts and Scatterplots

See next slide for visualization : R117_80 vs Aquaplaning

- Same as before but **with R117 80**
- Red boxes show very strong probability of correlation (**P-value <5%)**



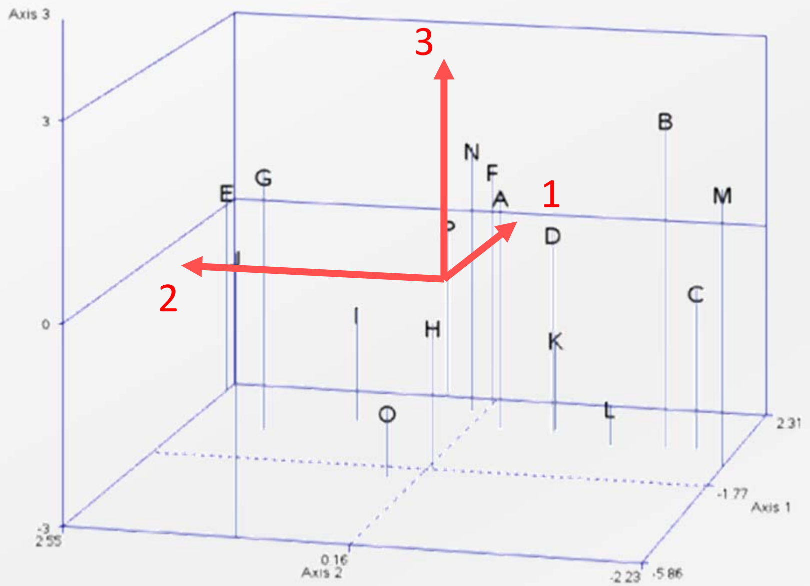
Tests results - Visualization

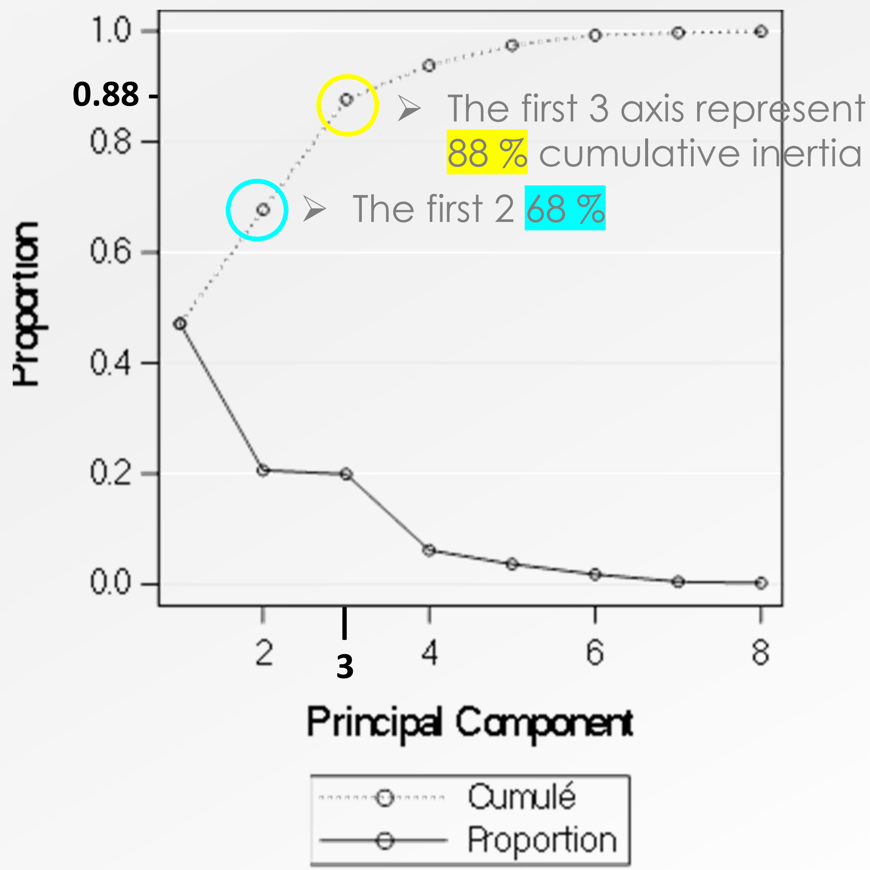
Strong correlation between R117 80 and Aquaplaning visually noticeable (sorted on R117 80)

	TEST															
	Rolling Resistance	Rolling Sound					Flat Trac		Wet Grip	Dry Grip		Longi. Aqua.	Lateral Aqua.	Weight	Void ratio	Tread Depth
List	RR (index)	R117 50 kph AVG (dB(A))	R117 80 kph Arr LR-1dB (dB(A))	R51A 50 kph (dB(A))	R51C 80 kph T° corr (dB(A))	R51C 50 kph T° corr (dB(A))	80% LI (N/°)	50% LI (N/°)	WG (index)	Ratio unladen (%)	Ratio laden (%)	Ratio LoA (%)	LaA (Integer)	(Kg)	% Void	Mean (mm)
I	7,865	62,9	68,4	65	70,4	64,3	1550	1278	1,69	97,14	95,57	94,76	54,18	9,55	31,9	7,01
H	8,454	63,2	68,5	66,6	71,1	64,6	1420	1130	1,43	92,59	90,06	94,96	49,11	9,19	29,9	7,46
O	7,175	63,6	69,2	66,5	71,2	64,7	1382	1168	1,27	89,69	90,99	92,08	47,52	8,27	40,8	6,87
G	9,002	63,6	69,6	65,5	71,7	64,9	1641	1337	1,38	91,89	94,03	102,05	57,49	9,62	23,1	7,83
L	6,449	63,9	69,7	65,8	71,5	65	1326	1126	1,64	94,14	96,9	97,92	55,48	8,23	41,8	6,89
P	8,336	63,9	69,7	65,9	71,4	64,9	1505	1351	1,74	100	100	100	67,65	8,77	32,3	6,97
J	9,760	63	70,1	67,4	71,8	63,8	1479	1090	1,06	76,48	75,54	93,03	41,28	11,8	33	8,18
B	9,949	64,9	70,3	66,3	72,2	65,7	1387	1080	1,46	94,06	94,31	108,76	70,52	9,55	42	7,82
F	8,953	64,7	70,3	66,3	72,5	65,4	1500	1294	1,63	99,74	98,18	103,99	69,75	8,86	43,4	7,3
M	8,389	66	70,6	69,2	72,6	66,8	1294	1126	1,67	86,53	84,63	110,29	63,39	8,43	39,7	7,92
A	8,985	64,8	70,7	66,4	72,4	65,5	1417	1288	1,57	95,52	93,7	103,22	63,96	8,18	36,8	6,87
C	8,142	65	70,8	67,1	72,8	66,1	1265	1099	1,51	96,37	97,76	103,67	61,43	7,84	46,2	7,44
N	7,666	65,1	70,9	67,3	72,5	66	1618	1271	1,56	93,92	93,14	109,43	73,05	8,83	37,4	7,4
K	7,075	65,1	71,0	67,5	73	66,6	1351	1232	1,50	97,85	99,02	100,8	59,74	8,14	40,9	6,39
D	8,444	65,1	71,1	67,5	73	66,4	1462	1144	1,56	96,58	96,71	103,2	63,29	8,27	24,7	7,13
E	8,117	65,8	72,4	67,4	73,8	66,8	1669	1507	1,55	96,04	98,66	100,18	66,15	8,13	34,3	6,53

Multidimensional Analysis - Axis

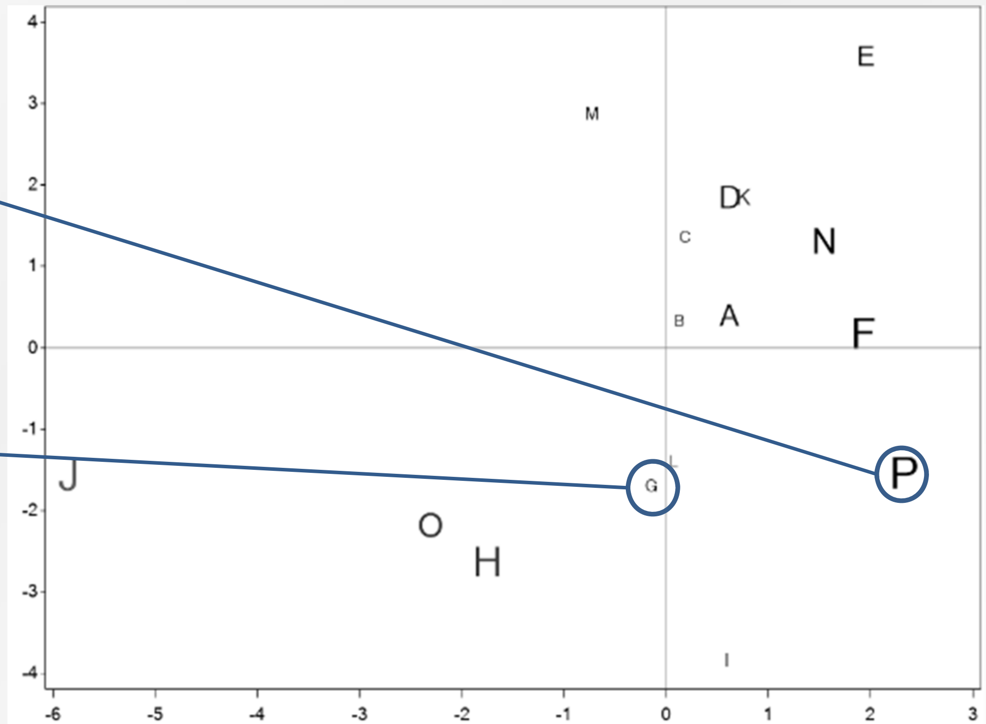
- **Principal Component Analysis (PCA)**
  - **Reduce the 8 studied characteristics** (Rolling Resistance, Wet Grip, Flat Track 80%, Flat Track 50%, Dry Grip unladen, Dry Grip laden, Longitudinal & Lateral Aquaplaning) **to 3 variables**





2D representation

- **In the 2D representation :**
  - The **bigger the letters**, the **more** the **axis** is **driven** by the **tyre** in comparison to the others for this 16 tyres sample
  - The **smaller the letters**, the **less** the **axis** is **driven** by this **tyre** in comparison to the others for this 16 tyres sample



Principal Component Analysis (PCA)

- **Axis 1** mainly represents **Wet Grip, Dry Grip, Lateral aquaplaning**
  To be noted that in axis 1 direction all tests performance improve
  - It is representative for **Safety**

- **Axis 2** mainly represents **Flat Track**
  - It is representative for **Handling**

- **Axis 3** mainly represents **Rolling Resistance** and **Longitudinal Aquaplaning**
  - It is representative for **CO2 Emissions** because Rolling Resistance factor is the most important

Part of inertia	47%	21%	20%
	Axis 1	**Axis 2**	**Axis 3**
Rolling resistance	-0.24951	0.08299	0.83255
Wet Grip	0.84198	-0.24064	-0.11640
Flat Trac 80%	0.26003	0.87159	0.30945
Flat Trac 50%	0.60116	0.73587	0.05038
Dry grip unladen	0.90781	-0.03298	-0.25292
Dry grip laden	0.88151	0.01045	-0.32418
Longi aquaplaning	0.50930	-0.48779	0.64278
Lateral aquaplaning	0.84231	-0.20959	0.45471

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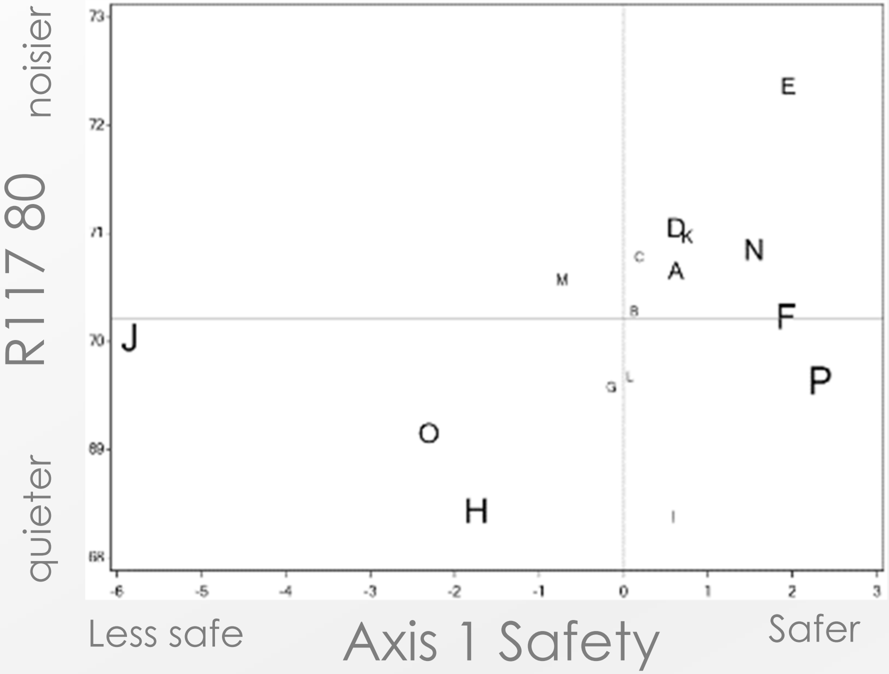
PCA Results (1st axis)

R117_80 vs Axis 1 Safety



	Axis 1	Axis 2	Axis 3
Rolling resistance	-0.24951	0.08299	0.83255
Wet Grip	0.84198	-0.24064	-0.11640
Flat Trac 80%	0.26003	0.87159	0.30945
Flat Trac 50%	0.60116	0.73587	0.05038
Dry grip unladen	0.90781	-0.03298	-0.25292
Dry grip laden	0.88151	0.01045	-0.32418
Longi aquaplaning	0.50930	-0.48779	0.64278
Lateral aquaplaning	0.84231	-0.20959	0.45471

Axis 1 mainly controlled by Wet Grip, Dry Grip, Lateral aquaplaning

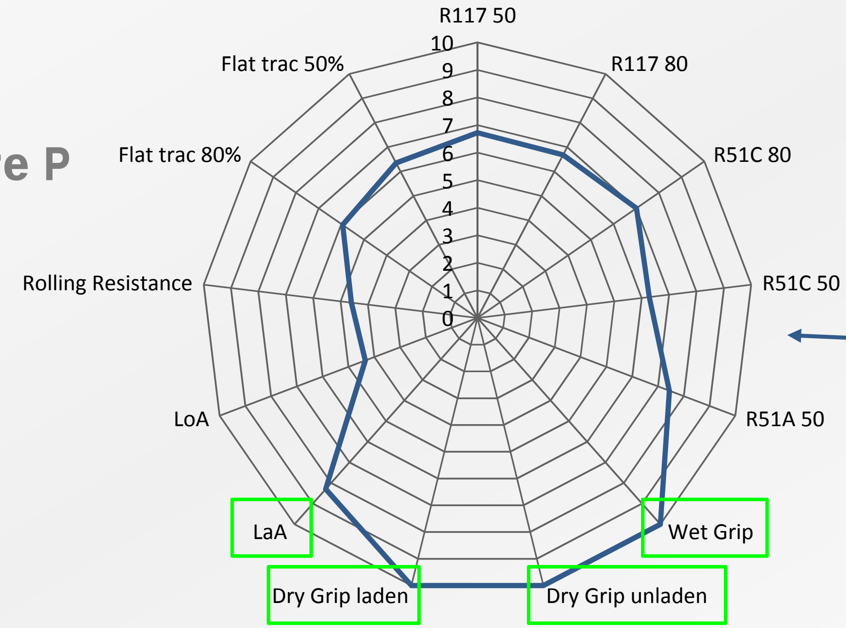
Interpretations (1st axis)

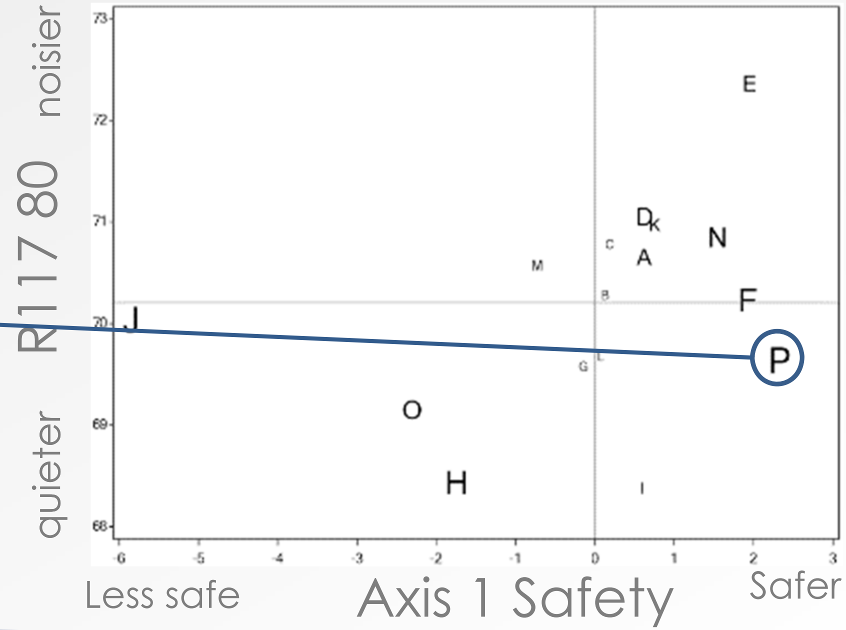
- **Axis 1** mainly represents Safety through **Wet Grip, Dry Grip, Lateral Aquaplaning**

- The statistic concerning our sample of 16 tyres shows a **conflict between Rolling Sound and Safety performances.**

	Axis 1	Axis 2	Axis 3
Rolling resistance	-0.24951	0.08299	0.83255
Wet Grip	0.84198	-0.24064	-0.11640
Flat Trac 80%	0.26003	0.87159	0.30945
Flat Trac 50%	0.60116	0.73587	0.05038
Dry grip unladen	0.90781	-0.03298	-0.25292
Dry grip laden	0.88151	0.01045	-0.32418
Longi aquaplaning	0.50930	-0.48779	0.64278
Lateral aquaplaning	0.84231	-0.20959	0.45471

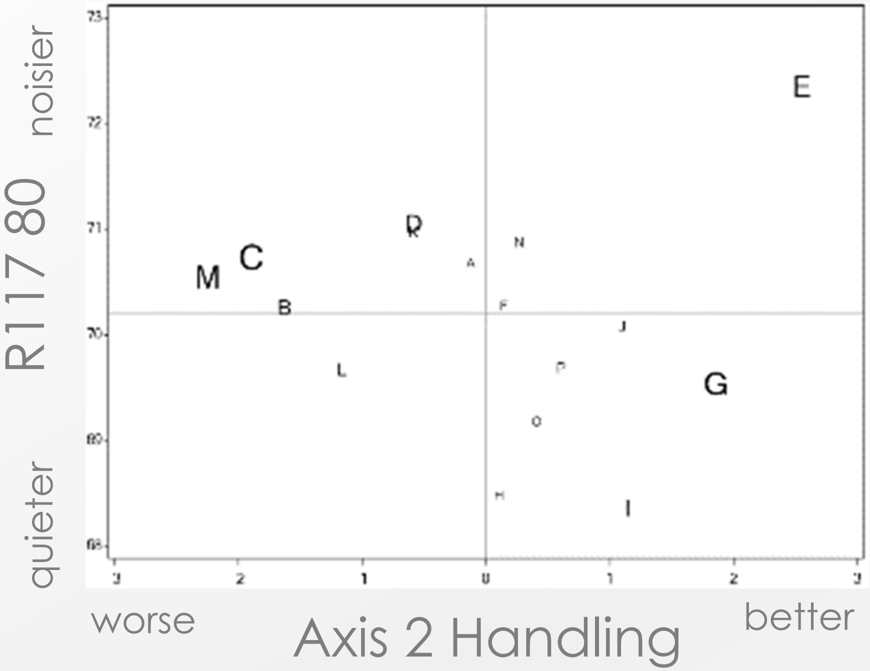
Focus on Tyre P





PCA Results (2nd axis)

R117_80 vs Axis 2 Handling



	Axis 1	Axis 2	Axis 3
Rolling resistance	-0.24951	0.08299	0.83255
Wet Grip	0.84198	-0.24064	-0.11640
Flat Trac 80%	0.26003	0.87159	0.30945
Flat Trac 50%	0.60116	0.73587	0.05038
Dry grip unladen	0.90781	-0.03298	-0.25292
Dry grip laden	0.88151	0.01045	-0.32418
Longi aquaplaning	0.50930	-0.48779	0.64278
Lateral aquaplaning	0.84231	-0.20959	0.45471

Axis 2 mainly controlled by Flat Track 50 % and Flat Track 80 %

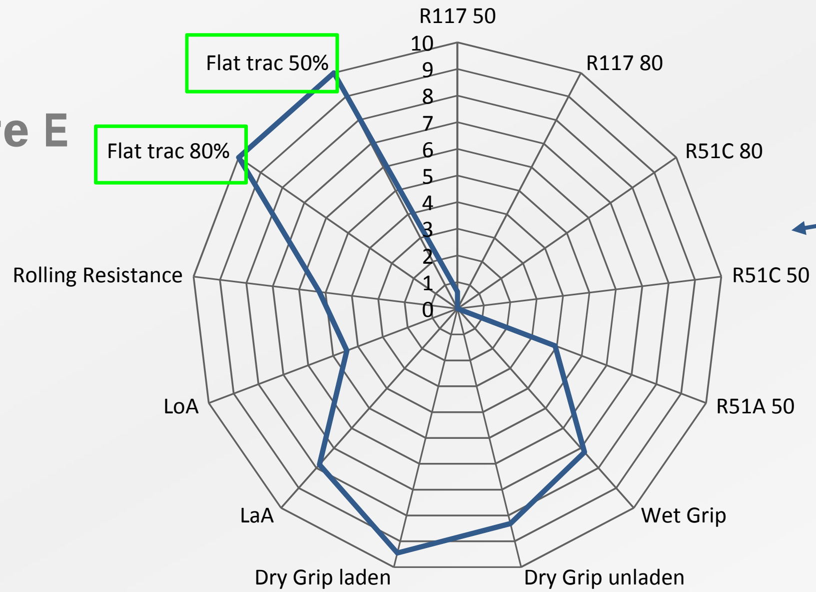
Interpretations (2nd axis)

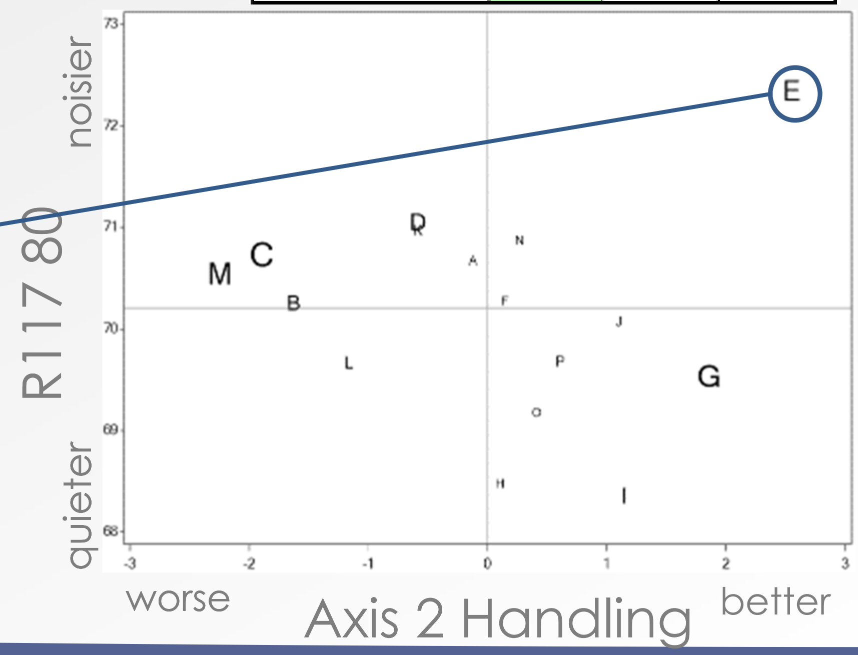
- **Axis 2** mainly represents handling through **Flat Track**

	Axis 1	Axis 2	Axis 3
Rolling resistance	-0.24951	0.08299	0.83255
Wet Grip	0.84198	-0.24064	-0.11640
Flat Trac 80%	0.26003	0.87159	0.30945
Flat Trac 50%	0.60116	0.73587	0.05038
Dry grip unladen	0.90781	-0.03298	-0.25292
Dry grip laden	0.88151	0.01045	-0.32418
Longi aquaplaning	0.50930	-0.48779	0.64278
Lateral aquaplaning	0.84231	-0.20959	0.45471

- **Noise and Handling performances improve together along Axis 2 (E does not follow the trend)**

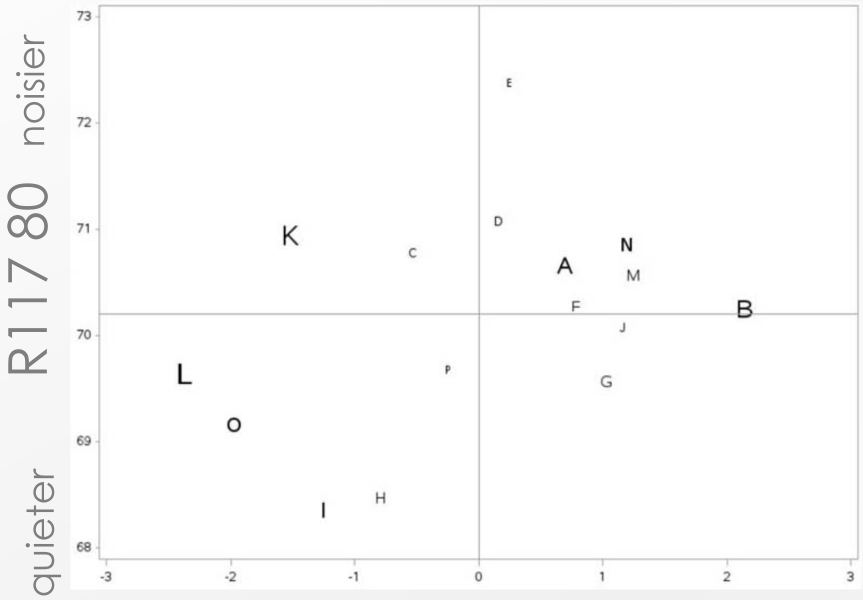
Focus on Tyre E





PCA Results (3rd axis)

R117_80 vs Axis 3 CO2



	Axis 1	Axis 2	Axis 3
Rolling resistance	-0.24951	0.08299	0.83255
Wet Grip	0.84198	-0.24064	-0.11640
Flat Trac 80%	0.26003	0.87159	0.30945
Flat Trac 50%	0.60116	0.73587	0.05038
Dry grip unladen	0.90781	-0.03298	-0.25292
Dry grip laden	0.88151	0.01045	-0.32418
Longi aquaplaning	0.50930	-0.48779	0.64278
Lateral aquaplaning	0.84231	-0.20959	0.45471

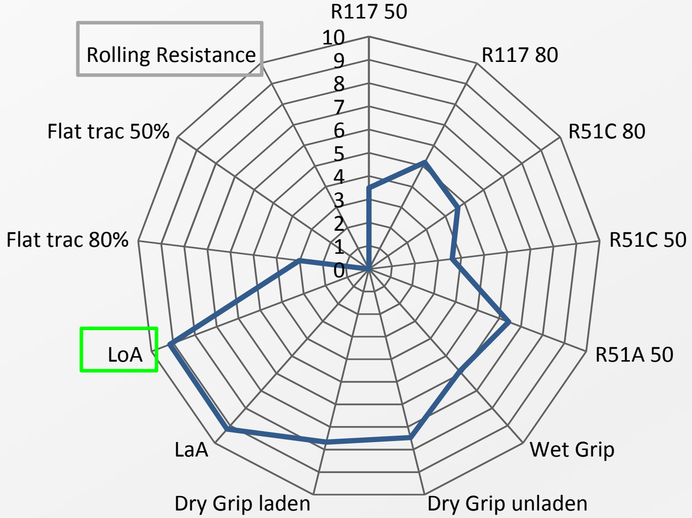
Axis 3 mainly controlled by
Rolling Resistance & Longitudinal Aquaplaning

Interpretations (3rd axis)

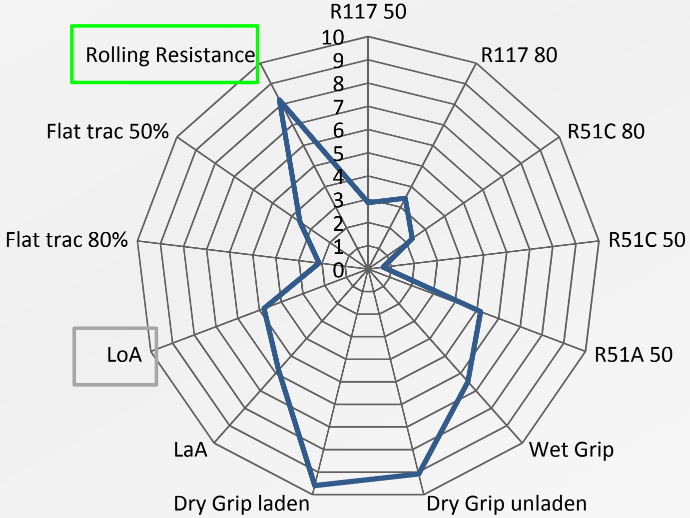
- **Axis 3** mainly represents CO2 Emissions (through **Rolling Resistance) and Longitudinal Aquaplaning.**
- **(!)** In this axis, performance in **Rolling Resistance decreases while increasing in Longitudinal Aquaplaning**

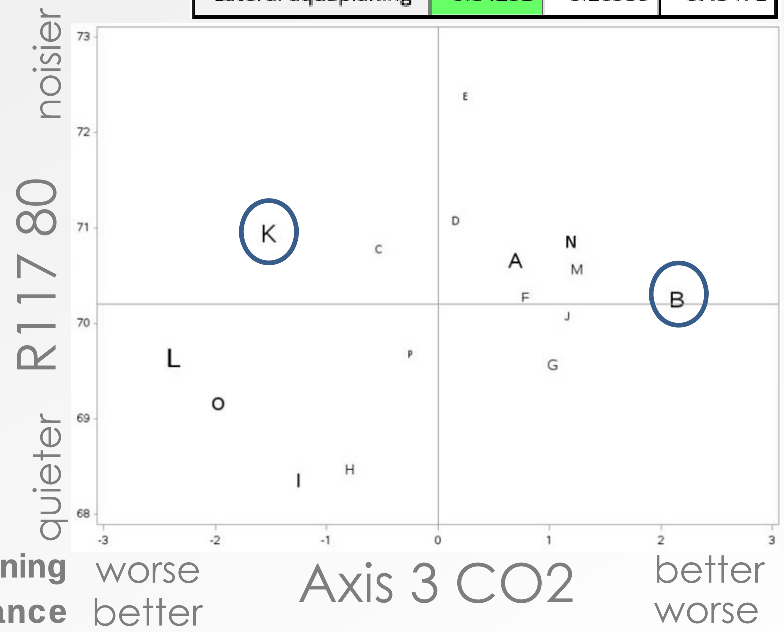
	Axis 1	Axis 2	Axis 3
Rolling resistance	-0.24951	0.08299	0.83255
Wet Grip	0.84198	-0.24064	-0.11640
Flat Trac 80%	0.26003	0.87159	0.30945
Flat Trac 50%	0.60116	0.73587	0.05038
Dry grip unladen	0.90781	-0.03298	-0.25292
Dry grip laden	0.88151	0.01045	-0.32418
Longi aquaplaning	0.50930	-0.48779	0.64278
Lateral aquaplaning	0.84231	-0.20959	0.45471

Focus on Tyre B



Focus on Tyre K





Simple conclusion can not be drawn on Axis 3

Conclusions – Literature Study

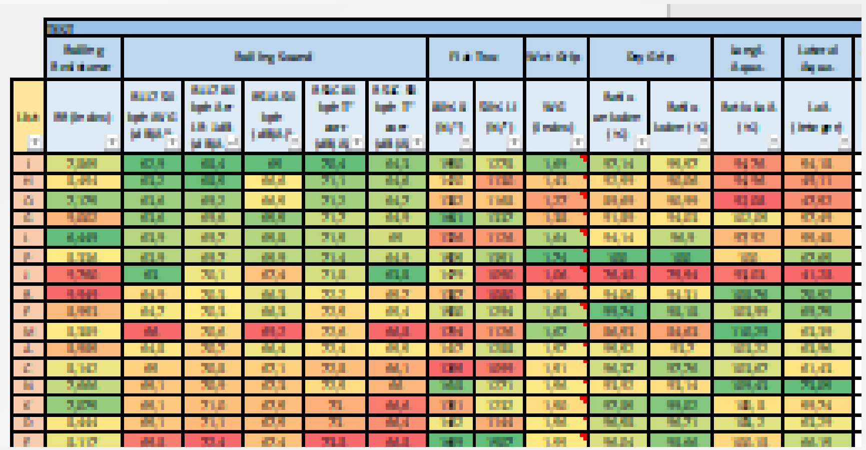
- **3 Tyre Manufacturers studies show antagonistic relationship between Noise and Safety (Aquaplaning, Wet Grip and Handling)**
- **2 Tyre Manufacturers studies show relationship between Noise and Rolling Resistance**
- **Test procedures or testing methods are disparate from one study to another**
- **General agreement on the major role of road surface on the noise emission**
- **Due to the purpose of the journalistic studies and the lack of technical information it is difficult to make a statement about the results**
  - The main goal of the journalistic studies is to rank a sample of tyres
  - Test methods are not described precisely and are different from one study to another
  - In some studies, repeatability conditions are questionable
  - Test data are not provided
- **ACEA Tyre Performance Study aims at determining the inter-dependency between rolling sound, rolling resistance and the main safety performances by carrying out tests according to regulatory or standard procedures**

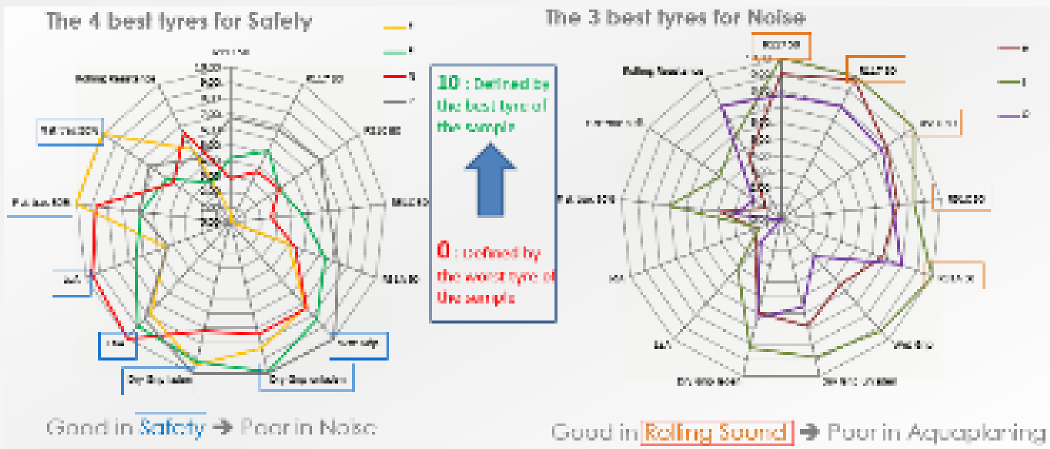
Conclusions

Measurement Program

- This new study offers a comprehensive toolbox to evaluate the relationship between rolling sound and the main other tyre performances according to standard measurement protocols.

- A correlation analysis shows that the 5 acoustic characteristics concerning R51.03 (Vehicle measurement) and R117 (Tyre measurement) at different velocities are correlated and can be represented by only one.





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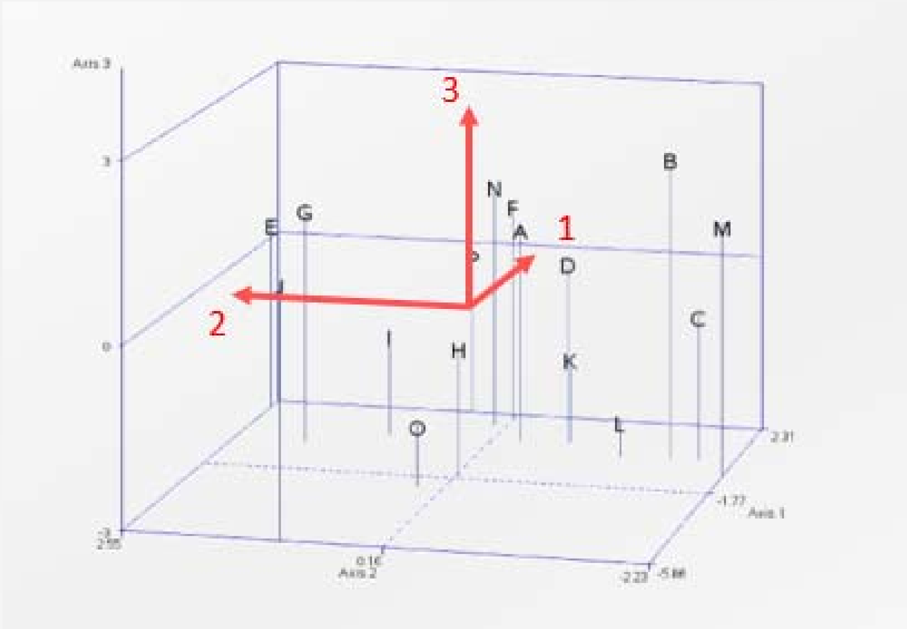
Conclusions

Statistical analysis

- We have described the relationship between the characteristics through 3 variables with a good level of representativeness (inertia of 88%)
- The main table, the spider diagrams and the Principal Components Analysis show **a conflict between rolling sound** (R117) **and Safety performances** (Wet Grip, Dry Grip, Lateral Aquaplaning)
- Simple conclusions regarding rolling sound, rolling resistance and Safety performance (Longitudinal Aquaplaning) cannot be drawn



Conclusions

Main conclusion

- Obtaining **a low level of Rolling Sound performance without a compromise** regarding other parameters essential **for vehicle safety and CO2 emission reduction could not be proven as feasible** by this Study

Conclusions

General conclusions

- ACEA Tyre Performance Study is the first study to analyze the inter-dependency of the parameters of the tyre with accurate reliable repeatable measurement methods
- ACEA Tyre Performance Study conclusions are consistent with the outcomes of the Literature Study regarding Rolling Sound and Vehicle Safety
- The ACEA Tyre Performance Study has not observed or deduced any correlation between Rolling Sound and Rolling Resistance as claimed by the FEHRL Study

Remark: WLTP has caused a shift in tyre technology in recent years, in order to provide improved Rolling Resistance. The tyres in the study may have been designed before this shift.

Conclusions

Recommendation for complementing the study:

- **Wear Life testing** was part of the initial test program but due to budget constraints the testing could not be performed, although the tyres are available and the test procedure has been defined.
- The tyres that could be used also for **Wear Life testing** can be provided by ACEA and we encourage the stakeholders to raise funding and do the wear test, thus complementing the study in order to deliver a more complete picture of tyre parameters interdependence.

Conclusions

Suggestions

- To prove that the conclusions of this study are also **valid for other tyre types,** the test program needs to be expanded to
  - Class C1 tyres with bigger outer diameter, tyre width, and lower rolling resistance
  - Class C1 tyres (winter and reinforced tyres)
  - Class C2 tyres and Class C3 tyres with bigger outer diameter and tyre width

THANK YOU FOR YOUR ATTENTION

Appendixes

1. Literature study
2. Statistical Analysis

APPENDIX 1 – LITERATURE STUDY

Literature study analysis Appendixes

- **Studies covered**
  - EVO103_LD (2015)
  - Auto Express Studies (2018)
  - Whichcar Wheels (2017)
  - GRB-61-03 Study based on TNO 2014 R10735 report (12 June 2014)
  - FEHRL – Study SI2,408210 Tyre/Road Noise (2007)
  - Noise Technology(Continental - 2011)
  - Noise Tradeoffs (Michelin - 2007)
  - Tire-Road Noise (Goodyear - 2018)
  - Noise (Michelin – 2015)
  - Inter.noise_HAMBURG 2016
  - Tyre modelling for rolling resistance (MASTER'S THESIS IN AUTOMOTIVE ENGINEERING) 2014

EVO103_LD Study (2015)

- **Framework**
  - Test campaign carried out in 2015, to demonstrate the importance of tyres in time performance
- **Settings**
  - The subjective parameter is the most important (40% of the overall score)
  - Parameters influencing performance (braking, timing) dominate price and noise criteria
- **Vehicle type**
  - For all tests it is a VW Golf GTI 230 Performance with a limited-slip electronic differential and a DSG box (this dual-clutch gearbox guarantees constant gear passages)
- **Tyre types, sizes and dimensions**
  - 10 different manufacturers' gums but equal tyresizes 225/40R18 Y92 except for bridgestone whose speed and load indices are W92
  - Each set of tyres comes from independent sources
  - They were all slightly sanded before the tests
  - Only one set is used for all measurements, the comparison starting with the least destructive tests, i. e. on wet track
- **Tracks**
  - For wet tests and dry braking : Pirelli de Vizzola test track
  - For dry tests : Tazio Nuvolari piste
  - For subjectively judges the noise and comfort : Open road around Vizzola test track
- **Test methods are not describe precisely. No information about**
  - Tyre inflation pressure from the manufacturer or the vehicle ? Tyre load ?
  - Track and ambient temperature. Period of tests during 2015 ?
  - Technical tools used : sound level meter distance to the vehicle, dB ponderation, personal qualification …
  - Technical guidelines or standard used

Auto Express Study (2018)

- **Framework**
  - The goal was to make a classification between tyres whose size is : 225/45 R17
- **Settings**
  - The test covers nine criteria, including a more driver-relevant cabin noise rating, dry grip and a range of wet road tests
  - Auto Express drivers carried out all tests apart from aquaplaning, which requires special training
  - Pass-by noise is measured in decibels (no ponderation)
- **Vehicle type**
  - No information : Pictures look at a VW Golf GTI, a VW Passat ? and an Audi A6
- **Tyre types, sizes and dimensions**
  - 10 different manufacturers' gums but equal tyre sizes 225/45R17 and had weight ratings of 94, as well as speed ratings of Y (up to 186mph)
  - No specify running-in period describes
- **Tracks**
  - Continental's proving ground at Uvalde, Texas. The 1.8km Uvalde wet handling track is a recreation of the one at Continental's Contidrom facility near Hanover, Germany
  - The tarmac was shipped from Europe to ensure comparable results
- **Test methods are not describe precisely. No information about**
  - Period of testing
  - Tyre inflation pressure from the manufacturer or the vehicle ? Tyre load ?
  - Track and ambient temperature
  - Technical tools used : sound level meter distance to the vehicle, personal qualification …
  - For Rolling Resistance test : all tests carried out to industry standard. Which ones ?

Whichcar Wheels Study (2017)

- **Framework**
  - The test campaign carried out in 2017, to compare eight brands
- **Settings**
  - A control tyre was deployed at regular intervals as a means of measuring track and car evolution, which could be addressed in the analysis
  - Taking the sound pressure level (SPL) results in decibels (dB)
- **Vehicle type**
  - For all tests it is a Mazda 6 Touring with aluminum rims
  - Its electronic stability control system was switched fully off
- **Tyre types, sizes and dimensions**
  - 8 different manufacturers' gums but equal tyre sizes 225/55R17s because that is the standard fitment on the Mazda 6 test mule
  - A series of hot laps of compact handling circuit, which served to scrub the surface of the tyres
  - Inflating each to 33psi as per the Mazda's placard
- **Tracks**
  - The tarmac surrounding the Sydney Dragway scrutineering shed
- **Test methods are not describe precisely. No information about**
  - Period of testing
  - Track and ambient temperature
  - Technical tools used : sound level meter distance to the vehicle, personal qualification …
  - For tyre noise : use an SPL meter to store a peak dB figure over a straight section of coarse chip road – test at 60km/h

TNO 2014 R10735 report (June 2014)

- **Framework**
  - The ministry of Infrastructure and Environment in the Netherlands has asked TNO to perform a 'quick-scan' study to evaluate the potential of high-quality tyres in terms of energy, safety and noise
- **The study compares two scenarios of tyre distribution in the Netherlands**
  - The baseline scenario : represents the tyre distribution as it currently exists in the Dutch vehicle fleet. The distribution of tyre labels is based on the tyre labels available in the retail database of VACO (VACO is the Dutch industry association for tyres and wheels)
  - The second scenario assumes that all currently-used tyres in the Netherlands are replaced by A-rated tyres
- **Vehicle type**
  - As the study is carried out on the distribution of tyres as it exists, it does not take into account the model of the vehicle that the tyre equips
- **Tyre types, sizes and dimensions**
  - On average vehicles in the Netherlands drive with a D-label for rolling resistance, a C-label for wet grip and a 2 waves label for noise
  - Tyres are classified according to the EU Regulation EC1222/2009
  - The set is based on the 7 brands and the 7 sizes with the highest market share
- **The energy savings potential of a shift to A-rated tyres for energy is evaluated for different vehicle types and tyre classes based on:**
  - The relative reduction in rolling resistance between the tyre X and tyre Y (based on the average of the range of RRCs)
  - The driving pattern, e.g. predominantly urban or highway (are estimated) because the rolling resistance is proportional to the vehicle weight and the share of air resistance in the vehicle's total driving resistance increases with speed
  - The fuel consumption, mileage and fuel costs (petrol and diesel)

TNO 2014 R10735 report (June 2014) 2/2

- **The potential annual safety improvement is calculated as reduced (severe) injuries, fatalities and their societal monetary benefits :**
  - The dry grip performance is therefore not related to the safety label for tyres and thus not assessed in this study
  - The wet grip performance is assessed by measuring the friction potential, which is highly correlated to the acceleration levels that can be achieved with the vehicle
  - From the acceleration levels the safety related quantities such as braking distance and safe cornering speed are calculated
  - In the analyses the calculation is done for a wet grip level of the reference tyre of 0.6
  - Several assumptions are made in the translation from impact speed reduction to societal cost. Seven assumptions are listed
- **The potential benefits in terms of environmental impact and health of a transition from the currently available tyre mix to tyres with the best performance :**
  - External rolling noise emission are computed according to the methods and assumptions that were developed in the VENOLIVA study
  - The EC database of type approval test results was used to assess the expected noise emission reduction during the acceleration and the constant speed tests caused by noise reducing measures, either to the power train or to the tyres or to both
  - From this emission reduction during the test the emission reduction in normal traffic was estimated, making a distinction between accelerating and free flowing traffic
  - The five different vehicle types used in the VENOLIVA computation method, were regrouped into three different vehicle categories (Light, Medium and Heavy)
  - A distinction was made between the tyre classes C1, C2 and C3. Within these classes the following subdivisions are made, following the specification of the noise emission limit values
  - 4 computation step was performed :
    - the average reductions of the tyre rolling noise for each of the tyre classes
    - the effective reductions of in-traffic vehicle noise emissions (according to vehicle category, driving speed, operating condition, type of road surface)
    - the reduction of the characteristic noise impact of a traffic flow for 8 different road / traffic combinations
    - the numbers of (highly) annoyed and (highly) sleep disturbed people from the changes of the traffic flow noise impact

FEHRL – Study SI2,408210 Tyre/Road Noise (2007) 1/2

- **Framework**
  - To assess the potential for reducing tyre noise through the implementation of more stringent type approval limit values, and to assess the impacts that such reductions might have on overall traffic noise, road safety and economy
- **Settings**
  - The collation of a comprehensive database collected from previous studies examining tyre noise, safety performance and rolling resistance
  - Some measurements are not taken precisely in accordance with the procedure provided in the tyre noise Directive but they are included in the database as additional useful information
  - To determining the tyre noise level of the database, it is necessary to adjust the raw measured values according to the procedures for rounding stipulated in the Directive
- **Some tests was performed by the UBA/˙TÜV Automotive**
  - Wet grip
    - on an artificially wetted asphalt surface. The water depth wad permanently kept below 1,5mm in order to exclude the effects of aquaplaning
    - ABS braking system on the 4 wheels was used
    - the vehicle was decelerated from approximately 85km/h to standstill. Speed and distance were measured from 80 to 10 km/h with a satellite-based measuring device
    - for each tyre set, at least 6 valid measurements were performed
  - Rolling resistance
    - measured using methods described in ISO 8767:1992 or 9948:1992 (provided by the ISO 18 164 : first edition from the 1st June 2005)
    - the coefficient Cr [%] is calculated from the average values of the rolling resistance force in Newton [N] divided by the test load in [kg] multiplied by 100 [%]
    - the mean weight of all four tyres of one set is determined prior the rolling resistance measurements
  - Longitudinal Aquaplaning
    - the test vehicles were equipped with rotational speed sensors on both wheels of the front axle
    - for the measurement of the floating speed the test vehicle was run on the test track with the right front wheel aligned with a water basin with 8mm water depth
    - when the vehicle reached the basin it was accelerated maximally
    - the floating speed VAqu is defined as that speed, at which a slip of 15% was reached
    - for each tyre set, at least 6 valid measurements were performed

FEHRL – Study SI2,408210 Tyre/Road Noise (2007) 2/2

- **Results of tests performed by the UBA/¨TÜV Automotive**
  - Tyre noise and wet braking performance
    - the tyre/road noise levels are compared with the wet brake deceleration values
    - no clear trend/correlation can be found between increasing noise levels and with increasing deceleration levels
  - Tyre noise and Rolling resistance
    - the tyre/road noise levels are compared with the rolling road resistance coefficients values
    - no clear trend/correlation can be found between tyre/road noise levels and rolling resistance coefficients
    - C1c winter tyres and C1c summer show opposite trend and no significant trends in either direction cans be seen for the other C1 classes
  - Tyres noise levels and Longitudinal Aquaplaning
    - the tyre/road noise level are compared with the aquaplaning speed values
    - no clear trend/correlation can be found between tyre/road noise levels and aquaplaning speed values
- **Addition tests/data (same data inter-noise HAMBURG 2016 ?)**
  - All data confirm the results present in the previous conclusion
- **Future trends in tyre design**
  - Regarding conventional tyres the literature review examines the potential benefits from adapting winter tyres for all year round use and describes modifications to the tread design to include :
    - changing the air/rubber ratio
    - changing the size of the tread elements and using different rubber compounds
  - The increasing use of run-flat tyre designs is also examined together with the potential noise advantages of ensuring that tyres are correctly inflated in use
  - Unconventional tyre designs include an overview of non-pneumatic composite tyres. The noise-reducing potential for a composite wheel has been demonstrated to be around 10dB(A)
- **Part of the mismatch between testing and real situations lies in the test surface used for type approval**

Noise Technology - Continental (April 2011)

- **Framework**
  - Tyre development is managing of target conflicts : Rolling Resistance – Braking – Noise
  - A tyre which have a Rolling Resistance optimized compound, is impacted by the performance on : Dry Grip, Wet Grip, Mileage and Noise
- **Settings**
  - Use an (internal ?) methodology to simulate the tyre noise
    - Focus on a tyre perimeter (contact with the road surface)
    - Divide the tyre by tracks (groove separation) (in general n)
    - Suppose a shift step
    - Compute the total number of positions for each track (in general m)
  - These assumptions allow to compute the total number of track constellations for a pattern : m(n-1)
- **Only one test for rolling noise is presented (serves as a preface)**
  - 4 car tyres of size 235/45R17 but with different tread compounds. A motorcycle slick tyre is used as a reference
  - No information on the tracks and vehicle used. Measurements according to the ECE R117
  - Conclusion :
    - Small slick tires are not always less noisy than wide slick tyres. The average sound level of a modern slick tyre is 68dB (A).
    - The sound level depends on the tread compound
- **Tyre design trade-offs**
  - Tread pattern design
    - A tyre with a 34% void ratio is better than a slick tyre for the wet braking and the aquaplaning in curve but is 3dB(A) noisier
  - Tread material
    - A tyre with a summer tread compound is better than a tyre with a very low stiffness tread compound for the cornering stiffness and the wear but is 3dB(A) noisier
  - Tread thickness
    - A tyre with a very low stiffness tread compound is 3dB(A) quieter than a tyre with normal tread but has a 15% increase in rolling resistance
  - Void volume effect on tyre noise
    - Longitudinal void is less important
    - Lateral void influences the noise level more

Noise Trade-Offs - Michelin (October 2007)

- **Framework**
  - Reduction of tyre/road noise through tyre design :
    - Tread pattern design
    - Tread rubber compound
    - Tyre internal structure
- **No specific test describe. Seems to be a cluster of studies (experience feedback)**
  - For each items : behaviour description between two tyres
  - Effect on longitudinal aquaplaning
    - Speed at onset of aquaplaning : 82km/h to 66km/h. Water depth 8mm
    - Sculptured tyre with a void ratio of 28% is 3,5dB(A) noisier than a slick tyre but is more safety on a longitudinal aquaplaning
  - Effect on aquaplaning in curve
    - Mean lateral acceleration between 55km/h to 85 km/h. Water depth 7mm
    - Sculptured tyre with a void ratio of 28% is 3,5dB(A) noisier than a slick tyre but is more safety on an aquaplaning in curve
  - Effect on wet braking
    - From 80 to 10 km/h on macro rough surface
    - Sculptured tyre with a void ratio of 28% is 3,5dB(A) noisier than a slick tyre but is more safety on a wet braking
  - Effects on wear and handling
    - A tyre with a very soft tread compound is quieter of -1dB(A) than a Standard tread compound but it is -15% in handling, thus less safety in avoidance manoeuvres. Furthermore, the wear decrease of -25%
    - A tyre with a thicker under-tread more important is quieter of -2dB than a tyre with a normal tread but it is -15% in handling
  - Effect on cost
    - A tyre with a thicker under-tread more important is +12% more expensive than a tyre with a normal tread

Tire-Road Noise - GoodYear (November 2018)

- **Framework**
  - Goodyear Dunlop's development goal is a balanced tyre with a strong focus on safety-related criteria
  - Tyre development considers +50 tyre performances. Optimized performances in function of vehicle, road and weather conditions
- **Significantly different noise testing in tyre and vehicle legislation**
  - Tyre Noise : Reg. (EC) No 661/2009
  - Vehicle Noise : Reg. (EC) No 540/2014
- **Balancing of the different noise sources required to reach an overall vehicle noise target under the vehicle noise regulation**
- **Tyre/Road Noise Generation Mechanisms**
  - Tread element impact — Running deflections — Road texture impact
  - Stick-slip adhesion — Air turbulence — Air displacement — Stick-snap adhesion
  - Helmholtz resonator — Pipe resonators — Horn amplification
  - Key role of road surface in all aspects of tire/road generation
- **Tyre and Road Influence on Noise**
  - Laboratory noise test at 50 km/h on a drum with 2 different road surfaces : Smooth road replica and coarse road replica
  - 6 tyres of the same size with different construction and tread pattern. 1 slick tyre (no tread pattern) with low noise construction
  - Result : 10dB difference between the two road surfaces. For majority frequency, slick tyre is quieter
- **Performed tyre sound power measurements in Low/High spatial resolution with a specific method describes**
- **Examples of tyre/road noise trade-offs**
  - Slick tyres. normal tyres : Size and dimensions : 235/40 R19. Noise at 50km/h : 67dB(A). Slick tyre is -1,5dB(A) quieter ; RR : Slick tyre is 10% worse ; Straight Aquaplaning : Slick tyre have an unacceptable level
  - Tread compound vs. High hysteresis tread compound : Noise at 50km/h : High hysteresis tread compound is -0,5dB(A) quieter ; RR :High hysteresis tread compound 25% worse
  - Standard belt vs. Heavy belt : Noise at 50km/h : Heavy belt is -0,3dB(A) quieter ; tyre weight : Heavy belt is 10% heavier
  - Tread pattern vs. Tread 25% lower groove volume: Noise at 50km/h : tread 25% lower groove volume is -0,5dB(A) quieter ; RR : Same result ; Straight Aquaplaning : tread 25% lower groove volume is 15% worse

Noise - Michelin (March 2015)

- **Framework**
  - A few words about mechanisms, an overview of the noise test procedure and impacting factors
- **2 main phenomena dominate the generation of exterior noise**
  - The structural vibration of the tyre caused by the roughness of the road surface and the tyre's tread pattern
  - Air pumping caused by the compression and decompression of the air trapped within the tread block and the road surface
- **3 main phenomena dominate the mechanisms that affect the exterior noise**
  - Resonance of air in the void network: Organ pipe
  - The horn effect in front and behind the contact patch
  - The absorption of the ground
- **Temperature impacts the noise level because tyre behavior and road surface behavior are temperature dependent**
- **The increase of the load leads to the expansion of the contact patch area but have a small effect on contact pressure**
- **The increase of inflation pressure leads to the shrinkage of the contact patch area and higher contact pressure**
- **Car manufacturer choses tyre size and category (sporty, all season, luxury, winter, …) to fit the vehicle**
  - For a given tyre size and category, difference in noise may be up to 3 dB(A)
- **Noise test procedure**
  - Coast-down (engine-off) at several speeds between 70 kph & 90 kph. At least 10 dB(A) difference with ambient noise
  - Load: Average between 70% & 80% of reference load
  - ISO surface (ISO 10844). 50m zone cleared of any obstacle
  - Preparatory phase : 100 km run-in for each set of tires and warming-up
  - Max pressure of each microphone is retained. Value is temperature corrected and rounded
  - A necessary linear regression is applied for measurement random deviation and speed peed sensitive tyre vibration effects
  - Interpolated value at 80 kph (C1 tires) is calculated
- **No specific test describe. Seems to be a cluster of studies (experience feedback) ➔ Noise Trade-Offs - Michelin (October 2007)**

Inter-noise HAMBURG (2016)

- **Framework**
  - This paper presents a study where noise and rolling resistance properties of tyres for winter conditions are compared to summer and all-season tyres
  - 3 Studies : first in 1995 to 2000, a second in 2011 to 2012 and the last in 2015 to 2016
- **Settings**
  - All measurements results have been normalized to a reference air temperature of 10°C in order to minimize that varying temperatures during the measurements affect the results
  - A measurements correction was applied for noise according to ISO/DTS 13 471-1
- **Vehicle type**
  - No vehicle. Use a trailer
- **Tyre types, sizes and dimensions**
  - Approximatively 50 car tyres have been measured with a trailer method
  - The winter tyres include types optimized for central European climate, tyres optimized for Nordic climate and tyres with studs
  - There is a special winter tyre design which is essentially optimized for northern climates but having silicium carbide granules evenly mixed into the rubber compound of the tyres tread
  - Use a SRTT : Standard Reference Test Tyre according to ASTM 2493:14
  - Use tyres in new condition and in used condition
  - Tyres were loaded essentially in accordance with ECE regulation R117 (406kg for noise, 408kg for rolling resistance)
  - Inflation pressure was adjusted in accordance with the specifications in ECE R117 : fixed 180kPa in cold condition for noise, regulated 200kPa for rolling resistance
- **Tracks**
  - All measurements made on two road surfaces : SMA 8 (the surface texture was characterized according to ISO 13 473-1) and DAC 16 (its texture appeared to be similar to the SMA 16)
- **Test methods are describe precisely**
  - For noise : using a dedicated CPX trailer, according to the procedure given in ISO/FDIS 11 819-2. With 3 speeds : 30, 50 and 80km/h an minimum 2 runs
  - For Rolling resistance : measurements were performed with the trailer owned and operate by the Technical University of Gdansk (TUG). With 2 speeds 50 and 80km/h

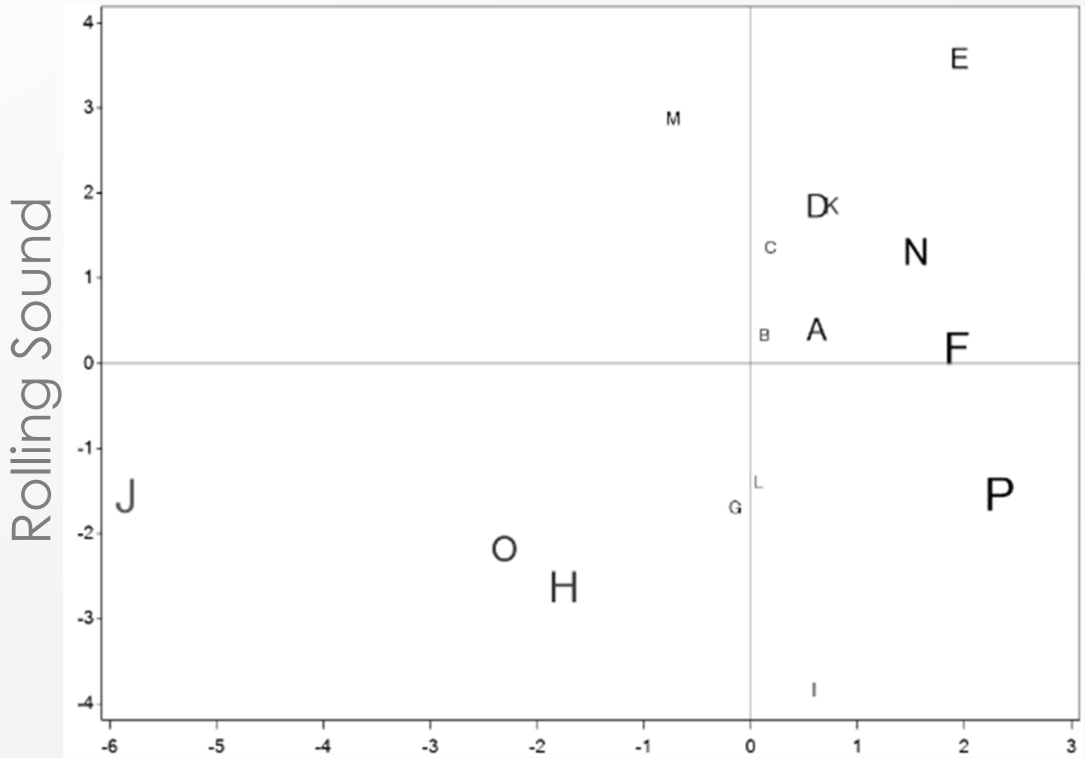
Thesis Report Tyre Modelling For RR (2014)

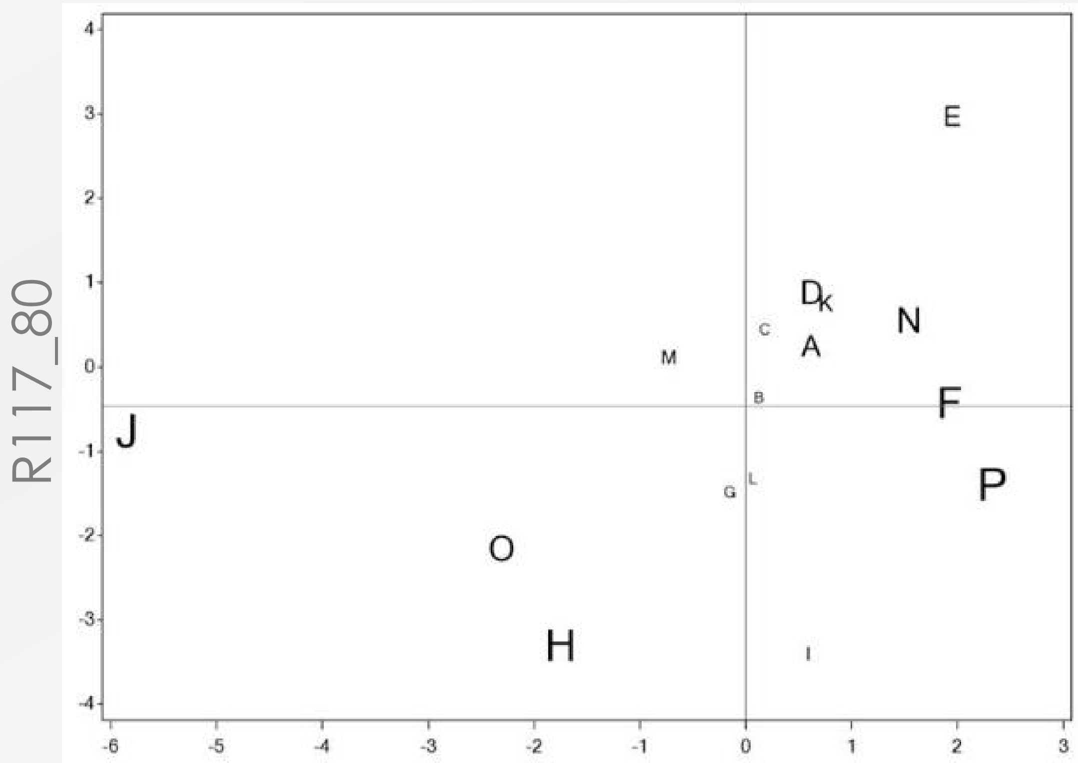
- **Framework**
  - This study investigates mathematical models based on physical understanding and literature reviews of tyre rolling resistance phenomena
  - The work aims to develop a tyre model that explains the influence of tyre inflation pressure, tyre size, velocity and normal load on the rolling resistance coefficient
- **Settings**
  - Some design parameters such as tyre material, tread pattern, road types and temperature are not considered
  - The tyre model applies to free rolling cases and does not include any torque application to wheels or longitudinal slip
  - There are many assumptions such as :
    - Contact patch shape is assumed to be perfect rectangle
    - Inflation pressure doesn't change with deflection
    - Tyre material and tread pattern are kept constant
    - Road type is fixed to hard, dry and flat surface
  - Most of the tyre information has been taken from various research papers and correspondingly, most constants used have been obtained thereof
- **Vehicle type**
  - No vehicle used in this study
- **Tyre types, sizes and dimensions**
  - No specifics tyres types, sizes and dimensions used in this study
- **Tracks**
  - No tracks used in this study
- **The results are describe for 4 parameters which influence on the rolling resistance**

APPENDIX 2 – Statistical Analysis

Representing Rolling Sound (1/6)

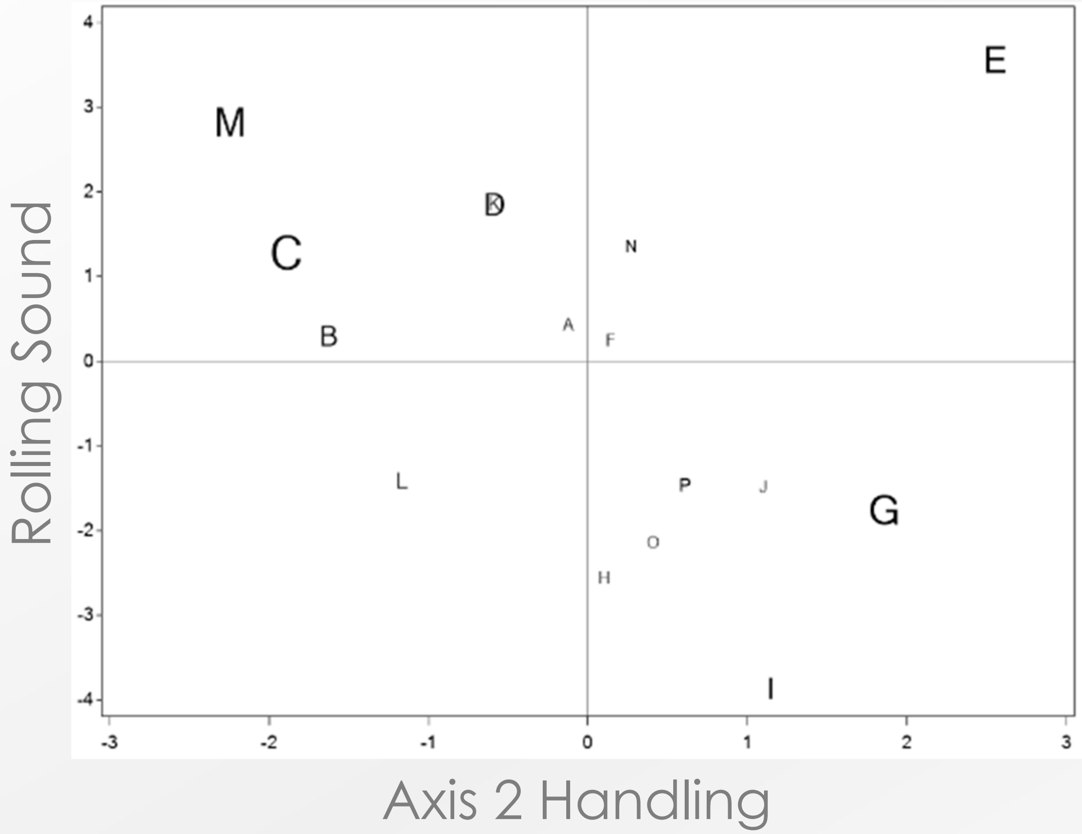
Representation of Noise and R117_80 vs Axis 1 Safety

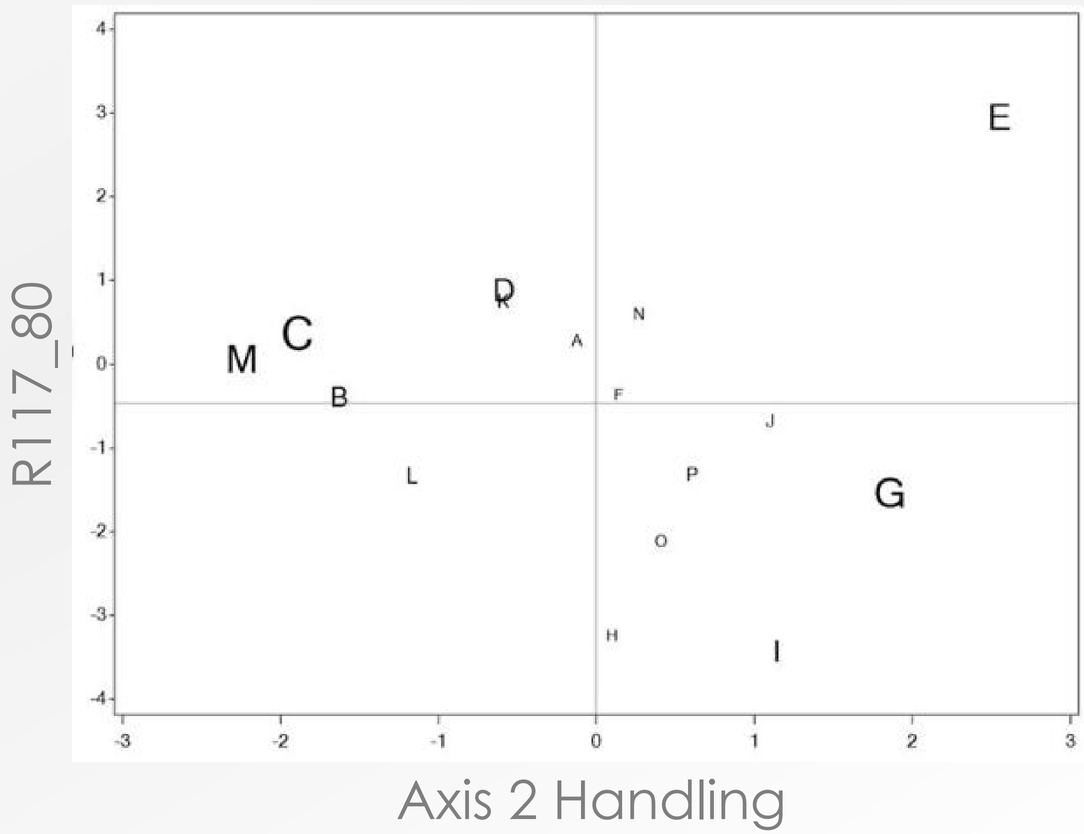




Representing Rolling Sound (2/6)

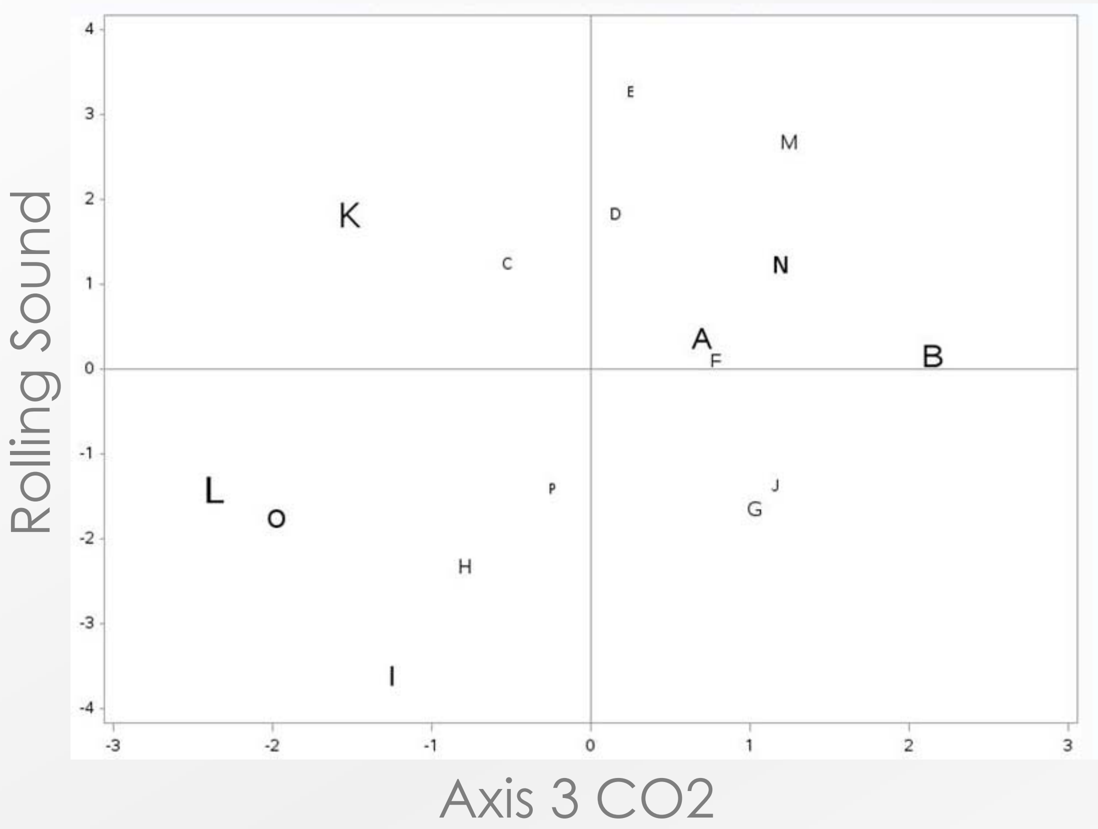
Representation of R117_80 vs Axis 2 Handling

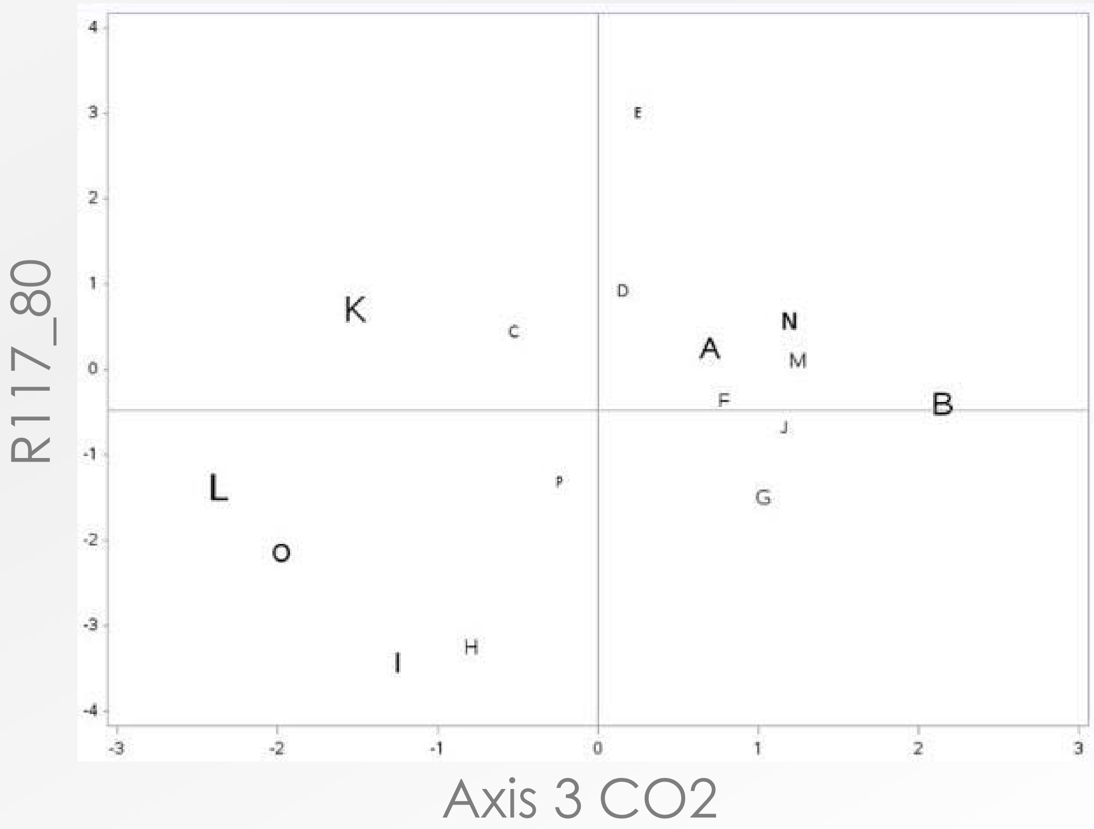




Representing Rolling Sound (3/6)

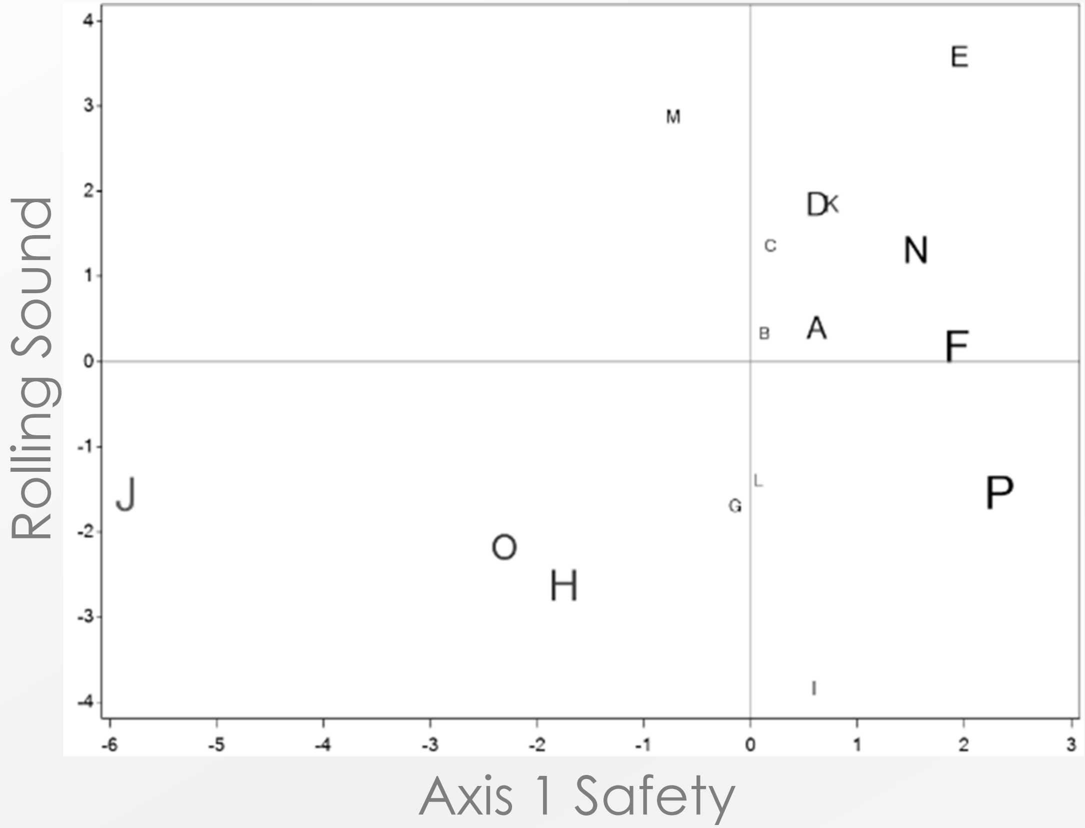
Representation of R117_80 vs Axis 3 CO2 Emissions

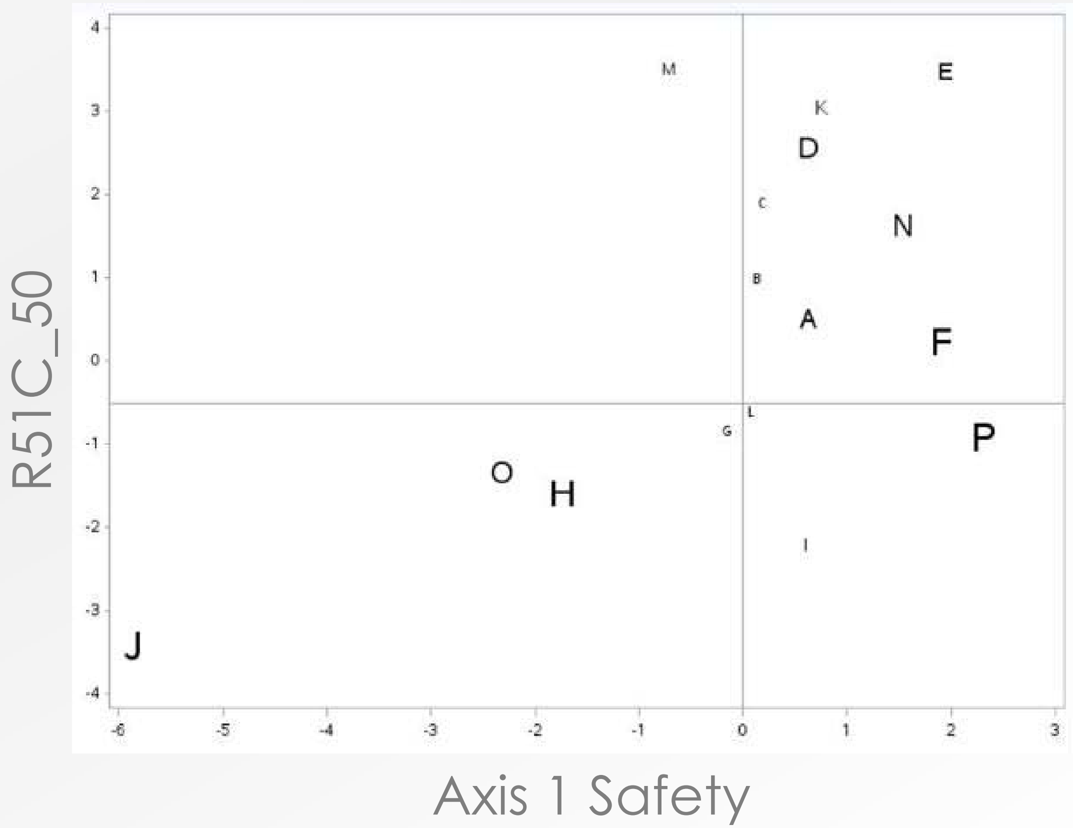




Representing Rolling Sound (4/6)

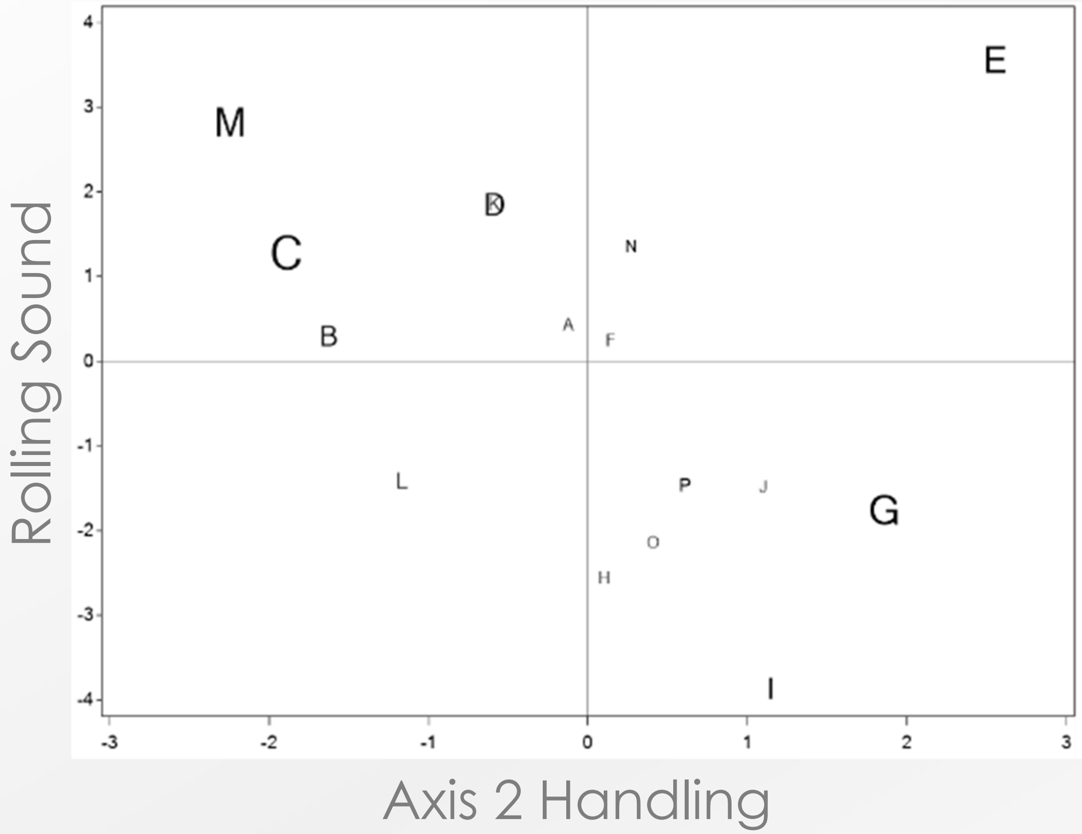
Representation of Noise and R51C_50 vs Axis 1 Safety

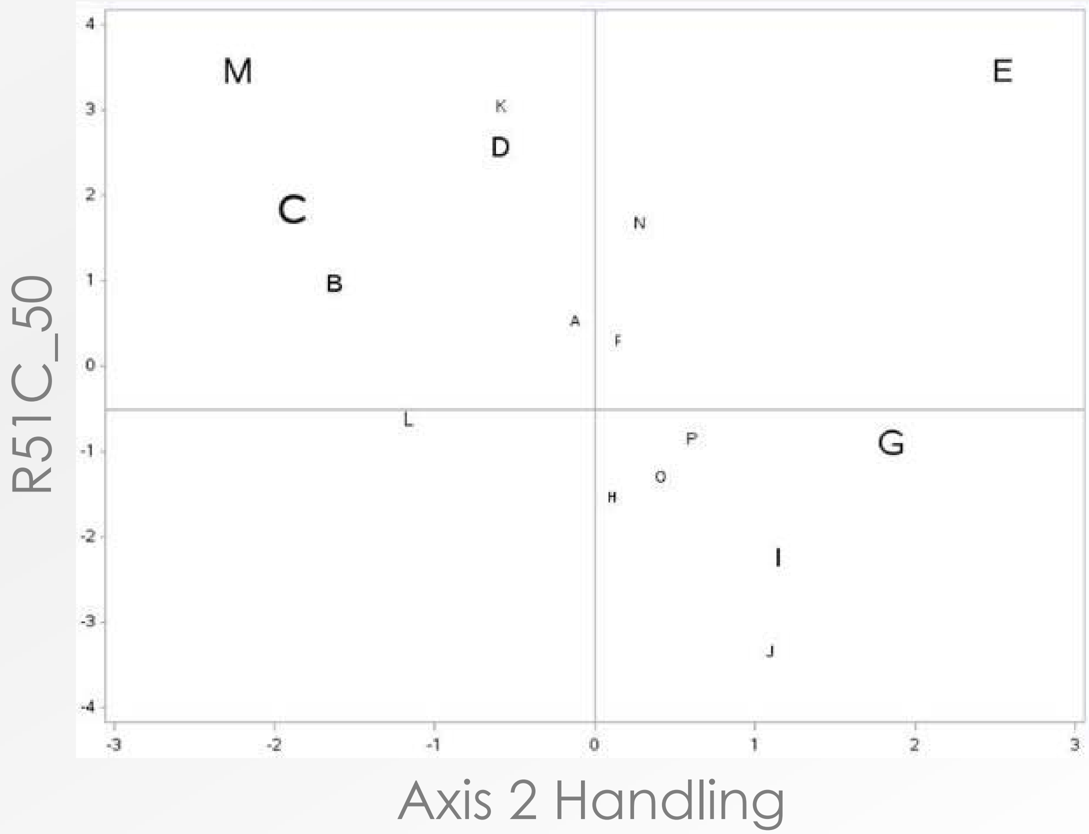




Representing Rolling Sound (5/6)

Representation of R51C_50 vs Axis 2 Handling





Representing Rolling Sound (6/6)

Representation of R51C_50 vs Axis 3 CO2 Emissions