G4 AMSTERDAM DEN HAAG ROTTERDAM UTRECHT

LVNS L-vehicles Emissions and Noise mitigation Solutions

Loud vehicle monitoring in four Dutch cities and mitigation options

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for UNECE GRBP Task Force Vehicle Sound

TNO innovation for life

Overview

1. Introduction and causes
2. Monitoring loud vehicles in G4 cities
3. Approach and results
4. Causes of high noise and observations
5. Potential mitigation options and policies
6. EU project LENS
7. Characteristic driving conditions
8. Vehicle modifications
9. Feasibility of noise cameras
10. Conclusions and follow-up
11. Some suggestions

Introduction

- Loud vehicles lead to many complaints and significant impact on residents along affected routes both in urban and rural areas
- Local communities and associations protesting and petitioning
- The high noise levels have minor effect on long term Lden average exposure levels
- Technical and policy solutions sought
- Monitoring of loud vehicles in four NL cities (G4)
- EU project LENS on mitigation of L-vehicle noise and emissions
- Study on feasibility of noise cameras

G4 Cooperation

- City cooperation on how to tackle the issue of loud vehicles and lobby to NL Ministries
- Lack of police capacity for enforcement – few options for cities
- High serious annoyance rate for loud vehicles (10-19%)

- TNO contracted to perform roadside measurements in Amsterdam, Rotterdam, The Hague and Utrecht

- **Aim: to investigate causes of high noise levels and potential mitigation measures**

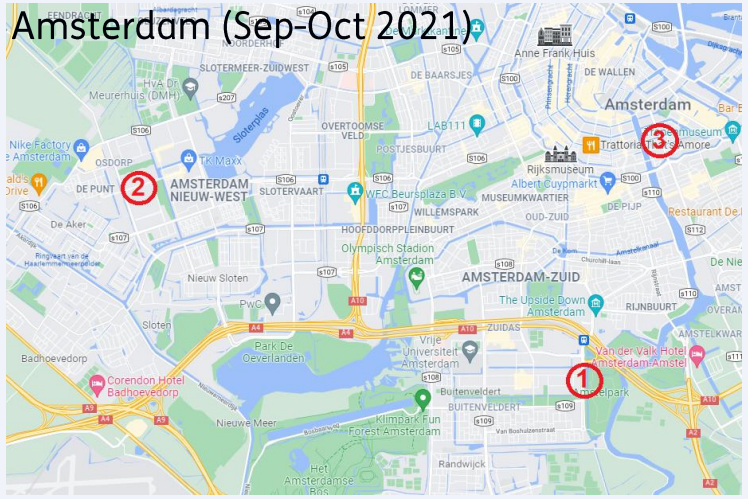
  (Not to develop a noise camera)

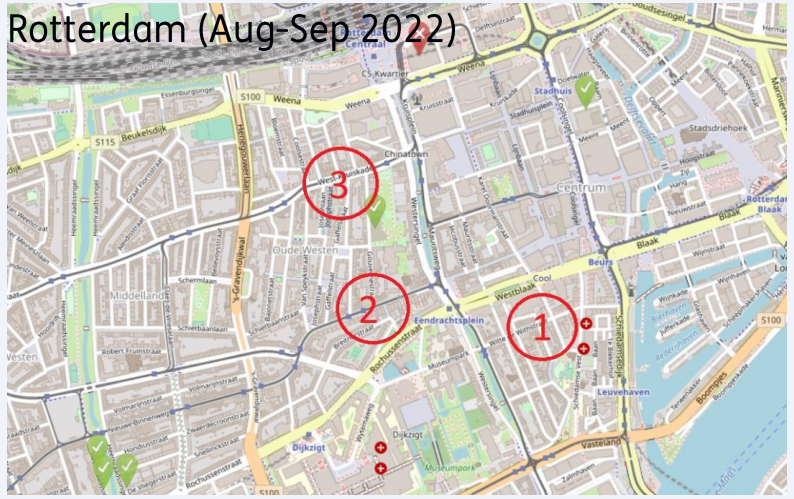
Causes of increased noise impact

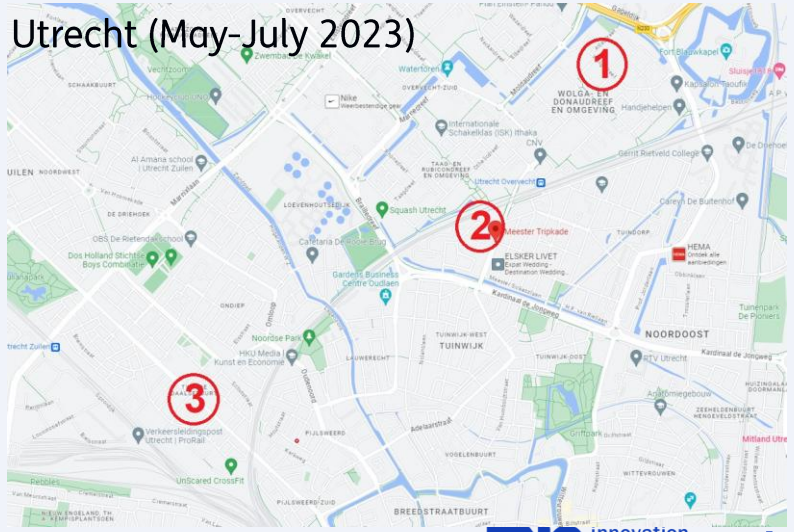
- More vehicles on the road
- Higher building density and noise sensitivity
- Low enforcement of vehicle noise
- Vehicle power has increased
- Driving behaviour
- Vehicle modifications: tuning methods, products and services to increase power and noise are widespread
- New vehicles are not necessarily quieter than previous models in practice

Monitoring of loud vehicles in the G4 cities

- 3 locations per city,
  5-7 days per location
- Mostly 50 km/h through roads,
  2x1 or 2x2 lanes
- Noise measurement with video and numberplate camera (ANPR) for vehicle identification
- Cars, motorcycles, mopeds/scooters, quads and trikes
- Objective: features of loud vehicles and sound levels per location, aimed at causes and measures

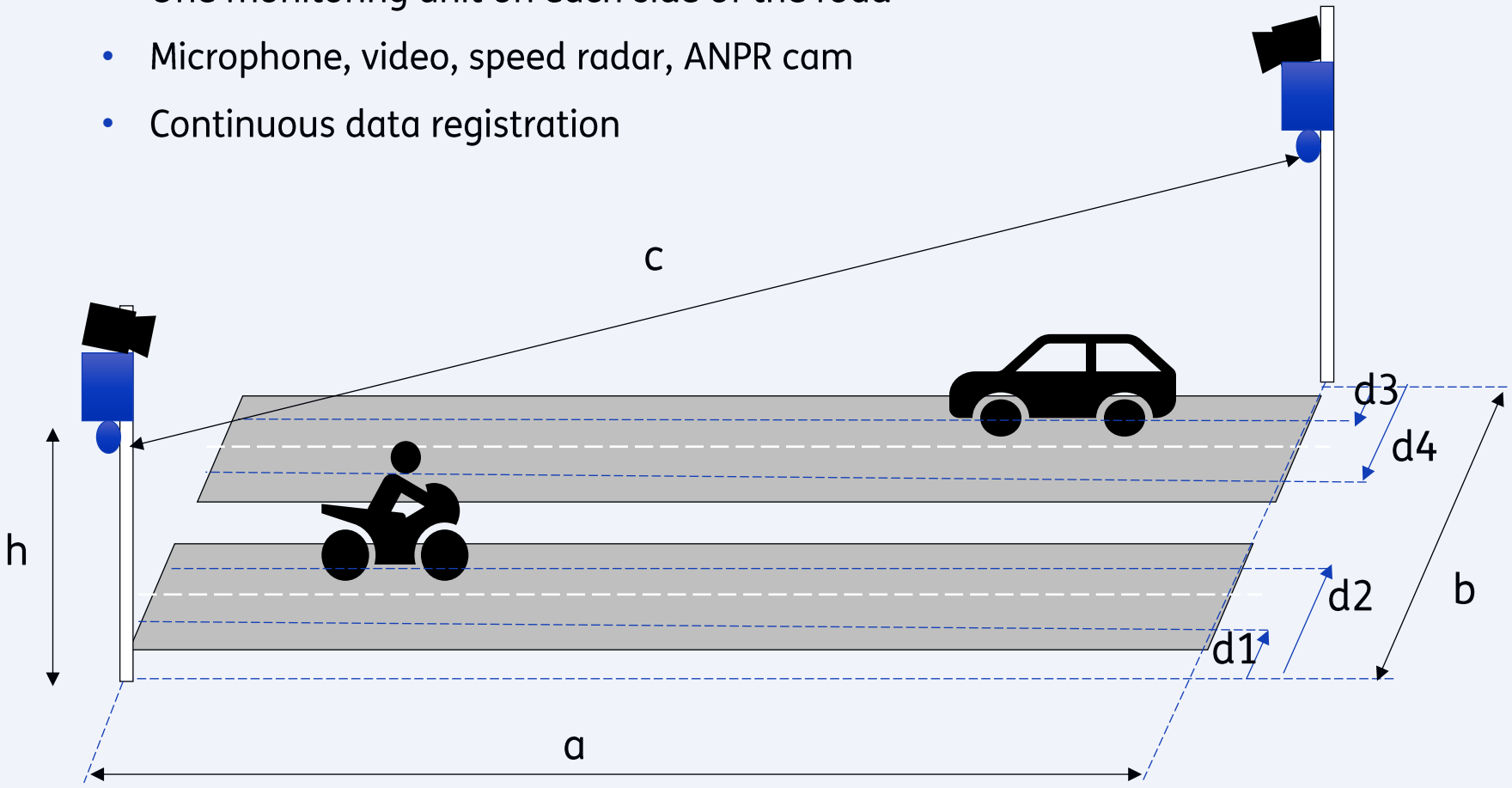




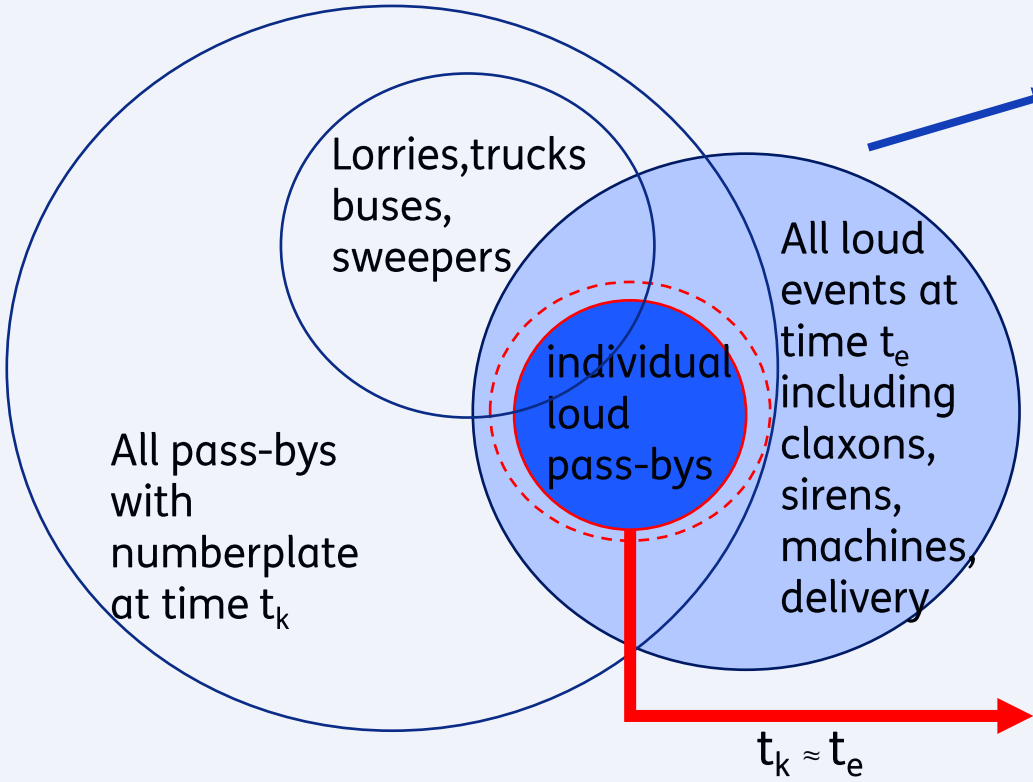


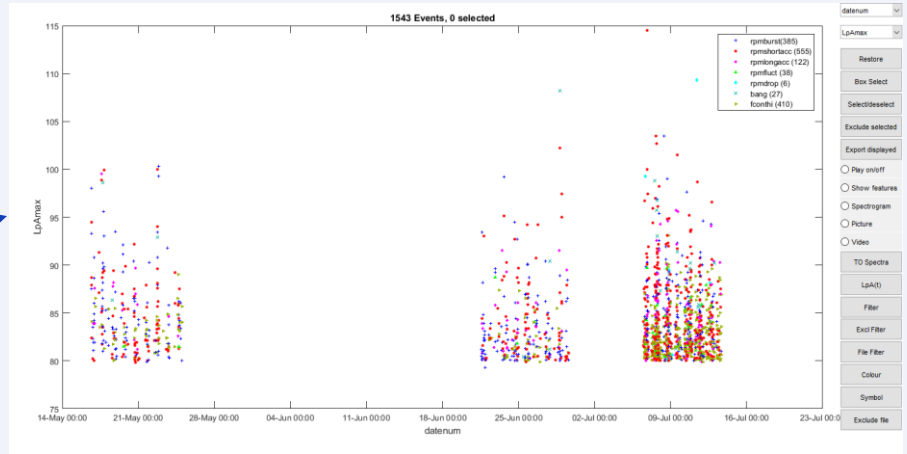
Measurement setup

- One monitoring unit on each side of the road
- Microphone, video, speed radar, ANPR cam
- Continuous data registration



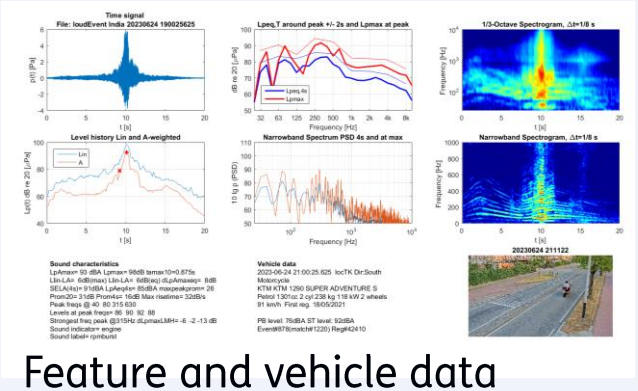
Selection process – from thousands to hundreds





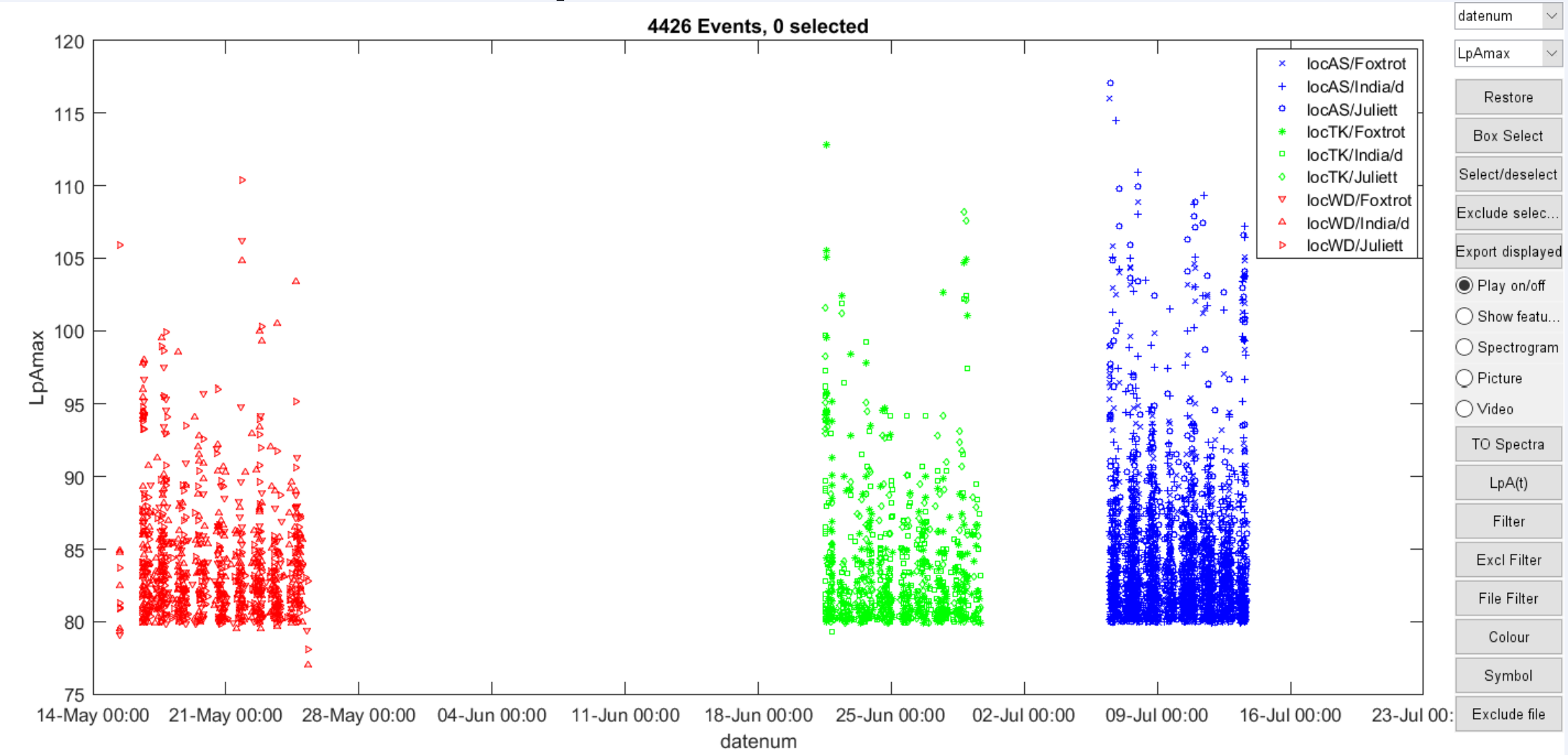
Event browser for detecting vehicle vs. non-vehicle sources and sound characteristics

Numberplate -> vehicle data
Sound level and acoustic features
Video and image
Only cars, motorcycles, mopeds,
trikes and quads

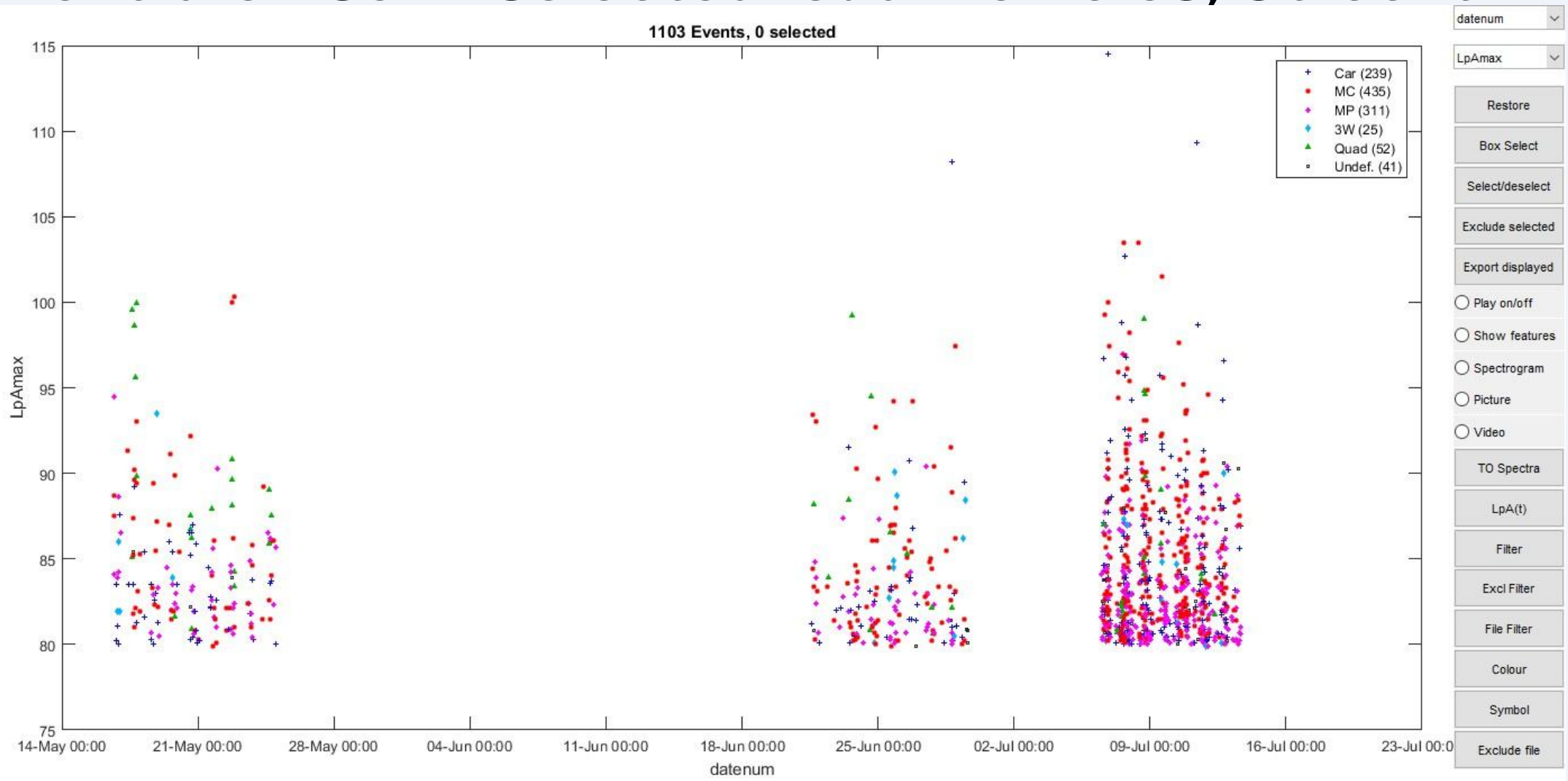


Feature and vehicle data overview

Event browser – L_{pAFmax} all events > 80 dB(A), Utrecht



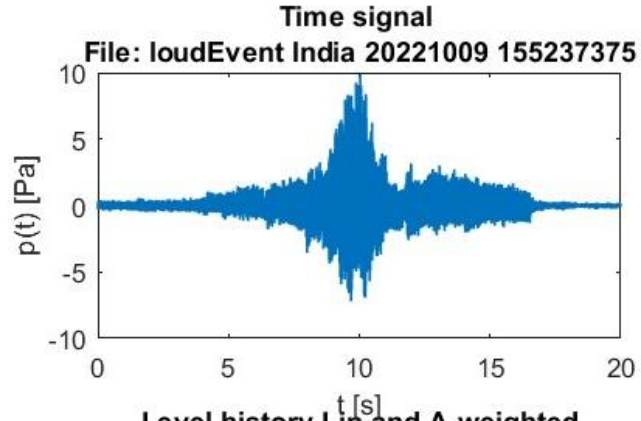
Event browser – selected loud vehicles, Utrecht

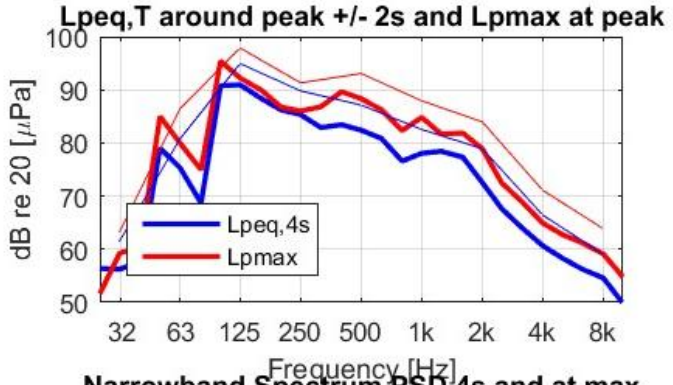


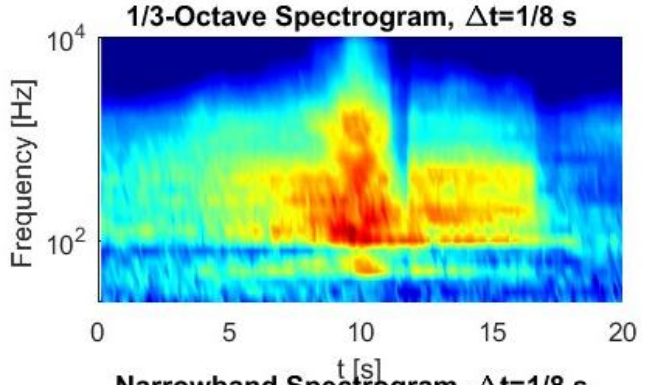
Sound features for each event

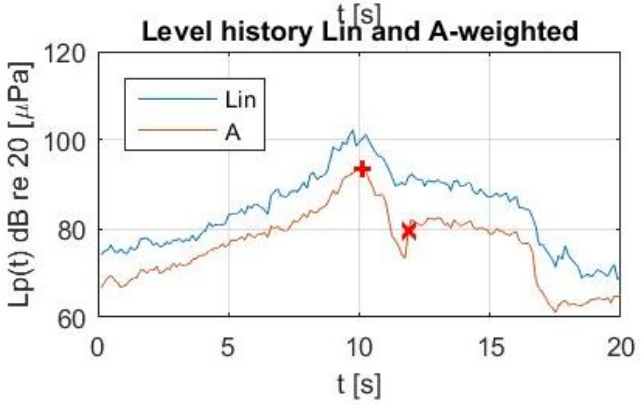
- Single value parameters:
  - L_{pAFmax} and L_{pFmax}, $L_{pAeq,4s}$ and $L_{peq,4s}$
  - Normalised low, medium and high frequency levels, defined as L_{pFmax}(total)-L_{pFmax}(frange) with frange = 20-250 Hz, 250-1000 Hz and 1000-10000 Hz
  - L_{pAFmax} - $L_{pAeq,4s}$, L_{pFmax} - L_{pFAmax}
  - Strongest frequency f_1 and spectrum amplitude $L_p(f_1)$
  - Number of narrowband harmonics, especially for engine noise
  - Rise time of the noise level history (dL/dt)max
  - Text labels indicative of sound content, such as ‘impact’, ‘siren’, ‘claxon’, ’engine’, ’repet’, ’fcontlo’, ’fconthi’, ’voice’ (specific algorithms)
  - Text labels for engine speed related sound content (specific algorithms)
  - And many others
- Array parameters:
  Time signal, level history, third octave spectrum and spectrogram, narrowband spectrum and spectrogram

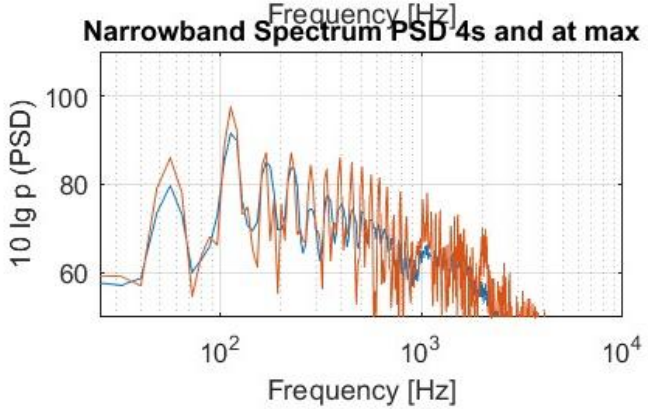
Sound features – High rpm moped 93 dB(A)

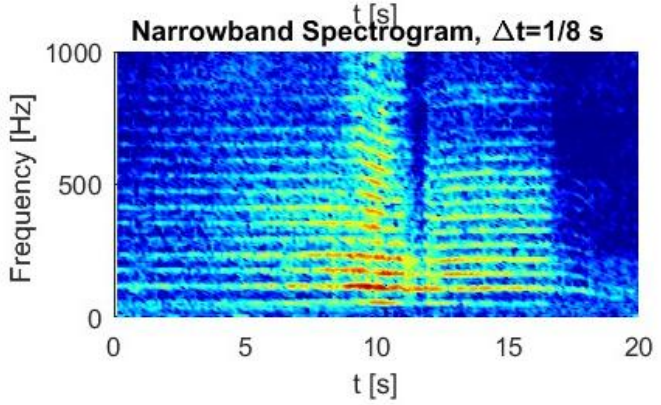










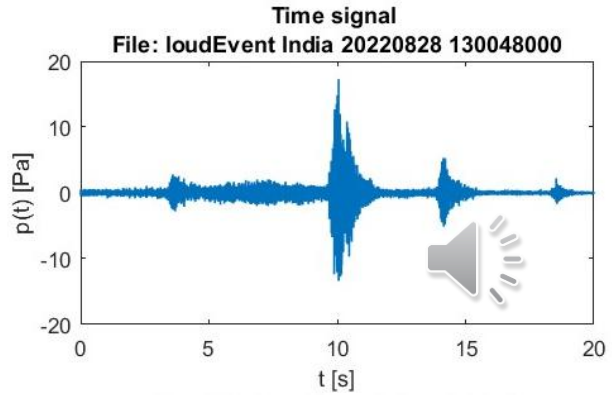


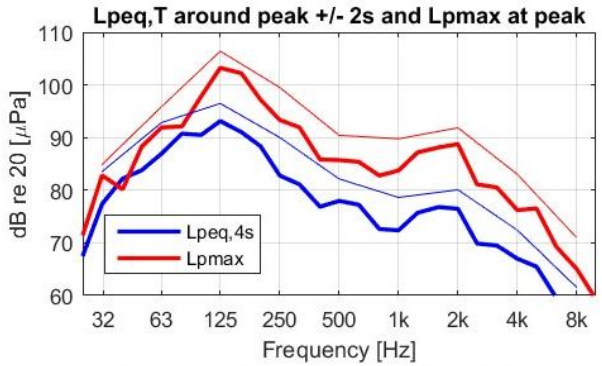
Sound characteristics
LpAmax= 93 dBA Lpmax=102dB tamax10=3s
Llin-LA= 9dB(max) Llin-LA= 8dB(eq) dLpAmaxeq= 5dB
SELA(4s)= 95dBA LpAeq4s= 89dBA maxpeakprom= 4
Prom20= 19dB Prom4s= 12dB Max risetime= 50dB/s
Peak freqs @ 50 400
Levels at peak freqs= 85 90
Strongest freq peak @400Hz dLpmaxLMH= -4 -6 -18 dB
Sound indicator= engineL fcontlo
Sound label= fconthi

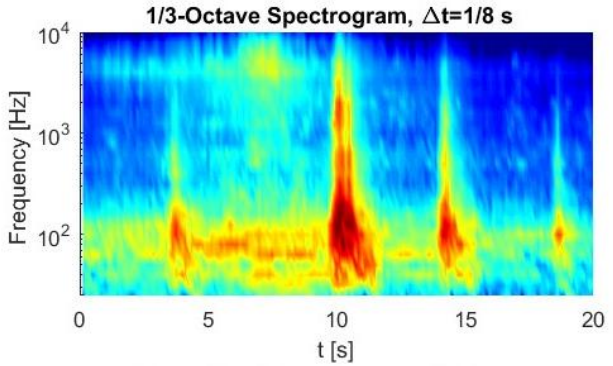
Vehicle data
2022-10-09 17:52:37.375 locAL Dir:North
Moped
HANWAY RAW 50
Petrol 49cc 1 cyl 96 kg 2.2 kW 2 wheels
48 km/h First reg. 30/07/2016

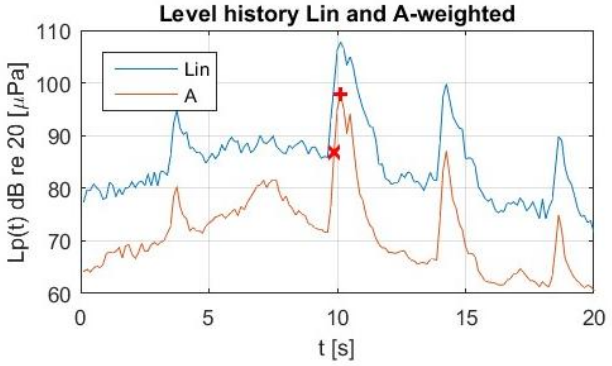
PB level: 69dBA ST level: 80dBA
Event#324(mid#746) Reg#81311

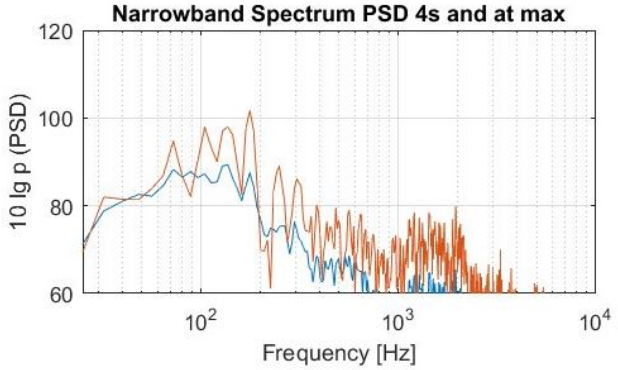
Sound features – Revving motorcycle 98 dB(A)

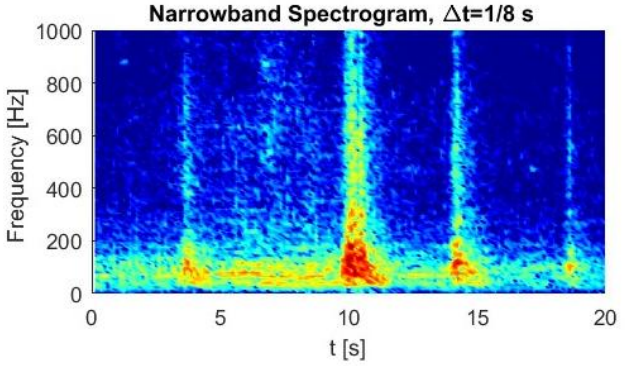










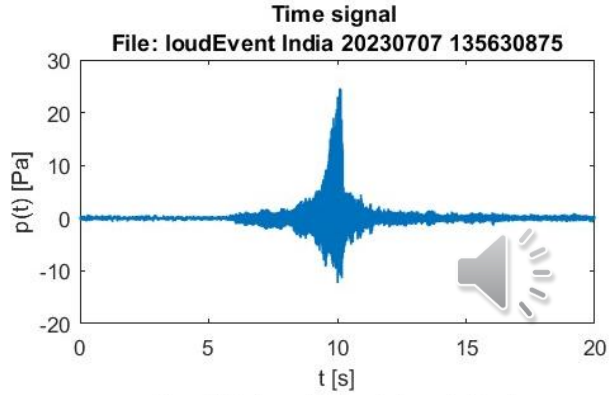


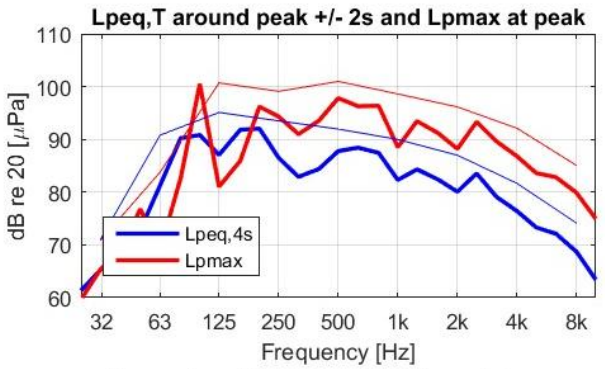
Sound characteristics
LpAmax= 98 dBA Lpmax=108dB tamax10=0.75s
Llin-LA= 10dB(max) Llin-LA= 12dB(eq) dLpAmaxeq= 10dB
SELA(4s)= 94dBA LpAeq4s= 87dBA maxpeakprom= 32
Prom20= 26dB Prom4s= 17dB Max risetime= 82dB/s
Peak freqs @125 2000
Levels at peak freqs=103 89
Strongest freq peak @125Hz dLpmaxLMH= -1 -7 -15 dB
Sound indicator= engineL
Sound label= rpmburst

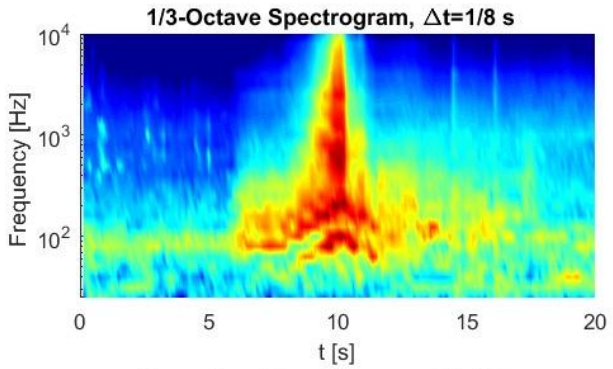
Vehicle data
2022-08-28 15:00:48.000 locWW Dir:West
Motorcycle
HARLEY DAVIDSON CVO ULTRA LIMITED
Petrol 1923cc 2 cyl 428 kg 78 kW 2 wheels
30 km/h First reg. 09/2021

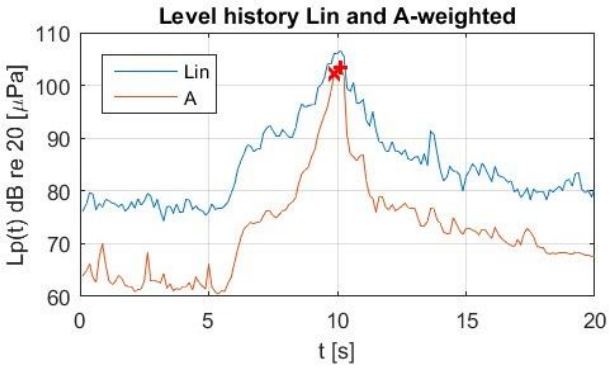
PB level: 76dBA ST level: 92dBA
Event#325(mid#866) Reg#17161

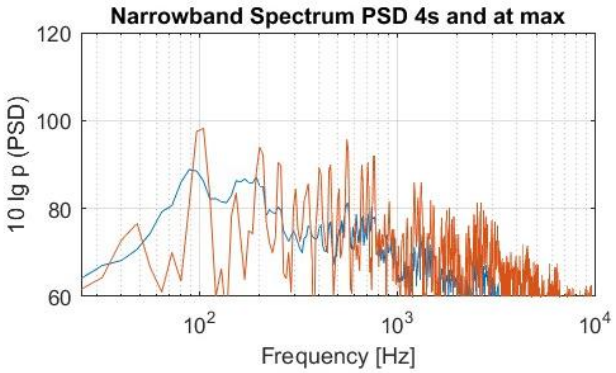
Sound features – Fast accelerating motorcycle 104 dB(A)

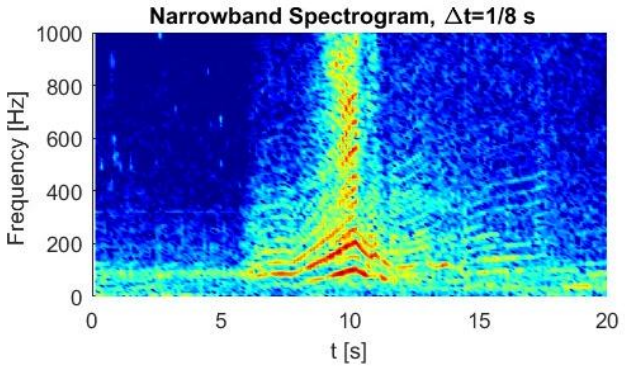












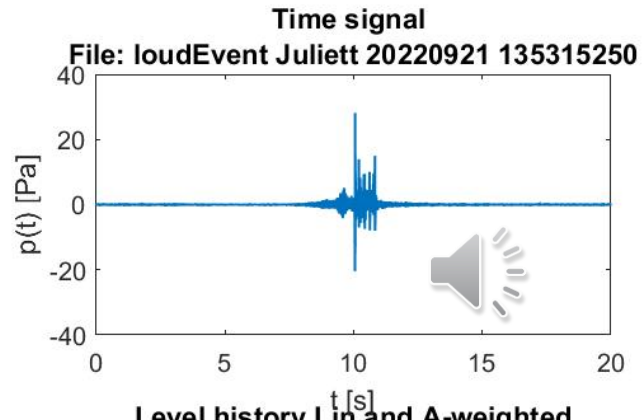
Sound characteristics
LpAmax=104 dBA Lpmax=107dB tamax10=0.875s
Llin-LA= 3dB(max) Llin-LA= 5dB(eq) dLpAmaxeq= 9dB
SELA(4s)=101dBA LpAeq4s= 95dBA maxpeakprom= 26
Prom20= 33dB Prom4s= 16dB Max risetime= 26dB/s
Peak freqs @ 50 100 200 500 1250 2500
Levels at peak freqs= 77 101 96 98 93 93
Strongest freq peak @100Hz dLpmaxLMH= -6 -2 -9 dB
Sound indicator= engine bangs
Sound label= rpmshortacc

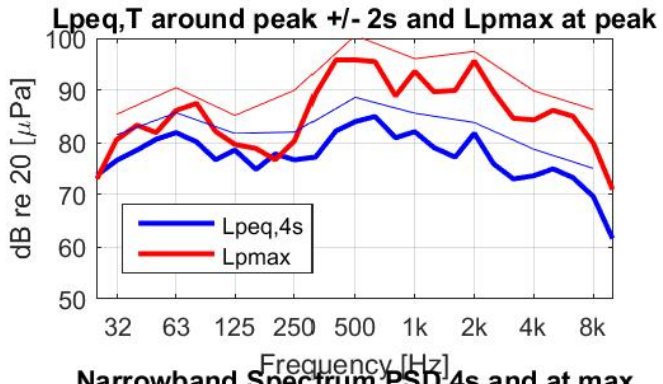
Vehicle data
2023-07-07 15:56:30.875 locAS Dir:South
Motorcycle
BMW R 45
Petrol 473cc 2 cyl 205 kg 26 kW 2 wheels
63 km/h First reg. 21/04/1979

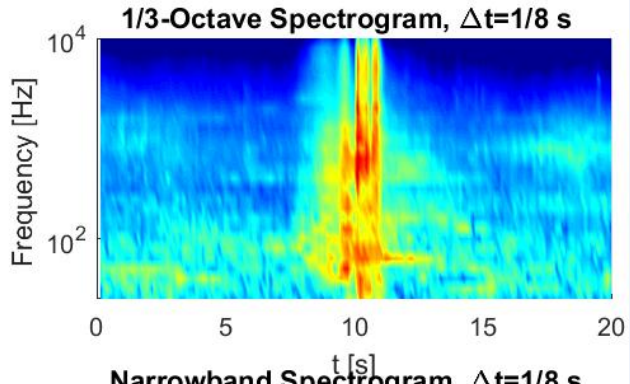
PB level: dBA ST level: 92dBA
Event#1543(match#2516) Reg#79032

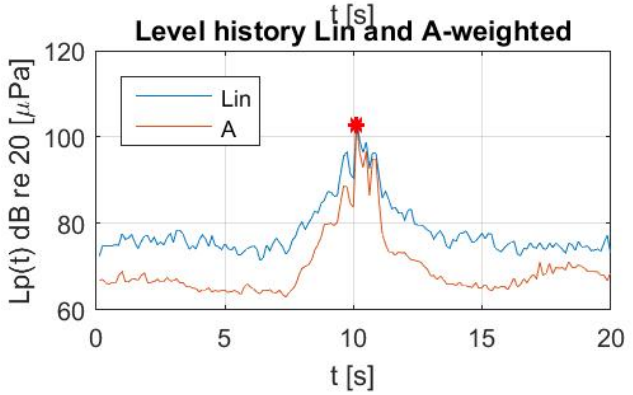
20230707 155727

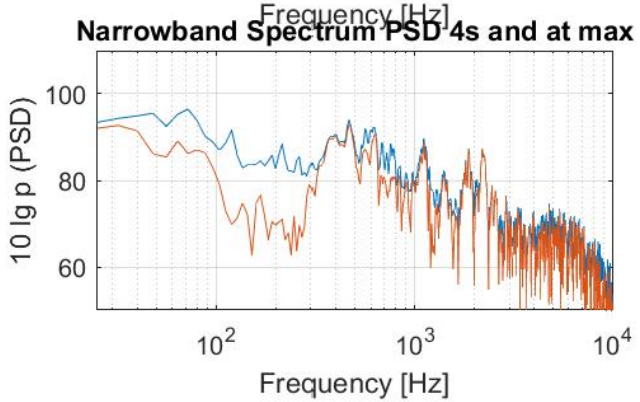
Sound features – Car with backfire noise 103 dB(A)

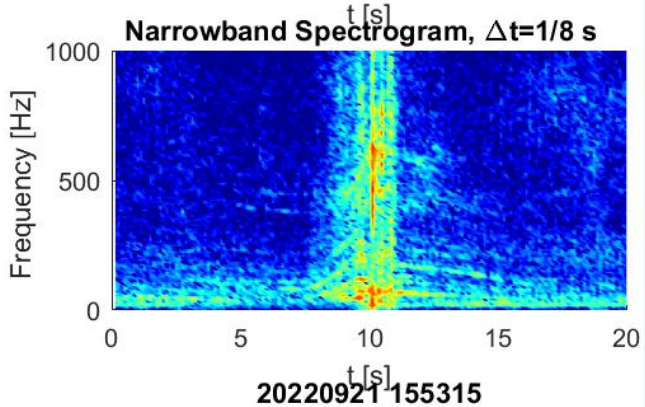










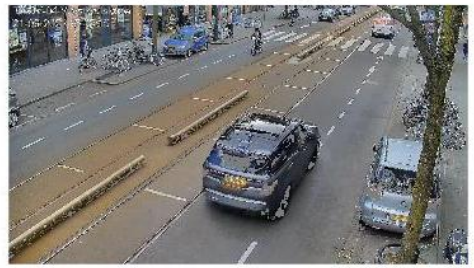


Sound characteristics
LpAmax=103 dBA Lpmax=104dB tamax10=0.75s
Llin-LA= 1dB(max) Llin-LA= 3dB(eq) dLpAmaxeq= 12dB
SELA(4s)= 97dBA LpAeq4s= 91dBA maxpeakprom= 7
Prom20= 34dB Prom4s= 18dB Max risetime=151dB/s
Peak freqs @ 80 1000 2000
Levels at peak freqs= 87 94 96
Strongest freq peak @2000Hz dLpmaxLMH=-11 -2 -6 dB
Sound indicator= engine vc
Sound label= bang

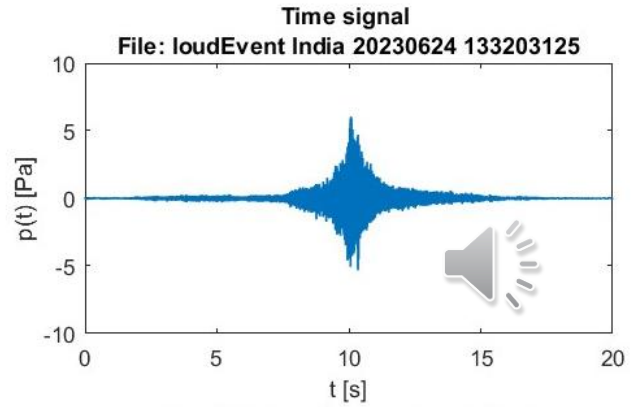
Vehicle data
2022-09-21 15:53:15.250 locWK Dir:West
Car stationwagen
LAND ROVER RANGE ROVER SPORT
Petrol 4999cc 8 cyl 2377 kg 423 kW 4 wheels
43 km/h First reg. 05/2018

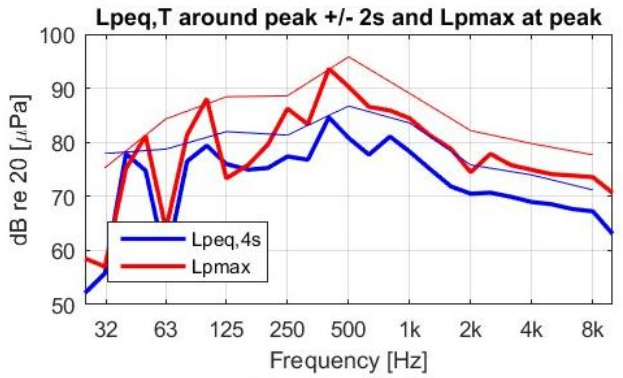
PB level: 74dBA ST level: 96dBA
Event index=5563 Reg index=140564

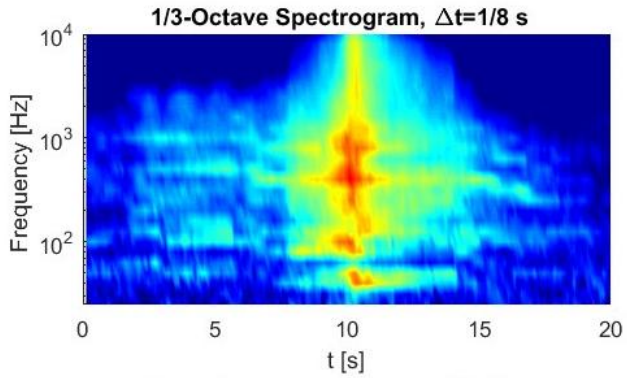
20220921 155315

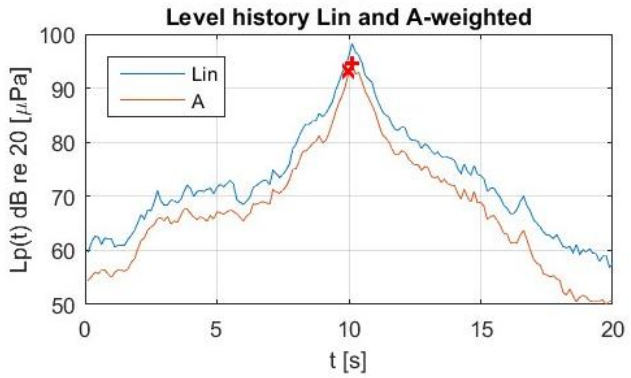


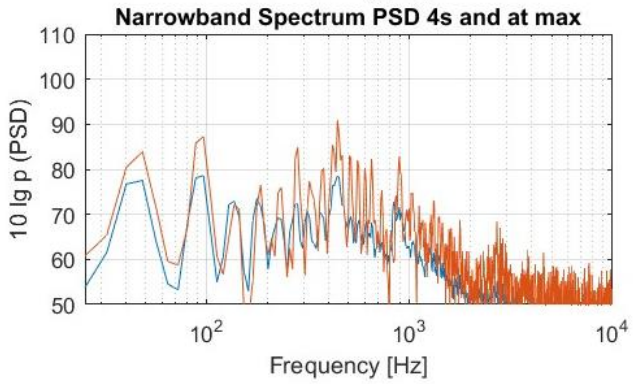
Sound features– Quad accelerating 95 dB(A)

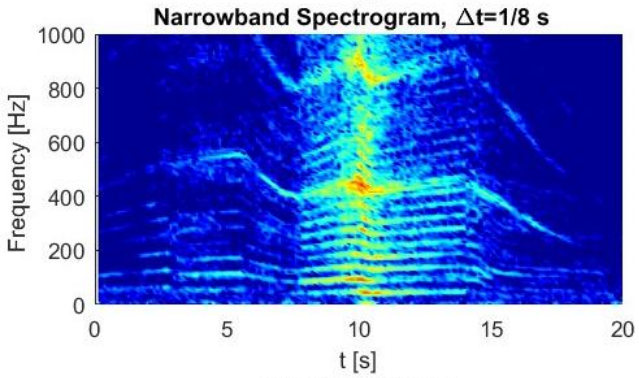












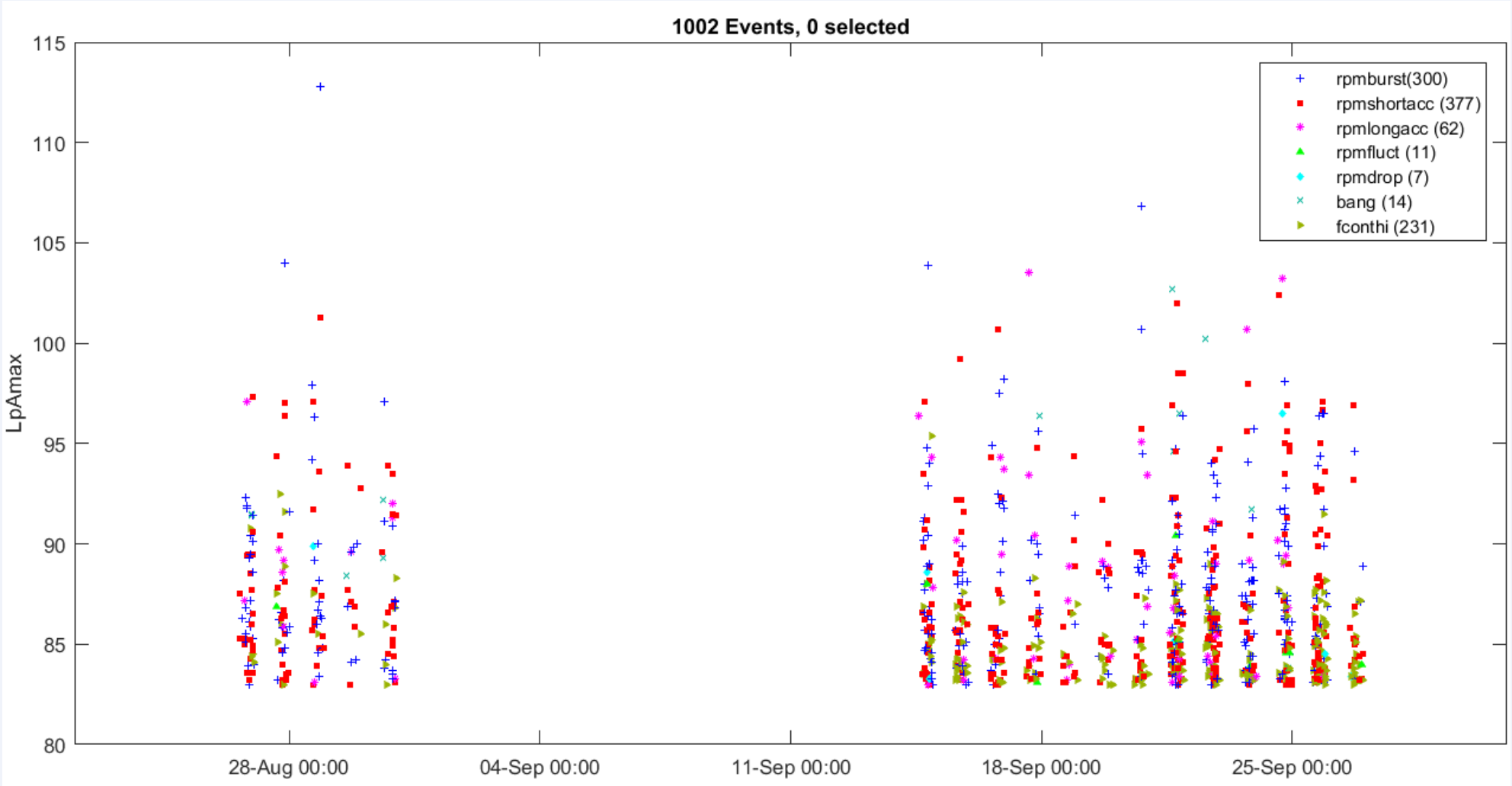
Sound characteristics
LpAmax= 95 dBA Lpmax= 98dB tamax10=1.625s
Llin-LA= 4dB(max) Llin-LA= 4dB(eq) dLpAmaxeq= 7dB
SELA(4s)= 93dBA LpAeq4s= 87dBA maxpeakprom= 23
Prom20= 31dB Prom4s= 15dB Max risetime= 21dB/s
Peak freqs @ 50 100 400 2500
Levels at peak freqs= 81 88 94 78
Strongest freq peak @400Hz dLpmaxLMH= -8 -1 -13 dB
Sound indicator= engine
Sound label= rpmburst

Vehicle data
2023-06-24 15:32:03.125 locTK Dir:South
3W
YAMAHA YFM 660 R
Petrol cc 1 cyl 200 kg kW 4 wheels
92 km/h First reg. 15/02/2003

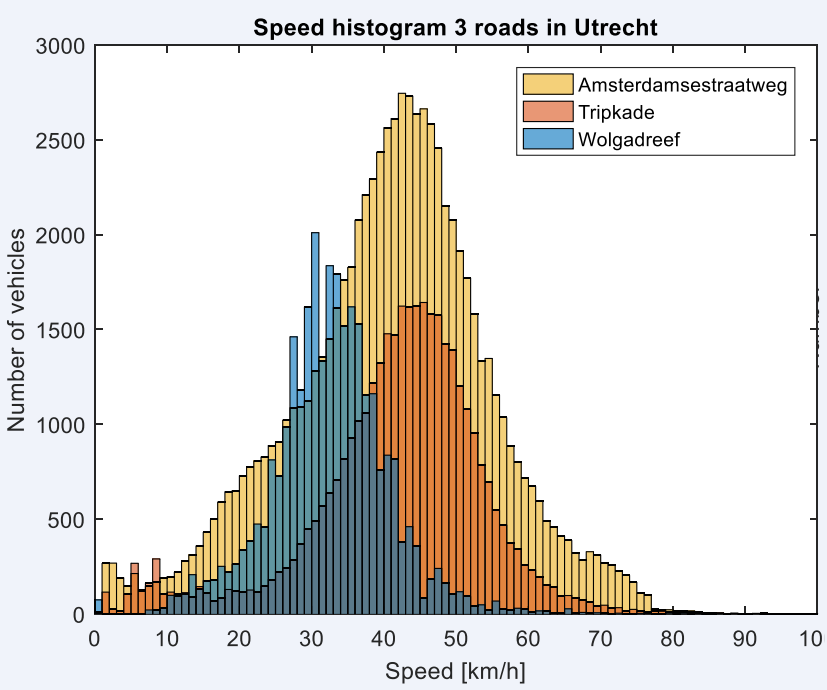
PB level: dBA ST level: dBA
Event#870(match#1206) Reg#40881

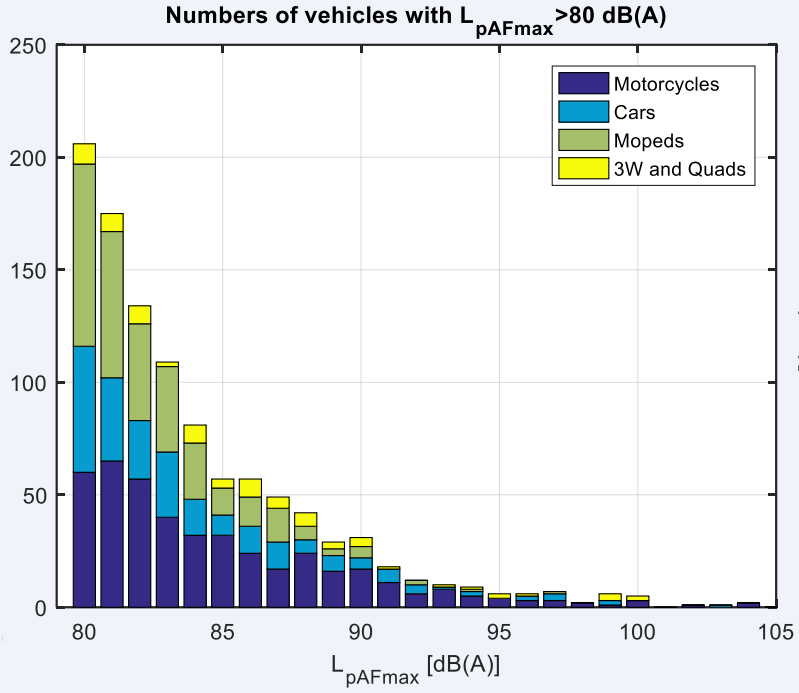
20230624 153333

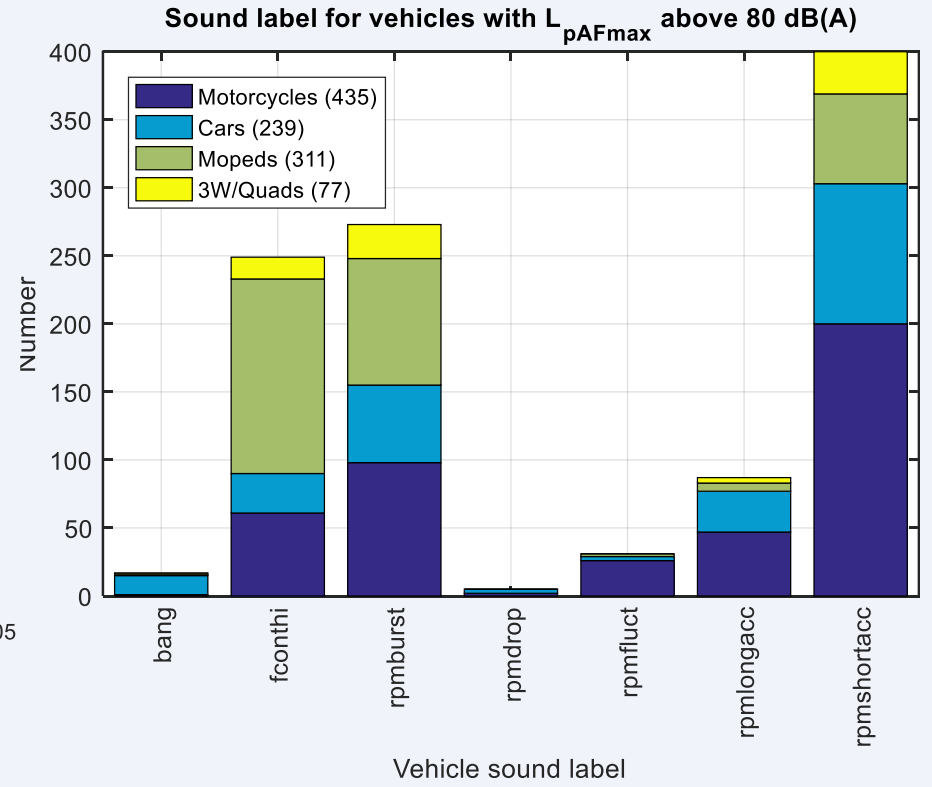
Event browser – sound features of loud vehicles (Rotterdam)



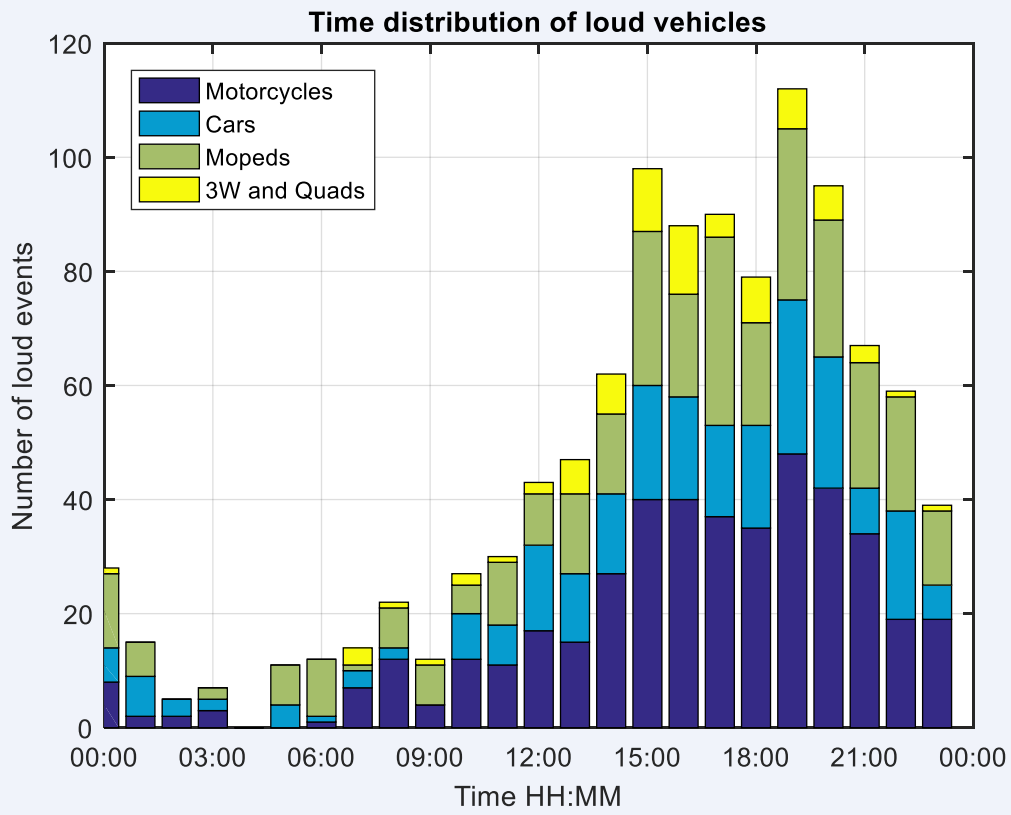
Speeds, numbers of loud vehicles, vehicle sound labels Utrecht

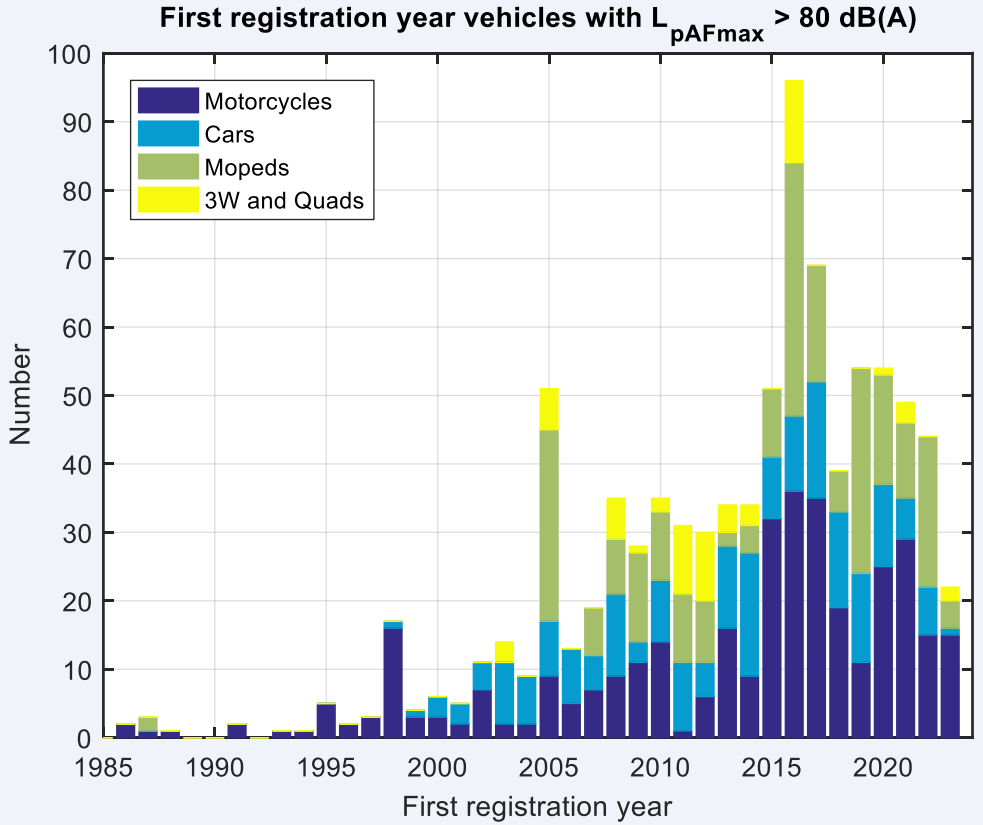




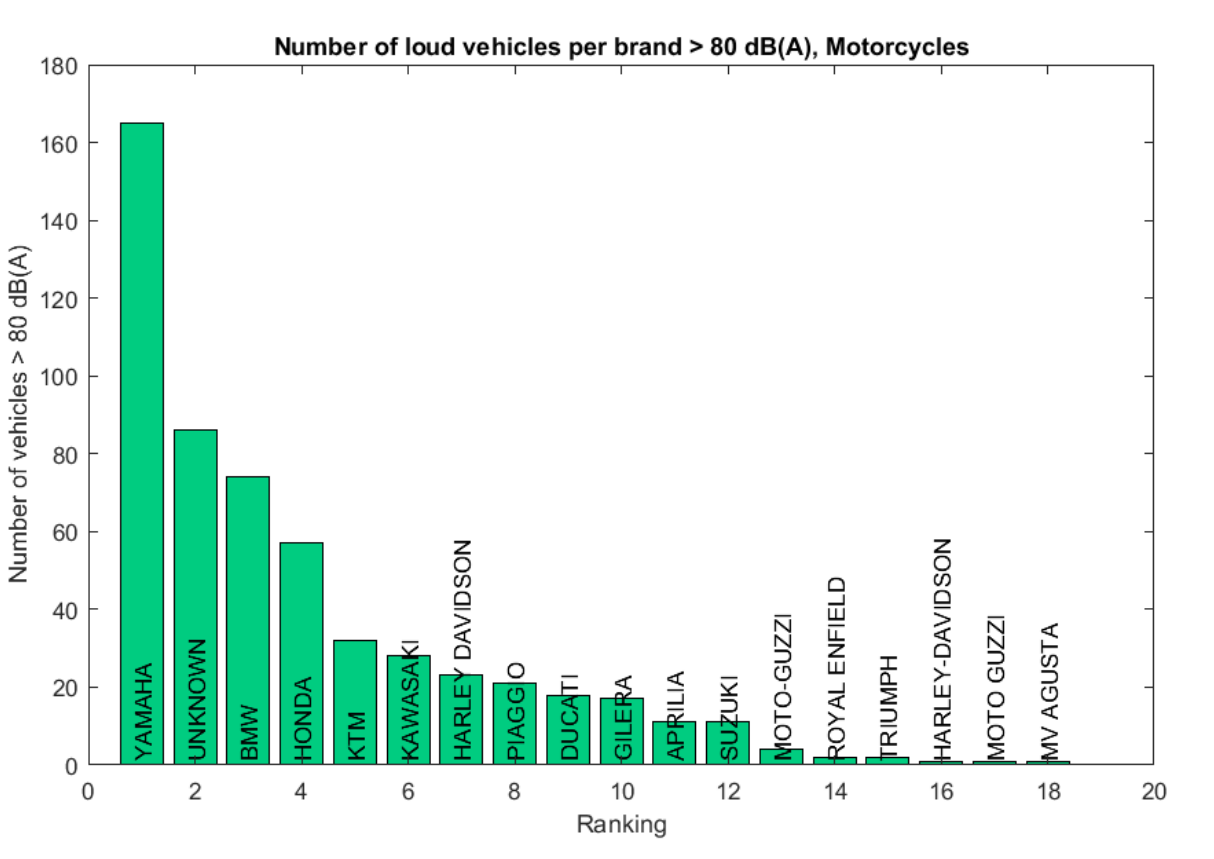


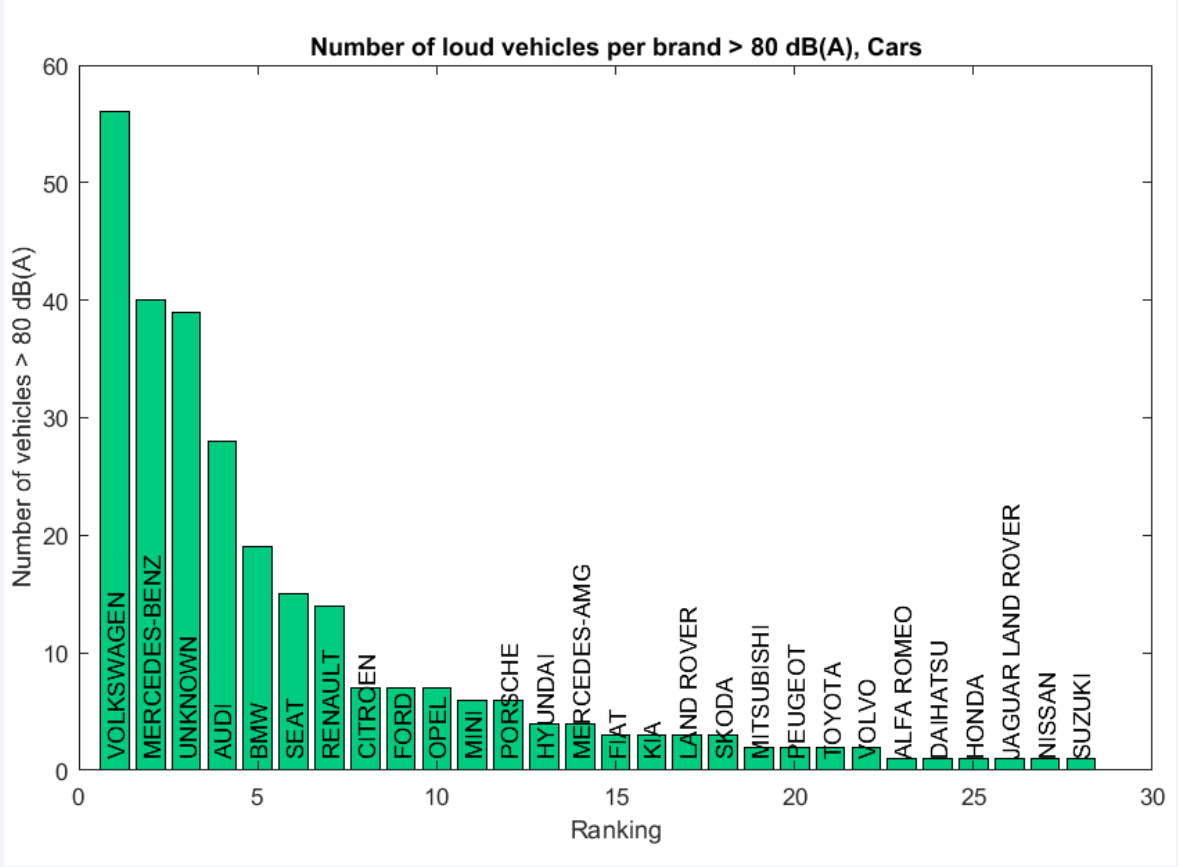
Time distribution and age of loud vehicles, Utrecht





Ranking of makes, motorcycles and cars, Utrecht





Ranking

Causes of high noise levels

- Driving behaviour, vehicle modifications or both
- Driving behaviour: engine revving, fast acceleration, late gear change, speeding, backfire
- Some new vehicles intrinsically loud ‘sports mode’ etc.
- Vehicle modifications: tuning, boosting (turbo, supercharger etc.)
- Partly detectable from sound

Components	Modification	Effect on noise	Effect on power
Electronic control unit (ECU)	Reprogramming or replacing		
	Boost power	Increase at higher torque or rpm	Increase
	Modify injection, timing or quantity	Increase and/or backfire in the exhaust	Increase
	Electronic derestriction	Increase at high rpm	
Mechanical derestriction	Derestriction set	Increase at high rpm	Increase
Air intake + and silencer	Widening, replacement or removal	Increase	Increase
Catalyst	Removal	Increase	Increase
Exhaust	Removal	Increase	Increase
Exhaust	Replace by non-compliant exhaust	Increase	Possible Increase
Exhaust	Replace by compliant louder exhaust	Increase	
Exhaust	Drill holes	Increase	
Exhaust	Damage or remove internal parts	Increase	
Motor	Modify intake or exhaust ports	Increase	
	Change compression	Increase	
	Change stroke, bore or cylinder volume	Increase	
	Change injection system or camshaft	Increase	
Transmission	Transmission ratio change	Increase	

Observations

- Many speeding vehicles
- High noise levels also at low speeds
- Motorcycles are loudest
- Show behaviour (backfire etc.)
- Particular brands are frequent
- Luxury sports cars but also smaller tampered vehicles
- Routes to recreational destinations (beaches, entertainment etc.),
  Café streets
  Long straight city roads, loud acceleration after crossings
- Some locations many loud quads (rental?)
- Canyon streets and high rise flats –reflections
- The busier the road and more complex the situation,
  the harder it is to correctly identify vehicles

Mitigation measures

- Measures matrix developed in 2020 (TNO report for Dutch Ministry)
- G4: General and location-specific measures, such as:
- Speed limit down to 30 km/h where possible
- Warning sign for drivers, static or electronic
- Access restrictions for vehicle types or individual
- More, improved or automatic enforcement (e.g. noise camera)
- Targeted enforcement based on hot spots and times
- Attended enforcement based on Regulation RVV Article 57, audible indications of too loud vehicles:
- - heard from afar
  - exhaust pops and bangs
  - unnecessary and loud engine revving
  - unnecessary and loud acceleration
  - speeding
  - visible modifications such as missing dB killer, small exhaust etc.

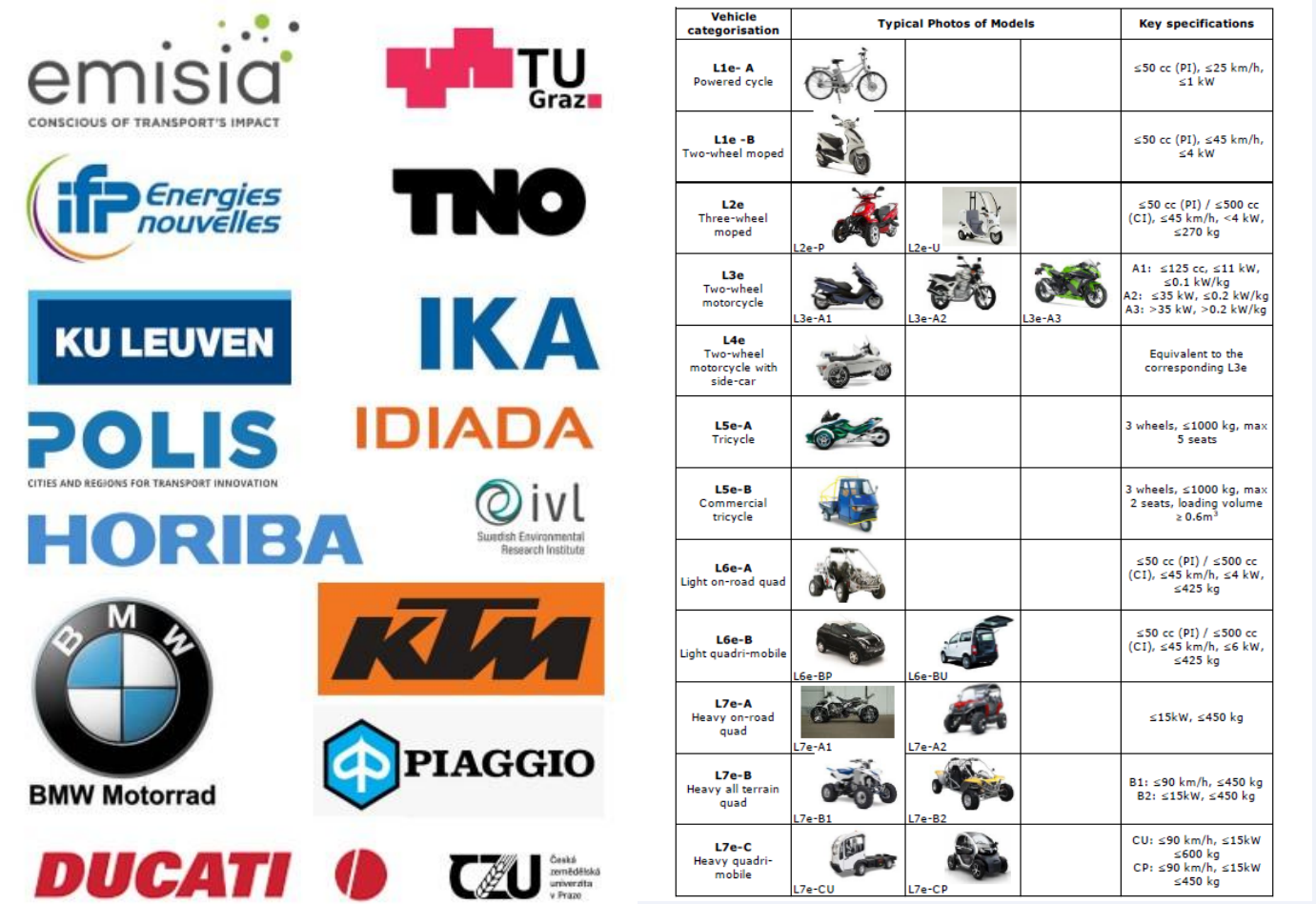
Policy progress

- November 2022 G4 memorandum
  - *Simpler enforcement process for the Police*
  - *Use of noise measurements for communication and enforcement*
  - *Communication to drivers*
- TNO report 2020 Policy options for noise of motorised two-wheelers (Tweede kamer/Parliament)
- RDW investigation on options 2022 (for Dutch parliament)
  - *Use of existing technical inspections*
  - *Improvement of regular enforcement by the police*
  - *other aspects*
- Review of enforcement options by Rotterdam en Amsterdam municipalities
- Warning signs for noise introduced by Rotterdam en Amsterdam 2023
- Police checks and fines in Rotterdam and the Hague
- TNO study on feasibilty of noise camera in NL 2023/2024
- Sorama noise camera tests in Amsterdam 2024

EU project LENS

LENS L-vehicles Emissions and Noise mitigation Solutions

- L-vehicles Emissions and Noise mitigation Solutions motorcycles/mopeds/scooters/trikes/quads 2022-2025
- Relevant driving conditions for highest exhaust emissions and noise
- Development of on board measurement systems for L-vehicles
- Research, detection and approach for tampering
- Measurement programme for 150 L-vehicles – on board and pass-by measurements for emissions and noise
- Impact analysis of noise and emissions
- Proposals for mitigation measures and improved testing methods



L-vehicles

Funded by the European Union

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. 101056777

LENS: Common driving conditions of loud vehicles

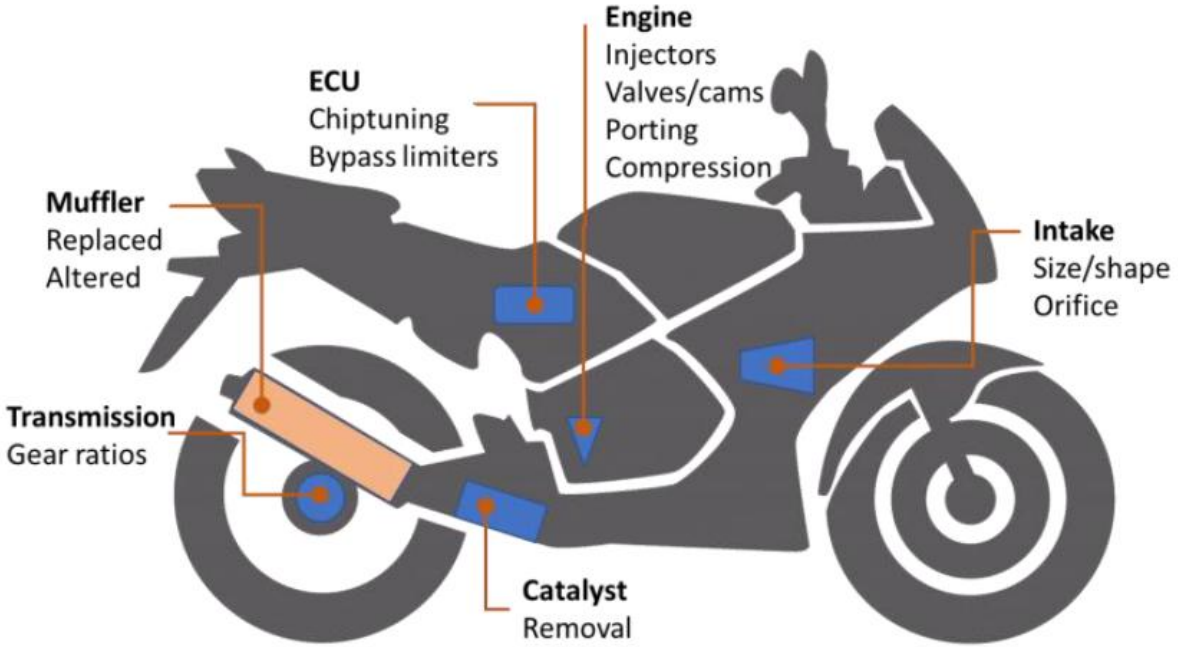
- Recommendations for driving conditions in LENS test programme
- Producing the highest exhaust emissions and noise levels

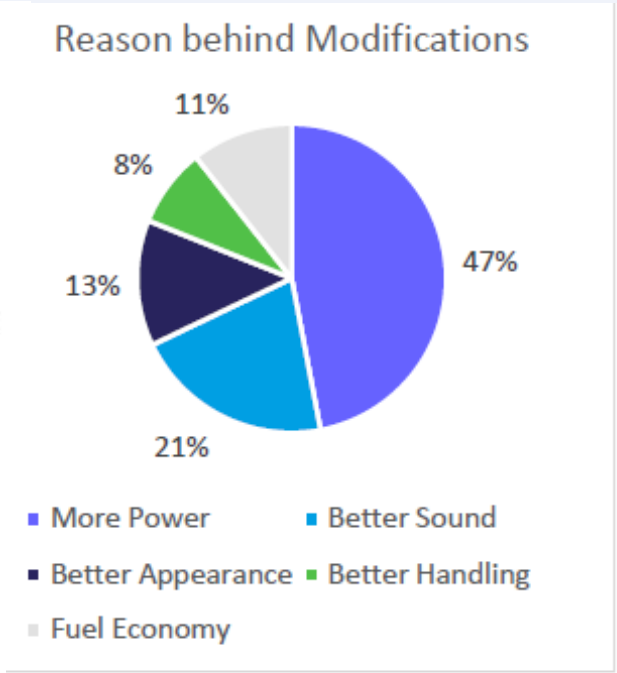
Condition	Vehicle operation	Short name	Already in noise TA?	Remarks
(1) Cold start (mainly for emissions)	Engine start	'coldstart'	No	
(2) rpm burst	Stationary, short activation and release of accelerator	'rpmburst'	No	From idling, 3x 50% max rpm
(3) Acceleration from standstill, G1, G2 Loaded + unloaded	Acceleration, late gear change	'rpmlongacc'	No	
(4) Max rpm passby esp. mopeds, scooters, sports MCs	Constant speed with max rpm	'rpmconthi'	No	
(5) Transition from constant speed or acceleration phases to deceleration phases	Deceleration	'rpmdropoff'	No	
(6) 'Max' acceleration from standstill, G1, G2	Acceleration	'rpmshortacc'	No	
(7) Acceleration at speed, from 50 to 100 kmh	Acceleration, may be varied	'rpmmidspeedacc'	MC: ASEP no, RD-ASEP yes	
(8) rpm fluctuation	Variable speed	'rpmfluct'	No	Accelerator intermittent
(9) Backfire (occurrence, distance not critical)	Multiple gear changing or manual operation	'bang'	No for R41.04. R41.05 measurement covers deceleration phase	Condition at which backfire would be most likely

Source: LENS report D6.1, TNO, Emisia/HSDAC, IFPEN

LENS: Vehicle modifications/ tampering

- Europe-wide survey on most common vehicle modifications and reasons





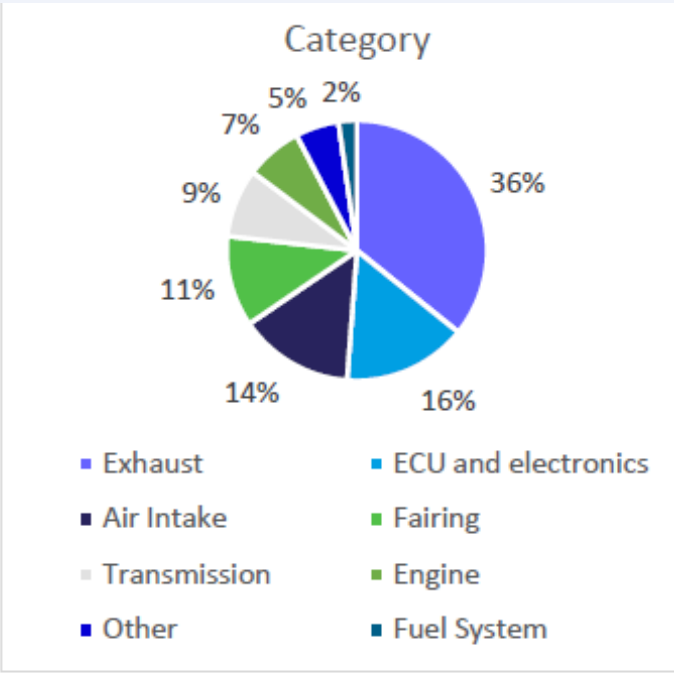


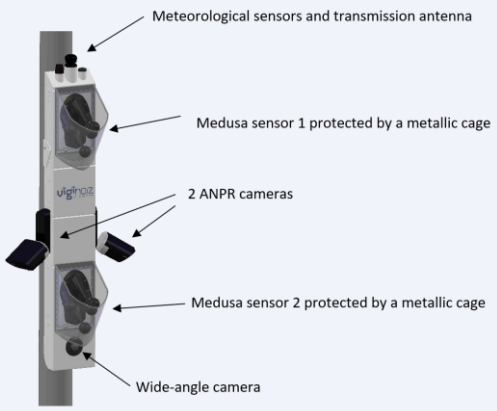
Figure 17: Questionnaire results regarding reasons behind modifications and modification category.

Source: LENS report D5.1, Emisia, TNO

Feasibility of noise cameras in the Netherlands

- TNO Study for NL cities and Ministry, 2024
- Review of required functionality and requirements
- Consultation of stakeholders (suppliers, authorities et al)
- Review of available systems and pilot tests
- Legal aspects
- Recommendations

dBFlash (FR)



Hydra/Bruitparif (FR)

Warning systems, Munisense (NL)

Sorama (NL)

SoundVue (UK)

Feasibility of noise cameras: Findings

- Systems are available, not yet certified, require pilot projects for evaluation
- Evaluations underway in several countries (FR,CH,UK,US,DE,BE at al)
- Analogy with speed cameras, also for enforcement process
- (semi) Mobile systems would be preferable
- 100% hit rate not probable, but allow rejection of false positives
  Manual checks for penalties
- Technical challenges: complex situation with heavy traffic
- Legal:
  Application for penalties is most demanding
  Some changes required to legislation to incorporate noise cameras
  Certification required, mainly for vehicle noise location
  Data privacy is important but can be fulfilled
  Threshold peak sound level is simplest criterium, depends on definition and road/traffic situation
  Tampering detection partly possible for some types (backfire, loud exhaust),
  but more complex to administer
- Benefits should be evident: reduced police effort and increased effectiveness

Conclusions and outlook

- Loud vehicle monitoring in the G4 cities provided insight into causes and potential mitigation measures
- Loudest vehicles are motorcycles, quads and three-wheelers, cars and mopeds
- Key causes are driving behaviour and vehicle modifications
- Overview of mitigation measures including roads, vehicles, drivers and enforcement
- From city monitoring and the LENS project:
  Main driving conditions for loud vehicles identified,
  some easy to detect
- LENS: Insight into vehicle modifications, detection methods for tampering, mitigation solutions and impact anaysis
- Feasibility of noise cameras in NL:
  Possible, but legislation changes, certification,
  pilot projects and process integration required

Some suggestions

- International cooperation on technology and regulatory framework for vehicle noise enforcement including noise cameras
- Visual and sound criteria for roadside and PTI inspection related to noise, tampering detection and vehicle condition
- Implementation in apps
- Information exchange on enforcement practice for both police and vehicle authorities
- Roles of R&D, UNECE Regulations, EU regulations
- ??

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- LENS Consortium
  www.lens-horizoneurope.eu
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  Frans Staats, Elisabeth van Pruisen, Nikol Gulgelmovic,
  Thomas Frateur, Pim van Mensch, Iddo Riemersma, Pierre Paschinger

- **Thank you for your attention!**

G4 AMSTERDAM DEN HAAG ROTTERDAM UTRECHT

LENS L-vehicles Emissions and Noise mitigation Solutions

Funded by the European Union

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. 101056777

Resources

- Policy options for reducing noise annoyance due to motorcycles, mopeds and scooters (In Dutch) TNO Report TNO 2020 R11995, December 2020. https://www.tweedekamer.nl/downloads/document?id=2023D11440
- TNO reports on city monitoring of loud vehicles (in Dutch) 2022-2023: https://publications.tno.nl/publication/34639225/HQhJBv/TNO-2022-R10053.pdf https://publications.tno.nl/publication/34642304/5YLYbE/TNO-2023-R10157b.pdf https://publications.tno.nl/publication/34642306/jfWTON/TNO-2023-R10459.pdf https://publications.tno.nl/publication/34642155/dn5zpu/TNO-2023-R12599.pdf
- Noise camera feasibility study (in Dutch), TNO report 2024. https://publications.tno.nl/publication/34642766/7vId7Dyt/TNO-2024-R10444.pdf
- Internoise article on loud vehicle monitoring (Proceedings Internoise 2024, Nantes) https://doi.org/10.3397/IN_2024_3652
- LENS project website: www.lens-horizoneurope.eu (including deliverable reports)