RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

Cerema
CLIMAT & TERRITOIRES DE DEMAIN

ENVIRONMENTAL ANALYSES OF AN AUTONOMOUS DRIVING : METHODOLOGY FOR ACOUSTIC AND VIBRATORY EVALUATION

08/06/2021

SÉCURITÉ
ACCEPTABILITÉ
MOBILITÉ AUTONOME

1. CEREMA (CENTRE OF STUDY AND EXPERTISE ON RISKS, ENVIRONMENT, MOBILITY AND AMENAGEMENT)

CEREMA

- 2 600 agents
- 240 M€ budget including 40 M€ of own resources
- 23 sites spread over the national and overseas territories
- 9 research teams

- 40 ongoing European projects
- 2 600 publications and reference documents in the online shop

Cerema's areas of intervention :

1. Expertise and territorial engineering

2. Building

3. Mobility

4. Transport infrastructure

5. Environment and risks

6. Sea and coastline

2. SAM PROJECT : SAFETY AND ACCEPTABILITY OF DRIVING AND AUTONOMOUS MOBILITY

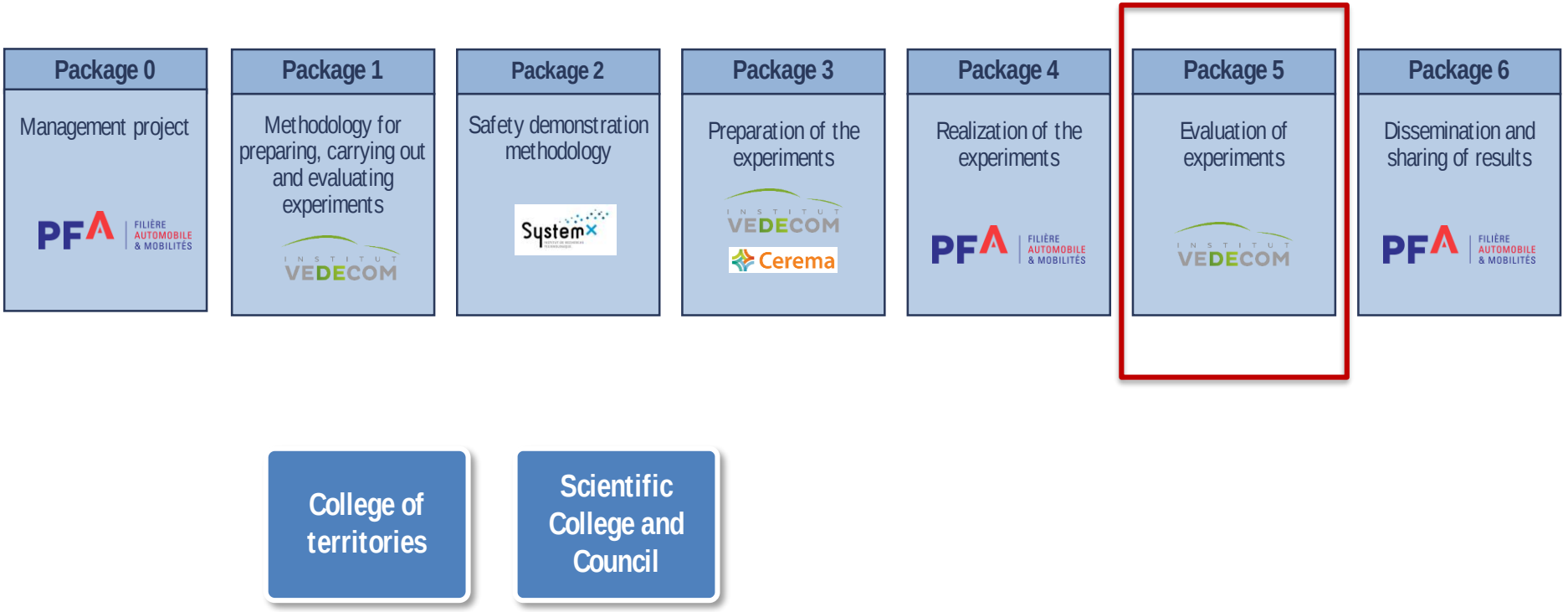
SAM PROJECT : SAFETY AND ACCEPTABILITY OF DRIVING AND AUTONOMOUS MOBILITY

SÉCURITÉ
ACCEPTABILITÉ
MOBILITÉ AUTONOME

SAM Consortium (list of partners)

SAM PROJECT : SAFETY AND ACCEPTABILITY OF DRIVING AND AUTONOMOUS MOBILITY

Structure of project



SAM PROJECT : SAFETY AND ACCEPTABILITY OF DRIVING AND AUTONOMOUS MOBILITY

Package 5 : different tasks

1. **Operational areas**
2. **Users acceptability**
3. **Users comportment and impact on road safety**
4. **Impact on mobility and traffic flows**
5. **Environmental impacts and life cycle assessment**
6. **Socio-economic impacts**
7. **Synthesis in the shared feedback base of the experiments**

LVMT Laboratoire Ville Mobilité Transport

- **Noise**
- **Vibration**
- **Air Quality**

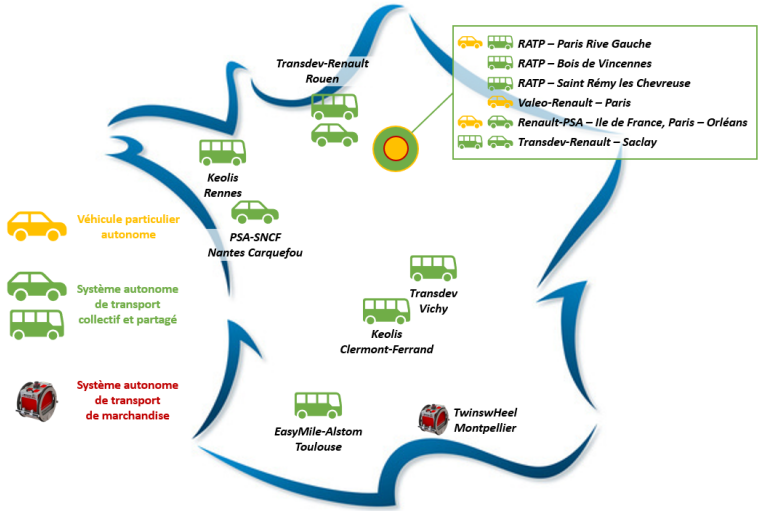
Cerema

ifp Energies nouvelles

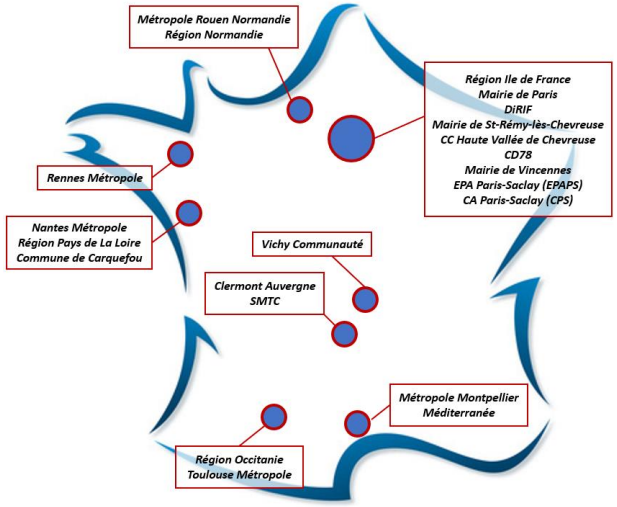
SAM PROJECT : SAFETY AND ACCEPTABILITY OF DRIVING AND AUTONOMOUS MOBILITY

13 experimentations (XP)

Autonomous driving, valet parking, VTC, mobility services, public transport, last mile delivery, etc.



Sites



Territorial partners

3. TASK 5.5 : ENVIRONMENTAL ASSESSMENT

TASK 5.5 : ENVIRONMENTAL ASSESSMENT

1. **Noise : analyse of the autonomous driving of shuttles for passengers / emission outside / scaling up / impact on populations vs a classic vehicle (Cerema)**

2. **Vibration : analyse of the autonomous driving of shuttles for passengers vs a classic vehicle (Cerema)**

3. **Air quality : emission (IFPEN) and concentration (Cerema) of pollutants (PM and NOx) with scaling up the service and impact on populations**

4. ACOUSTIC AND VIBRATION METHODOLOGY

ACOUSTIC AND VIBRATION METHODOLOGY

Evaluated for acoustic and vibration measurements :

- **The average levels over a pass time and the associated spectrums / average levels and associated spectrum by course's typology**
  - **L_T in mm/s² or dBv and dB(A)**
  - **Spectrum : FFT 0-4000 Hz thin band for vibration and 20-20000 Hz in 1/3 octave for acoustic**

- **Impact of different events on level's variations and frequencies**

- **Reaction's time per event (station or emergency braking, acceleration) in second**

- **The outside noise levels and spectrum during the passage of a shuttle (LAmax in dB(A) and spectrum 20-20000 Hz in 1/3 octave) to scale-up with service**

ACOUSTIC AND VIBRATION METHODOLOGY

Basis of Cerema methodology on Rumble Strips for different vehicles :

- **drowsiness at the wheel (sound and vibration)**
- **Impact on local residents (sound)**
- **Road worker alert (sound)**
- **with different vehicles : car, truck and motorcycle**

=> Determination of max levels and spectrum in acceleration and noise

For more information : https://www.editions-rgra.com/revue/960/recyclage-et-retraitement/marquages-sonores-routiers-de-type-rumble-strips

5. EXPERIMENTAL SITE : BOIS DE VINCENNES (EAST OF PARIS)

EXPERIMENTAL SITE : BOIS DE VINCENNES (EAST OF PARIS)

APPLICATION XP BOIS DE VINCENNES

Extension of the public transport service : Interoperability in an environment representative of the municipalities in the Paris region

Informations :

- **Pilot : RATP**
- **Territorial partners : City hall of Vincennes**
- **Shuttles : 3 Easymile and 1 Navya**
- **Course : 6 km**
- **Max speed : 18 km/h**
- **Experimentation of 12 000 km on 2 years (208 days)**

Source : Navya

Navya Shuttle

Source : Easymile

Easymile Shuttle

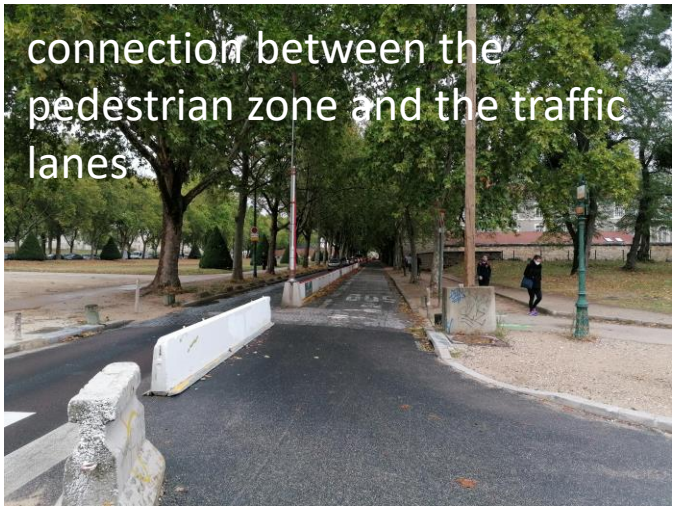
APPLICATION XP BOIS DE VINCENNES

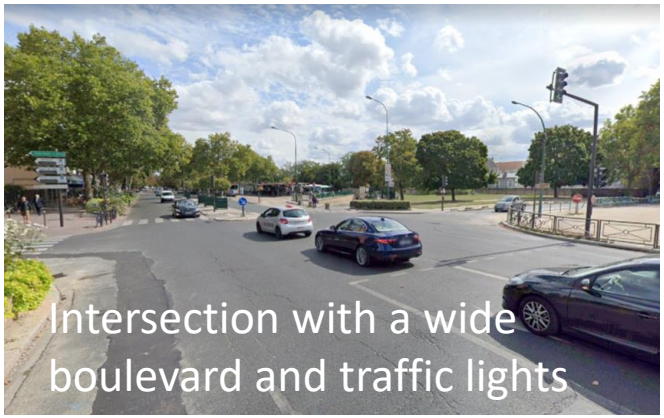
Interest of this site : different shuttle's behaviour with city traffic, traffic lights, pedestrian zone, intersection with a wide street

APPLICATION XP BOIS DE VINCENNES

Urban typology

City hall





Pedestrian zone

APPLICATION XP BOIS DE VINCENNES

- Shuttle's Instrumentation (microphones and accelerometers)
- Continuous measurements several times on the shuttle's course
- Comparison with a conventional vehicle as a reference
- Acoustic measurement outside to quantify the impact of autonomous driving on the surrounding noise
- Modelling of a large-scale deployment (only for one site for the moment)
- Calibration of the model with the acoustic outside measurements

APPLICATION XP BOIS DE VINCENNES

Shuttle's instrumentation (easymile)

Seat accelerometers

Tri-axis accelerometer

APPLICATION XP BOIS DE VINCENNES

Outside instrumentation (pedestrian zone)

2 sound-meters (fix points) on urban furniture

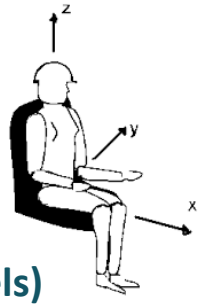
1 sound-meter (mobile point, 2 positions) with a technician who measure only when the vehicle passes

APPLICATION XP BOIS DE VINCENNES

Vibration interpretation

7 measurement channels (in the shuttle) to analyse :

- **X for the pitch and the acceleration (2 channels)**
- **Y for the roll (2 channels)**
- **Z for the damping (3 channels)**
- **=> with 3 sensors**



- **File cleaning: high-pass filtering of signals, 50 Hz filtering ...**
- **Determination of the average level per course and for all courses (to eliminate parasitic vibrations)**
- **Determination of spectrum (FFT thin band 0-4000 Hz)**
- **Characterization of events due to autonomous driving**

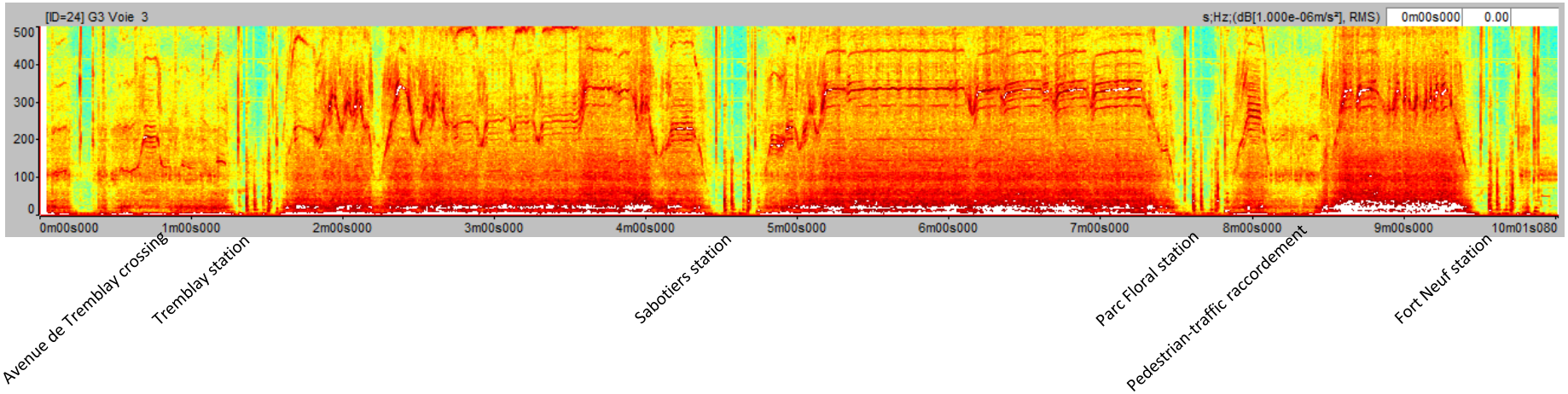
APPLICATION XP BOIS DE VINCENNES

Some videos

APPLICATION XP BOIS DE VINCENNES

Vibration interpretation

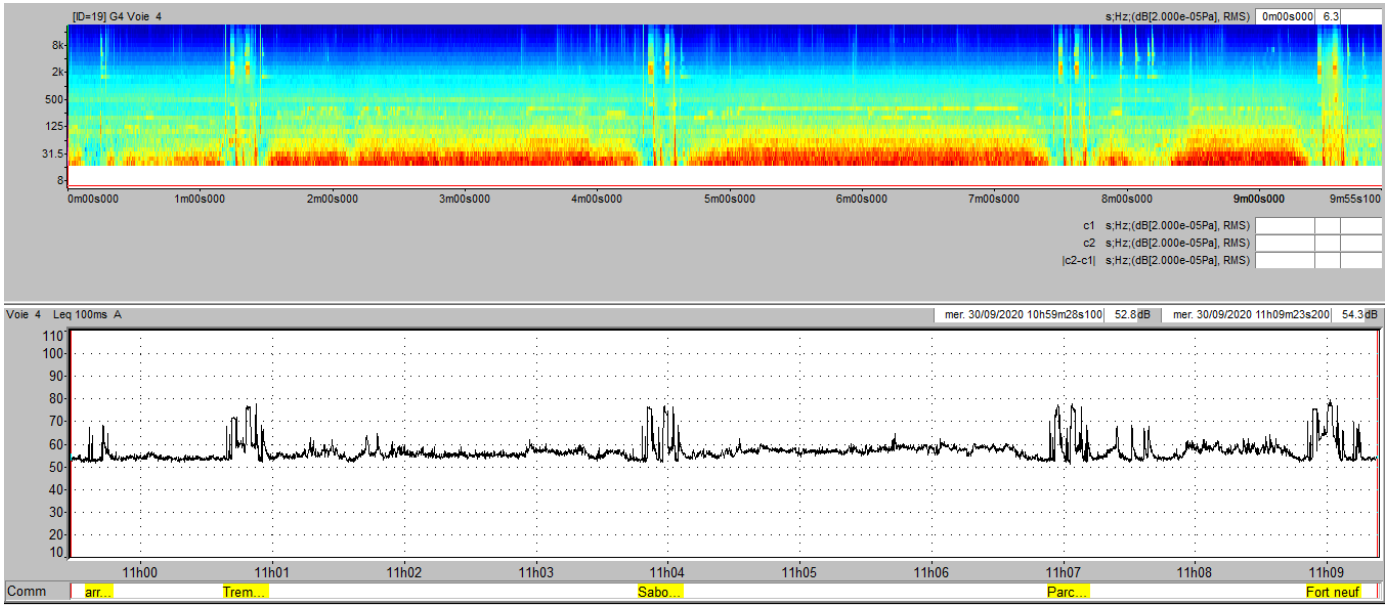
Example of a sonagram for the Z axis between the Avenue de Tremblais crossing (in the woods) and the Fort Neuf station (beginning of the urban area), frequency band 0-500 Hz



Acceleration and deceleration phases can be observed with changes in amplitude and frequency

APPLICATION XP BOIS DE VINCENNES

Inside acoustic interpretation



- **Sonagram (20-20k Hz)**
- **Acoustic level, global A (in black)**

In yellow : station's shuttle

Many noises from the bell and the horn at the stations at more 70 dB(A)

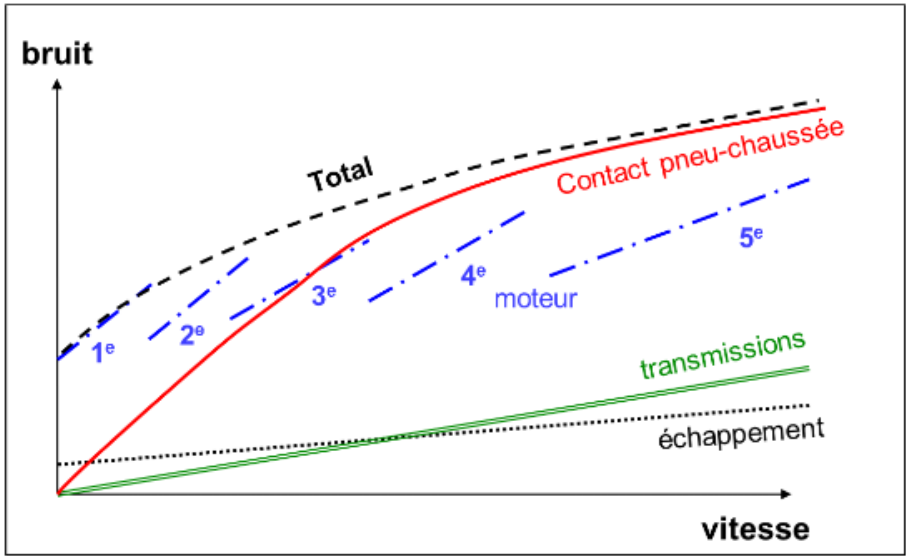
APPLICATION XP BOIS DE VINCENNES

Outside acoustic interpretation

For an internal combustion vehicle, the sources of noise come from :

- **the mechanical system : propulsion noise from the engine**
- **transmissions and exhaust**
- **tyre-road contact : rolling noise**

Rolling noise predominates from 30 to 40 km/h for (recent) light vehicles . At lower speeds, propulsion noise predominates.



Schematic diagram of the evolution with the speed of the different noise sources of all types of internal combustion vehicles (VL or PL) (source Gustave Eiffel University)

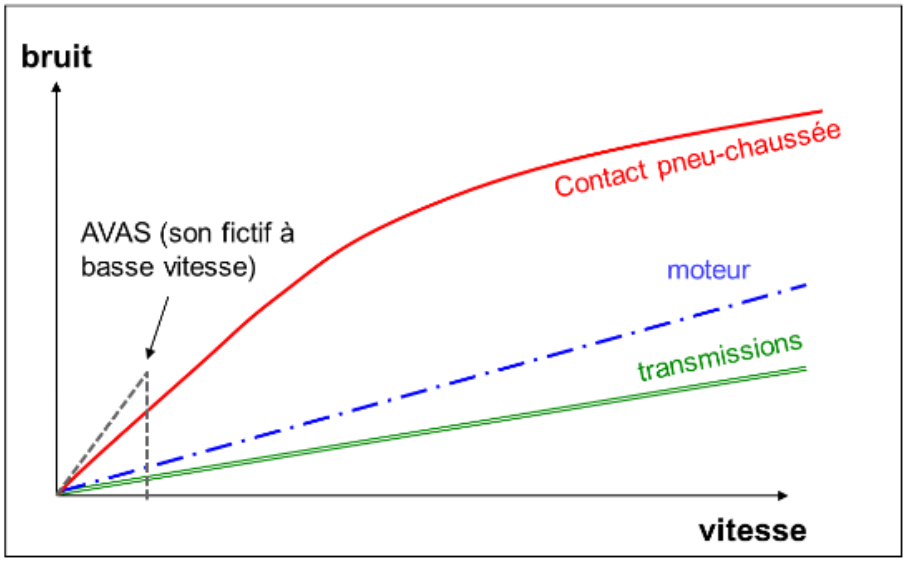
APPLICATION XP BOIS DE VINCENNES

Outside acoustic interpretation

For electric vehicles, mechanical noise is very low, as there is no exhaust and the electric motor is much quieter than the internal combustion engine.

=> Rolling noise predominates at all speeds.

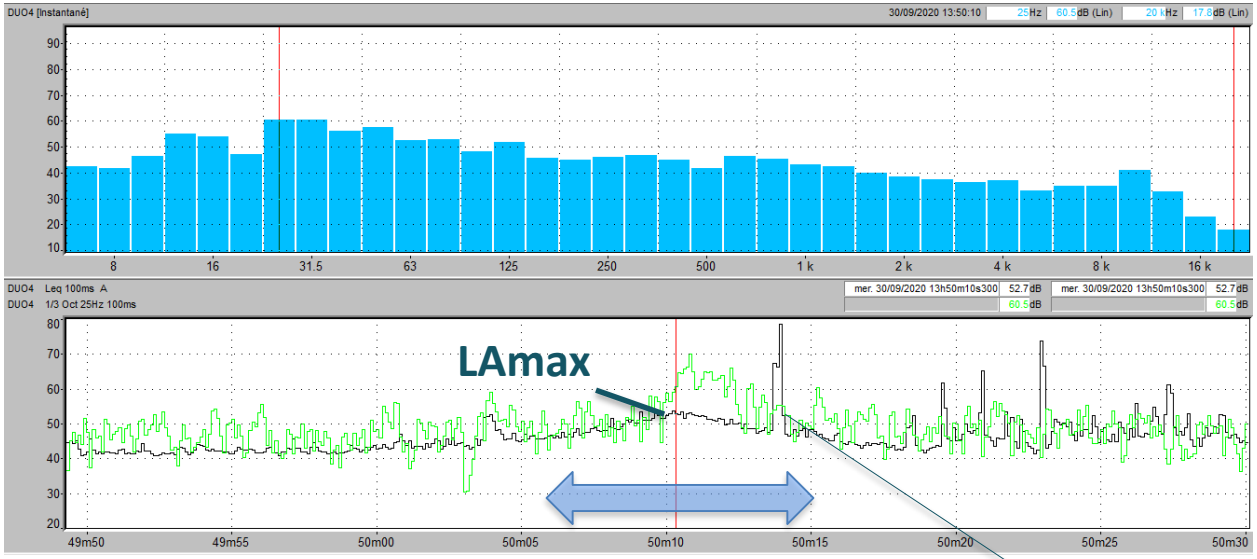
Recent regulations require to add a device to alert pedestrians (AVAS - Acoustic Vehicle Alerting System - device that operates below 30 km /h)



Schematic diagram of the evolution with the speed of the different sources of noise of all types of electric vehicles (VL or PL) (source Gustave Eiffel University))

APPLICATION XP BOIS DE VINCENNES

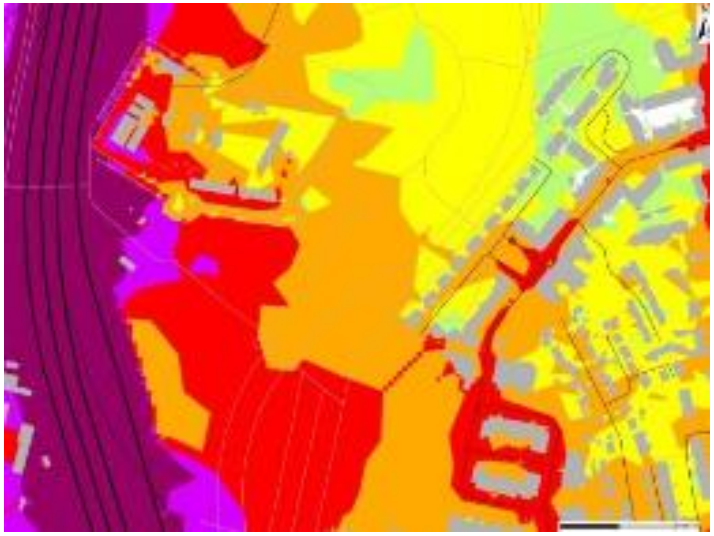
Acoustic outside interpretation



- Instantaneous spectrum for LAmax, 1/3 octave
- Acoustic level, global A (in black) and 1/3 octave 25 Hz (in green)

APPLICATION XP BOIS DE VINCENNES

Acoustic outside : scaling up



Map of isophones creation

Acoustic modelling, needs to have data on :

- **New traffic**
- **Road**
- **Population**
- **Building**
- **Topography**
- **Characteristic of shuttle : noise spectrum**
- **Calibration of the model with outside measurement**

6. AIR QUALITY (IFPEN-CEREMA)

AIR QUALITY

Collaboration with IFPEN

- **Unitary environmental assessment of autonomous services**
- **Microscopic modelling of GHG emissions and consumption**

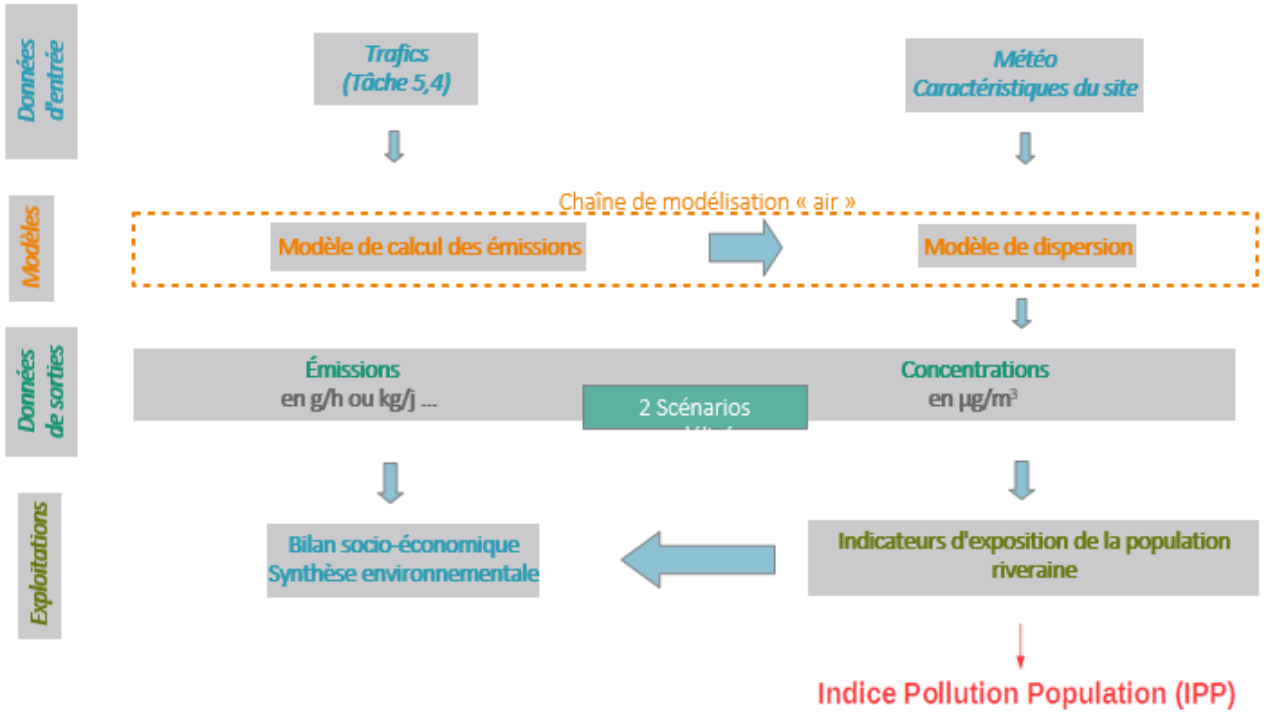
- Instantaneous profiles of GHG emissions (fine particles excluding exhaust)

- Instantaneous profile of consumption (in kWh)

AIR QUALITY

Methodology inspired by technical note TRET183307N of 22 February 2019 and its Methodological Guide about the air and heath impact studies for roads projects.

Analysis of air quality impacts on NO2, particulate matter and GHG (emissions and concentrations) by comparing the 2 scenarios modelled : "reference" scenario (traffic modelling without the service) and "project" scenario (with the service and scaling up)



Synopsis of the methodology

RÉPUBLIQUE FRANÇAISE
Liberté Égalité Fraternité

Cerema
CLIMAT & TERRITOIRES DE DEMAIN

THANK YOU

Contact : Philippe Dunez

Tel : +33 7 77 34 24 16

@mail : Philippe.dunez@Cerema.fr