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NOISE REDUCTION POTENTIAL OF ELECTRIC PASSENGER CARS AT URBAN INTERSECTIONS USING MEASURED VEHICLE TRAJECTORIES

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Abstract

This contribution presents results of the NExUS project on noise from battery electric vehicles (BEV) under acceleration in urban settings. The potential of replacing internal combustion engine (ICE) passenger cars with BEVs to reduce noise levels for residents is investigated with scenario calculations using measured traffic data and emission models generated from pass-by measurements. Individual vehicle trajectories and driving states were extracted from aerial drone videos of urban intersections. To create the emission models, a measurement campaign was conducted with various driving profiles, which were enforced by means of real-time feedback to the driver. Sound exposure levels of nine pairs of comparable BEV and ICE passenger cars were captured and used to derive spectral emission models. The model coefficients were determined with an iterative optimization algorithm, solving the inverse problem considering a variety of speeds and accelerations. Combining these emission models with real-world trajectories enables predicting noise exposure levels for virtual residents near the intersections for either BEV or ICE vehicle fleets. The BEV-only scenario reduces L_{Aeq} by 1.5 dB average in a 50 m radius of the investigated intersections. For a receiver at a distance of 10 m to the nearest stop line, the effect reaches up to 3 dB at times with high traffic volume. At low frequencies, differences up to 10 dB were observed.

Keywords: *road traffic noise, electric vehicles, urban traffic, acceleration*

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1. Introduction

Noise pollution is a major problem in urban areas with road traffic noise being the main source [1]. Noise of road vehicles consists of two main contributors: rolling and propulsion noise [2], [3]. Due to their lack of combustion and gas-exchange noise, BEVs have the potential to be quieter than ICE vehicles at low speeds and under acceleration, when propulsion is the dominant source. To assess the potential noise reduction of BEVs under various conditions, acoustic source models with accurate acceleration implementation of these vehicles are needed. Therefore, previous studies already addressed the issue of measuring and modeling BEVs and comparing them to ICE vehicles: Steps in this direction were made in 2016 by Pallas [4] who adapted the propulsion parameter $L_{\mathrm{W,P}}$ for BEVs in the CNOSSOS model [2]. Controlled pass-by measurements of eight BEVs with constant speeds above 20 km/h were conducted, capturing the L_{AFmax}. The pass-bys were replicated with the CNOSSOS model in octave bands resulting in correction coefficients for the propulsion component of BEVs in octave bands. Baclet [5] measured different BEVs with constant speed and maximum acceleration. A correction depending on speed and proportional to the maximum acceleration was proposed. The model could not be validated for speeds below 40 km/h and the 63-125 Hz octave bands were discarded due to the lack of a clear trend. In 2024, Empa conducted pass-by measurements and compared A-weighted sound exposure levels of several pairs of BEV and ICE vehicles from various vehicle classes. At high/moderate acceleration, the results show lower L_{AE} of BEVs compared to ICE vehicles for low pass-by speeds up to 40 km/h [6].

To fully evaluate the potential impact of electrifying passenger cars, not only accurate source models but also realistic driving conditions need to be considered. For this, Espadaler [7] used video data from multiple drones to extract vehicle trajectories in urban environments for noise assessment. The CNOSSOS model was then used to calculate sound levels. To exploit the detailed acceleration data, the acceleration correction was replaced with the one of the IMAGINE model [8]. Despite the progress in modeling BEV noise emissions, none of the studies combines detailed acoustical and acceleration measurements of BEV and ICE vehicles, realistic driving behavior in urban situations and a spectral source model to predict the impact of the electrification of individual passenger traffic on nearby residents, motivating this research approach.

This paper is structured as follows: Section 2 presents our measurement campaign on BEV and ICE vehicles under controlled acceleration, from which vehicle-specific source models are derived in Section 3. The process of extracting vehicle trajectories is explained in Section 4 and the results of modeling fleets of BEVs and ICE vehicles in realistic traffic scenarios are found in Section 5.

2. Measurement campaign of accelerating BEVs and ICE vehicles

To collect acoustical data of different vehicles at different driving states, we conducted a measurement campaign with 18 different passenger cars on a closed test track with dense asphalt in Switzerland in 2024 at the TCS Center Stockental. Eight free-field measurement microphones were laterally distributed along one side of the track in the standard geometry of ISO 11819-1 [9] to record sound pressure and measure spectral sound exposure levels of single vehicle pass-bys. Table 1 lists the two vehicle fleets of nine cars each. One consists of only BEVs, the other one of comparable ICE vehicles. All of these were the most recent models at the time of the measurement campaign. Equipped with automatic transmissions and operated in their respective default driving mode (”comfort”, ”normal”, etc.), the professional drivers' influence was kept at a minimum. The cars were equipped with new sets of their respective Original Equipment (OE) tires (see Table 1), which were run in for 500 to 1000 km and warmed up. With each car, the drivers completed predefined driving profiles with different speeds and accelerations (see Table 2). An in-house developed kinematics module was mounted on the roof of the car that was currently performing measurement runs (Figure 1) to capture the vehicle kinematics using differential GNSS for the later analysis. To support the driver in real-time in adhering to the target acceleration, indicator LEDs were mounted on the windshield. Air, road and tire temperatures were monitored. The test track was characterized using CPX measurements at 50 and 80 km/h with the P1 and H1 reference tires (ISO 11819-2 [10]), and road surface texture measurements using a laser profilometer. The CPX level at 50 km/h is 89.1 dB and 90.2 dB for the reference tyres P1 and H1, respectively. The texture level reaches a maximum of 41.4 dB in the 10 mm 1/3 octave band. To check consistency across the campaign, additional pass-bys with a reference vehicle at 60 km/h were measured between test runs.

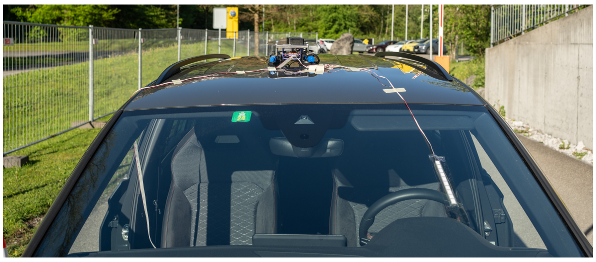

Figure 1: Module for measuring position, velocity and acceleration mounted on a test vehicle. Acceleration indicator LEDs are on the windshield for real-time feedback.

Overall, more than 1700 valid car pass-bys were measured and analyzed in 1/3 octave bands from 50 Hz to 10 kHz. First results from these measurements on A-weighted sound pressure levels were presented in 2025 in [6] and were provided to the UNECE GRBP Task Force on Vehicle Sound. The same data is further used in this paper to develop the source models.

3. Development of vehicle-specific source models

A source model is the key element to investigate complex road traffic scenarios with different vehicles and dynamic driving conditions. We used the measurement data from Section 2 to develop a vehicle-specific source model for each of the 18 measured vehicles.

3.1. Model equation

Each source model describes the vehicle's sound power L_W in 1/3 octave bands as a function of instantaneous speed v and acceleration a. In accordance with today's engineering models, the sound power consists of the energetic summation of a rolling ($L_\mathrm{W,R}$) and propulsion ($L_\mathrm{W,P}$) noise contribution. We model these two contributions using a combination of the sonROAD18 [3] and the IMAGINE [8] approach:

$$L_{\mathrm{W,R},i,j} = A_{\mathrm{R},i,j} + B_{\mathrm{R},i,j} \lg\left(\frac{v}{v_0}\right) \quad (1)$$

$$L_{\mathrm{W,P},i,j} = A_{\mathrm{P},i,j} + B_{\mathrm{P},i,j} \frac{v - v_0}{v_0} + C_{\mathrm{P},i,j} \frac{a}{a_0} \quad (2)$$

with indices i for the 1/3 octave bands between 50 Hz and 10 kHz, indices j for the vehicles, reference speed v_0 and reference acceleration a_0. Please note that both, v and a, are assumed to be positive. Each vehicle j is characterized by five spectral coefficients (A_R, B_R, A_P, B_P and C_P). The acceleration influence on sound power is considered in the propulsion contribution only. The additional acceleration-dependent term ensures that at zero acceleration ($a = 0$) expression 2 simplifies to the expression for constant speed.

Table 1: List of vehicles used in the BEV (upper half) and ICE vehicle fleet (lower half), including manufacturer, model and year as well as details of the according OE tires, including tire brand, model, front- and rear size.

Manufact.	Model	Year	Tire Brand	Tire Model	Front Size	Rear Size
Peugeot	e-208	2020	Michelin	Primacy 4	205/45R17	205/45R17
VW	ID.3	2020	Goodyear	EfficientGrip Perf. +	215/45R20	215/45R20
Volvo	EX40	2024	Pirelli	Scorpion SF2 VOL ELECT	235/45R20	255/40R20
Tesla	Model Y	2024	Hankook	ventus S1 evo3 soundabs. t2	255/45R19	255/45R19
Skoda	Enyaq	2023	Hankook	ventus S1 evo3 ev	235/50R20	255/45R20
Tesla	Model 3 Per.	2022	Michelin	Pilot Sport 4S	235/35R20	235/35R20
Volvo	EX30	2024	Michelin	Pilot Sport 4S	245/40R20	245/40R20
Hyundai	Ioniq5	2022	Continental	PremiumContact7	235/55R19	235/55R19
VW	ID.Buzz	2023	Continental	EcoContact 6 Q	235/55R19	255/50R19
Peugeot	208	2021	Michelin	Primacy 4	205/45R17	205/45R17
Seat	Leon	2020	Bridgestone	Turanza T005 AO	225/40R18	225/40R18
Volvo	XC40	2024	Pirelli	P Zero	245/45R20	245/45R20
Skoda	Kodiaq	2023	Continental	ContiSportContact 5	235/45R20	235/45R20
Seat	Tarraco	2023	Pirelli	Scorpion Seal Inside	255/45R19	255/45R19
Mazda	6	2023	Bridgestone	Turanza T005 A	225/45R19	225/45R19
Mazda	CX-3	2022	Bridgestone	Turanza T005	215/60R16	215/60R16
Ford	Kuga	2022	Goodyear	EfficientGrip 2	225/65R17	225/65R17
VW	Multivan T7	2024	Falken	Ziex ZE310A ECORUN	235/55R17	235/55R17

Table 2: Driving profiles completed by each vehicle. The velocity v_{target} is defined for the beginning of the pass-by and changed during accelerated profiles. The acceleration a_{target} is set to remain constant during the pass-by.

ID	v_{target} (km/h)	a_{target} (m/s^2)
1	60	0
2	10	0
3	30	0
4	0	Max. acceleration
5	50	0
7	0	1.6
9	40	0.8
10	0	0.8
12	0	2.4

3.2. Estimation of model coefficients

Obtaining the source model coefficients for expressions 1 and 2 is not a trivial task. The two source contributions cannot be easily separated and during accelerated driving the sound power of the vehicle changes over time. Therefore, each pass-by was cut into segments using precise location and timing data from the differential GNSS measurements. Then the sound power was calculated according to expressions 1 and 2. Depending on the duration, the sound power of every segments is converted to a sound exposure level in a distance of 1 m. To reproduce the microphone level, propagation considering geometrical spreading and air attenuation is applied to each segment, then the levels are summed up. The five coefficients per vehicle and frequency band were determined independently using a global parameter optimization approach. For this paper, we used measured sound exposure levels from the driving profiles of Table 2 (excluding profile 4) and from seven microphones.

To estimate the set of coefficients, we used a programming solver to find the minimum of a constrained, nonlinear, multivariable objective function, the root mean square deviation (RMSD) of measured and modeled sound exposure levels. The optimization was initialized with 8000 independent sets of coefficients randomly chosen within predefined bounds. Each initialization leads to convergence toward a local minimum. The set of coefficients yielding the smallest RMSD was selected as the result of the optimization. This optimization task took multiple days to run on a modern workstation with 96 CPU cores. As a result, a total of 2160 parameter values (18 vehicles × 5 parameters × 24 frequency bands) were derived to describe the sound powers of the 18 measured vehicles as a function of instantaneous speed v and acceleration a.

A model verification has shown that the model can reproduce the measured scenarios without a bias: Averaged over driving states and vehicles, the modeled sound exposure levels of both fleets deviate less than 0.2 dB per 1/3 octave band, the deviation for each individual vehicle is less than 0.6 dB. When considering the RMSD, the ICE fleet's deviation is higher in the frequency bands below 250 Hz. This can be explained by the combustion and gas exchange noise, which changes depending on speed, acceleration and selected gear. The modeling approach used cannot reproduce this complex relationship.

4. Vehicle trajectories of real traffic

Spatially and temporally resolved traffic data is needed as an input to the source models from Section 3.1 and to calculate sound propagation from the source to the receiver. We selected four different urban intersections (Table 3) in order to capture real urban traffic behavior, including low speed, acceleration and full stops. Video recordings were taken at multiple times of the day to capture differences in traffic volume. Traffic was filmed top-down at a height of 120 m with a small multicopter and vehicle trajectories were extracted from the aerial drone videos. Limited by the battery runtime, each video has a duration of 15 to 20 min. The footage was recorded with a 3840×2160 px resolution and a frame rate of 30 fps. The recorded video was stabilized in multiple steps to eliminate vibration, rotation and drift resulting from the drone's operation.

Table 3: List of intersections where measurements were done, including type and whether it is controlled by traffic lights (TL). Multiple measurements at different traffic volumes were conducted.

ID	City	Type	TL	Vehicles/h
1	Fribourg	Roundabout	no	1400-1500
2	Fribourg	T-type	yes	850-1150
3	Zürich	Roundabout	no	650-1650
4	Zürich	T-type	yes	150-1700

Afterwards, the vehicle types and their movements were obtained through automated image processing with image recognition and object tracking software [11]. By georeferencing the stabilized video, trajectories of all vehicles were obtained consisting of position, speed and acceleration histories.

An example snapshot of a signalized T-type intersection is shown in Figure 2 with markings on the recognized and tracked vehicles. For this paper, only the trajectories from passenger cars are used and data from other vehicle types such as buses or trucks are ignored. Overall, more than 5000 trajectories were recorded of which over 3000 were usable and from passenger cars.

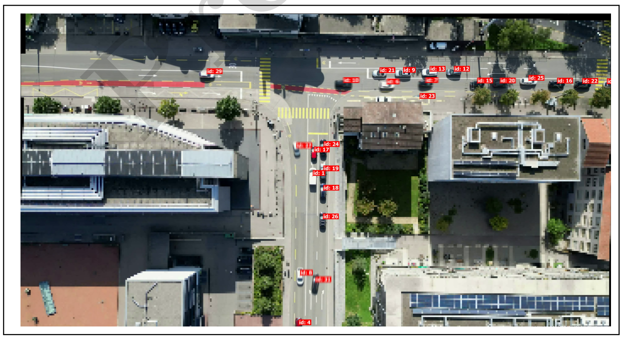

Figure 2: Aerial perspective of one investigated intersection (Table 3, ID 2). Recognized vehicles are marked with a red box [11].

5. Results on traffic scenarios

We performed scenario calculations using the gathered measurement data to predict the noise exposure of hypothetical residents in the vicinity of urban intersections. We compared two scenarios: Passenger car traffic with fleet 1 consisting of only BEVs vs. fleet 2 containing only the comparable ICE vehicles. We express the scenario difference by level differences ΔL, where negative values mean that the BEV fleet produces lower noise levels than the ICE vehicle fleet.

We combined the developed vehicle-specific source models and the real-world traffic data with an elementary propagation model considering geometrical spreading and air attenuation. In the simulation, each virtual car passing the intersection was modeled separately. Distributed point sources along the vehicle path were introduced based on the measured vehicle trajectory. For each source point, the measured speed and acceleration was used to compute the sound power of the vehicle according to 3.1. Each trajectory was completed by all 18 vehicles of the two fleets. All trajectory parts with negative acceleration are neglected due to the constraints of the model. For each intersection, receiver points were introduced along the facades facing the road at a height of 4 m. Finally, for both vehicle fleets, sound exposure levels L_{E} in 1/3 octave bands were computed at all receivers.

Figure 3 shows example results of a roundabout with four entries and four exits and a traffic volume of 1500 veh/h. Black lines indicate vehicle trajectories and circles represent receiver points with the level difference between the scenarios color-coded. Across the shown 45 receivers, level differences ΔL_{AE} in the order of -0.5 to -3 dB are found within a 50 m radius (grey zone) with an average of -2.2 dB. As expected, a positive effect of the BEV fleet can be mainly observed for receivers close to the roundabout where more vehicles accelerate. This dependency on distance is illustrated in Figure 4 where data from all intersections and different traffic volumes is pooled. Here, the level differences are shown against the distance d_{H} from the receiver to the nearest traffic stop line. At very close distances d_{H} of only 10 m, level differences between -1 and -3 dB in L_{AE} occur. With increasing distance, the level differences clearly drop. At 50 m to the nearest stop line, the level differences are only between 0 and -1 dB. The variability was found to be mainly explained by traffic volume. When traffic volume is high, stop-and-go occurs more often, leading to more frequent acceleration situations.

The level differences are frequency-dependent (Figure 5) and are largest at very high and at low frequencies, i.e. below 160 Hz. At 50 Hz, differences of up to 10 dB between the two propulsion concepts were found, which can be attributed to the absence of combustion and gas exchange noise in BEVs. This evident low frequency level reduction of BEVs compared to ICE vehicles would be expected to have a positive impact for residents living near urban intersections. This only applies if all vehicles run with electric mo-

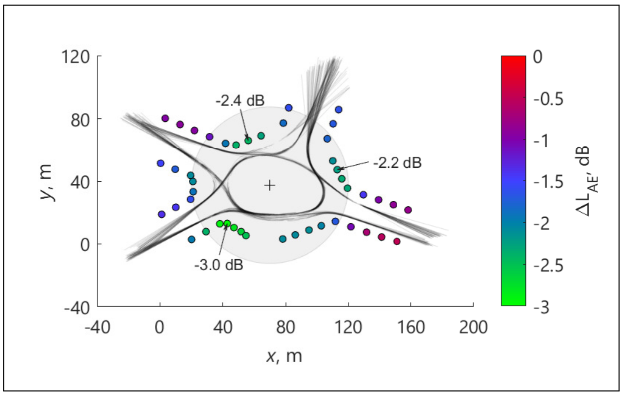

Figure 3: Example result of scenario BEV vs. ICE vehicle fleet for a roundabout with high traffic volume (Table 3, ID 3). Receiver level differences ΔL_{AE} of A-weighted sound exposure level of passenger cars are color coded.

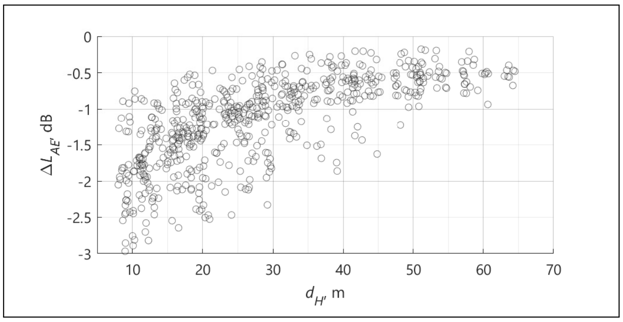

Figure 4: Receiver level differences of A-weighted sound exposure level L_{AE} between a BEV and a ICE vehicle fleet for different urban traffic situations as a function of distance d_{H} between receiver and nearest stop line. The spread of level differences is due to different traffic volumes and intersection.

tors and do not liquidate this potential benefit with an exterior sound enhancement system. The reasons for the difference above 6 kHz remain unclear.

6. Conclusions and Outlook

We investigated the effect of a BEV passenger car fleet to an ICE passenger car fleet on noise exposure for residents near urban intersections. From a dedicated measurement campaign, where we measured pass-by levels of different vehicles at different driving states including acceleration, we successfully derived vehicle-specific spectral emission models. To capture real scenarios, we gathered detailed traffic data using a video drone flying above different urban intersections and combined both data for scenario calculations. In a 50 m radius around the investigated intersections, the BEV-only scenario reduces L_{Aeq} by 1.5 dB on average. The level reduction depends on the distance of the receiver to the nearest stop line. The maximum effect of 3 dB was observed for a receiver at only 10 m from the nearest stop line for a situation with high traffic volume. At low frequencies, larger differences were found with a level difference of 10 dB at 50 Hz.

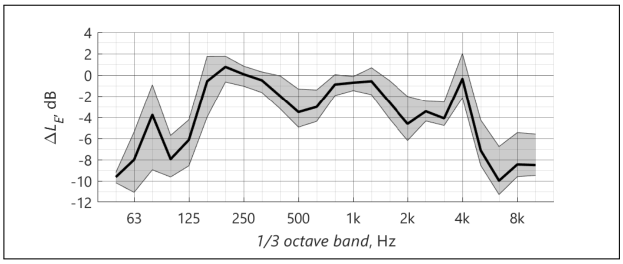

Figure 5: Spectral receiver level differences ΔL_{E} of passenger cars between BEV and ICE vehicle fleet for urban traffic situations near intersections (min, median, max of different situations and receivers).

The found A-weighted exposure level differences between urban BEV and ICE vehicle traffic is strongly influenced by tire noise. Our results are valid for the used OE tires and the specific pavement of the test track. Furthermore, the influence of individual driving style was minimized by using automatic gearboxes and non optimal gear selection was not taken into account. In the next phase of the NEẍUS project, the influence of different modern tires and low-noise pavements will be investigated by conducting a new, larger measurement campaign on different BEVs and matched ICE vehicles. They will be equipped with different tire sets in pairs, and perform multiple driving profiles on two different pavements.

7. Acknowledgments

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References

[1] European Environment Agency. and European Commission. Joint Research Centre., *Zero Pollution Monitoring and Outlook 2025.* LU: Publications Office, 2025. DOI: `10.2800/6470682` Accessed: Jun. 22, 2026. [Online]. Available: `https://data.europa.eu/doi/10.2800/6470682`

[2] European Commission. Joint Research Centre. ICHP., *Common Noise Assessment Methods in Europe (CNOSSOS-EU): To Be Used by the EU Member States for Strategic Noise Mapping Following Adoption as Specified in the Environmental Noise Directive 2002/49/EC.* LU: Publications Office, 2012. DOI: `10.2788/31776` Accessed: May 21, 2026. [Online]. Available: `https://data.europa.eu/doi/10.2788/31776`

[3] K. Heutschi, B. Locher, and M. Gerber, "sonROAD18: Swiss Implementation of the CNOSSOS-EU Road Traffic Noise Emission Model," *Acta Acustica united with Acustica*, vol. 104, no. 4, pp. 697–706, Jul. 1, 2018, ISSN: 1610-1928. DOI: `10.3813/AAA.919209` Accessed:

May 4, 2026. [Online]. Available: https://dael.euracoustics.org/landing_pages/aaua/52535.html

[4] M.-A. Pallas, M. Bérengier, R. Chatagnon, M. Czuka, M. Conter, and M. Muirhead, "Towards a model for electric vehicle noise emission in the European prediction method CNOSSOS-EU," *Applied Acoustics*, vol. 113, pp. 89–101, Dec. 2016, ISSN: 0003682X. DOI: 10.1016/j.apacoust.2016.06.012 Accessed: May 4, 2026. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0003682X16301608

[5] S. Baclet, J. Cesbron, P. Aumond, A. Can, and R. Rumpler, "A correction model for the noise emissions of light electric vehicles during acceleration," *Applied Acoustics*, vol. 236, p. 110 713, Jun. 2025, ISSN: 0003682X. DOI: 10.1016/j.apacoust.2025.110713 Accessed: May 4, 2026. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S0003682X25001859

[6] A. Heusser, J. Jäggi, M. Elser, S. Grunder, and R. Pieren, "Comparing Measured Pass-by Levels of Accelerating Battery Electric Cars and Combustion Engine Cars," in *Proceedings of the 11th Convention of the European Acoustics Association Forum Acusticum / EuroNoise 2025*, Málaga, Spain: European Acoustics Association, Dec. 25, 2025, pp. 5627–5633, ISBN: 978-84-87985-35-5. DOI: 10.61782/fa.2025.0227 Accessed: May 6, 2026. [Online]. Available: https://dael.euracoustics.org/confs/landing_pages/fa2025/000227.html

[7] J. Espadaler-Clapés, E. Barmpounakis, and N. Geroliminis, "Traffic congestion and noise emissions with detailed vehicle trajectories from UAVs," *Transportation Research Part D: Transport and Environment*, vol. 121, p. 103 822, Aug. 2023, ISSN: 13619209. DOI: 10.1016/j.trd.2023.103822 Accessed: May 4, 2026. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S1361920923002195

[8] B. Peters and G. Van Blokland, "The noise emission model for European road traffic," 2007.

[9] International Organization of Standardization, *ISO 11819-1: Acoustics – Measurement of the influence of road surfaces on traffic noise - Part 1: Statistical pass-by method*, 2023.

[10] International Organization of Standardization, *ISO 11819-2: Acoustics – Measurement of the influence of road surfaces on traffic noise - Part 2: The close-proximity method*, 2017.

[11] SWISSTRAFFIC Group. "SWISSDRONE AI. "[Online]. Available: https://swisstraffic.ai/drone