A STUDY ON AFFECT OF ADOPTING SILENT ELECTRIC VEHICLES ON PEDESTRIANS IN INDIA

Importance of Acoustic Vehicle Alerting Systems (AVAS) for EVs in India

by

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[MME (Mech.), MBA (Marketing), DTDM (Mech.)]

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<Associate Dean’s Name, Degree>, Associate Dean

Dedication

I dedicate my dissertation work to my family and friends. A special feeling of gratitude to my loving parents Shri Sunirmal & Smt. Namita Dhara Sharma whose words of encouragement and push for tenacity ring in my ears. My loving wife Smt. Sutapa Dhara Sharma and my daughter Nilakshi have never left my side and are very special. I would also like to dedicate this dissertation work to my professional colleagues and friends from the automotive industry those who have inspired me and have also extended their support. My special thanks to those who believed in my initial thoughts for the need of this research and acknowledged my work.

Acknowledgement

At the onset, I would like to thank my mentor Dr. Eduard Plavec from SSBM, University of Zagreb, Faculty of Electrical Engineering and Computing, Croatia for his invaluable advice, continuous support, and patience during my research. I would also like to extend my sincere gratitude to the Swiss School of Business and Management, Geneva for providing me this opportunity. The lectures and training provided by SSBM on formulating a systematic research work was very helpful during my research. It also introduced me to a whole new world of research papers, whitepapers, articles and dissertations that became a big inspiration and support all the way of my research duration. I would also like to extend my sincere gratitude towards my industry colleagues who helped me a lot with their ideas and kept me floating till the end to reach the final results of my research. I would also like to thank all the previous researchers on this topic for their extremely commendable research. This research has immensely benefitted with their earlier work and have tried to carry forward their work with more analytics on what was incepted by them.

Abstract

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Subhashis Dhara Sharma

2023

Dissertation Chair: <Chair’s Name>

Co-Chair: <If applicable. Co-Chair’s Name>

Vehicle powered by electric motors can be very quiet at low speeds, which can lead to new road safety issues. It becomes very hard for the pedestrians to recognize the presence of these vehicles due to the masking effect of background city noise and the co-existence of the internal combustion engine (ICE) vehicles running along with these new generation electric vehicles in turn becoming a potential cause for increasing road accidents. Many countries such as EU, USA, Japan, Korea and China have already brought in mandatory regulations to adopt AVAS in each EV. However, India is yet to bring such regulations. Further, the conditions in India in terms of various factors like population density, traffic density, road infrastructure, type of vehicles, city ambient noise etc. makes it different than other countries. The main intention of

the studies presented in this paper was to study the ambient traffic noise at various different cities of India to benchmark and standardize the overall background noise in an as is condition thereby identifying the suitable AVAS sound dBA levels for each type of EV that can possibly ply on the busy Indian roads, so as to make it easy for the pedestrians which may include children, senior citizens and physically impaired people. The strategy incorporated a dual approach to narrow down to the exact solution along with the specifications that would be most appropriate for implementation of AVAS in India. First was to survey among common people, both, those owing an EV vehicle and general commuters and pedestrians to collate their experiences. Second was conducting field trials to analyze city ambient noise at various locations, minimum and maximum sound levels (dBA) in Indian context as per the vehicle type, their speeds and distance from the center line of the driving lane. Through the survey among the EV owners and the pedestrians it was clearly evident that both the groups do acclaim that an AVAS system will be quite helpful for them to avert potential accidents on road. As per the various experiments and tests conducted in this research, the normalized mean values of city ambient noise and traffic noise shows 84.6 dBA for highway and 84.3 dBA for city. Therefore, the EV must produce and emit minimum 2 to 3 dBA more than 84.6 dBA to be audible in a traffic. This minimum value should be emitted at low speed of 10kmph. The dBA should increase with increase in the speed level of the vehicle. It is not only the maximum sound level of AVAS which influence the potential detection by pedestrians. As part of the development of different AVAS sound design, the frequency content is very important. In the regulations for AVAS and minimum noise levels, it is recommended that the frequency content should be clearly specified. The regulations should have specific recommendations for minimum sound levels in the frequency spectra from 160 to 5000 Hz. Further, the frequency of the sound should resemble an ICE vehicle sound profile to make it more effective in audibility. In our experiment we have collected the frequency spectrum of ICE vehicle that

shows the frequency is spread until 6500 Hz at an amplitude between 80 to 90 dBA. The AVAS sound for EV should also be designed in a similar fashion so as to improve its audibility distance.

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Chapter 1

Introduction

1.1 Motivation

The International Monetary Fund has projected India's GDP growth at 9.5% in 2021 and 8.5% in 2022, making it the fastest-growing economy. At the same time, with a population of more than 1.2 billion, India is the world’s largest democracy. To fuel the growth of this mega economic structure, the Indian automotive industry is playing a key role. The automotive industry in India, one of the largest globally, is estimated at 18.6 Mn units in FY21. It is further estimated to grow at a CAGR of 8.6% during FY21-30 out of which 2-Wheeler’s account for ~80% of the sales. This accounts for a considerable contribution in India’s carbon footprint. India has a strong impetus to decarbonize its transport sector and shift to electric vehicles. The transport sector contribution towards Green House Gas (GHG) emissions is close to 23%. Fourteen (14) out of twenty (20) world’s most polluted cities are in India. Deaths in India linked to air pollution in 2017 were 2.3 million. Oil import bill for India in 2019-20 was USD 102 Billion. Therefore, in order to promote adoption of electric vehicles in the country, the Government launched the Faster Adoption and Manufacturing of Hybrid & Electric Vehicles in India (FAME India) Scheme since 2015 on pan India basis. Presently, Phase-II of FAME India Scheme is being implemented for a period of 5 years w.e.f. 01st April, 2019 with a total budgetary support of INR 10,000 crores.

Govt. of India targets to achieve 30% penetration of EVs in passenger cars and more than 50% in all other segments by 2030. India is well equipped to make the shift to EVs due to availability of skilled workforce and abundance of renewable energy. Other macro-economic factors such as disposable income, environmental consciousness and Internet of Things (IoT) are expected to accelerate on-going disruptions in the automobile industry, especially for Electric Vehicles. These factors have pushed the Indian government to issue aggressive targets to leapfrog from conventional ICE Vehicles to Electric Vehicles in the next 10 years. FAME II subsidy scheme, initially which was proposed to be implemented over three years, is extended for a period of two years up to 31 March 2024. NITI Aayog has suggested the government to give EV purchase subsidy over and above FAME-II subsidy along with interest subvention on loan amount taken for EV purchase. Energy Efficiency Services Limited, Ministry of Power, Govt. of India, will aggregate demand for 300,000 electric 3-Wheelers with segment specific targets and for remaining electric Buses under the FAME II scheme in nine (9) cities under the OPEX model. Sanctioned by Department of Heavy Industries, setup of 3,397 charging stations of which 2636 are already approved. The second phase of FAME (Faster Adoption and Manufacturing of Hybrid and Electric vehicles) scheme aims to provide additional ~INR 10,000 Cr of demand incentives for EVs. In nutshell, the Govt. of India has set specific EV adoption targets for each vehicle segment. However, considering various socioeconomic factors it is estimated that these initiatives will still leave a long-haul co-existence of ICE at least coming 15 years. Various secondary researches estimate EV adoption in India to be ~28% for E-2W, ~100% for E-3W, ~16% for E-Cars, ~27% for E-LCVs and ~37% for E-Buses until FY30. The current scenario has raised the need to understand the effect of adopting these silent electric vehicles on the pedestrians. It becomes very hard for them to recognize the presence of these vehicles due to the masking effect of background city noise and the co-existence of the internal combustion engine (ICE) vehicles running along with these new generation electric vehicles in turn becoming a potential cause for increasing road accidents. As per (Yamauchi, 2019) the Japanese guideline for AVAS was arranged to be the international guideline that was published from UNECE World Forum for Internationalization of Vehicle Regulation (UNECE/WP29).

The WP29 established an informal group for quiet road transport vehicles (UNECE, 2017), and have been discussed on the development of the regulation. Finally, in March 2016, the UN Regulation No.138 (R.138) on Quiet Road Transport Vehicles, QRTV, with regard to their reduced audibility was published. In Japan, as following the publication of the UN regulation, MLIT have announced officially that the mandatory for installing the system will be enforced from March 2018. As per (Fagerlönn et al., 2018), Electric vehicles (EVs) can be very quiet at low speeds. Their quiet characteristics may be considered comfortable, however, researchers have pointed out that EVs may have a negative impact on traffic safety, as they may simply be more difficult for pedestrians to detect. Further, as per (Fagerlönn et al., 2018), the European Parliament has decided that quiet vehicles should be equipped with an Acoustic Vehicle Alerting System (AVAS). On similar lines, Govt. of India should carve out regulations for the adoption of AVAS. Suitable mechanism should be deployed in all Battery Electric Vehicles (BEV), Plug-in Hybrid Electric Vehicles (PHEV) or Hybrid Electric Vehicles (HEV) and to avert potential road accidents in India.

1.2 Problem Statement

Laib and Schmidt, (2019) mentioned that starting July 1, 2019, all new types of hybrids electric and pure electric vehicles in EU must be equipped with an AVAS, in particular to warn pedestrians at low driving speed. In India context, this problem is further enlarged as the urban demography experiences much higher ambient traffic noise primarily due to large number of 2-wheelers and 3-wheelers plying alongside the passenger car (PC) and heavy commercial vehicles (HCV). For example in various parts of New Delhi, as per the analysis carried out by Mishra et al., (2019), after the analysis of the collected data, it is revealed that at each monitoring location, the traffic noise level was found more than the standard noise level as prescribed by Central Pollution Control Board (CPCB). Another side is about the visually impaired population in India. The number of blind persons in India in 2020 could be close to 31.6 million (Dandona et al., 2001) though WHO estimates that 63 million Indian people are blind or have poor vision. Based on either of these estimates, there are clearly a sizeable number of persons who are therefore at increased risk of victimization. In the given scenario is it quite evident that identifying the presence of a silent electric vehicle will be very difficult for the pedestrians under the urban noise and can be a potential cause for increasing road accidents. Through the literature review it has been observed that AVAS should be adopted in each EV by the EV manufacturing OEMs in India. Further a deep study needs to be carried out for India to carve out suitable specifications for AVAS as the city traffic noise for India is not similar to that of other countries. As per (Mishra et al., 2019), the current urban city noise at various locations in Delhi ranges from 72.4 to 81.6 dB(A) which is much higher as compared to the rest of the world. Also, the population demography is another factor which needs to be considered. The co-existence of other ICE vehicles also imparts the overall noise and makes it difficult to identify a silent EV. In this research conducted for India, similar surveys and road tests are conducted as seen in the literature review. Further, suitable adaptive sound levels are also to be derived to understand the most effective ones which can make the vehicle easily identifiable from the required minimum safe distance.

However, to arrive upon a suitable regulation with detailed specifications of AVAS sound (dBA) level to be adopted for various types of vehicles depending upon their type (scooters, motorcycles, 3-wheelers, Passenger Cars, LCVs or MCVs), laden weight, maximum vehicle speed, etc., a detailed study needs to be conducted in cognizance to the ambient traffic noise in India. This study intends to facilitate formation of a suitable regulatory mandate for India.

1.3 Research Objectives

The main aim of this research is to arrive upon a suitable regulation with detailed specifications of AVAS sound (dBA) level to be adopted for various types of vehicles depending upon their type (scooters, motorcycles, 3-wheelers, Passenger Cars, LCVs or MCVs), laden weight, maximum vehicle speed, etc. It aims to study the city ambient traffic noise at various location of India to arrive upon the optimum sound dBA levels. Further, it intends to survey among pedestrians, general commuters and EV vehicle riders to understand their perspectives on the various conditions that they face while in traffic. The research also aims to conduct various acoustic tests in laboratory and simulate on road conditions to derive AVAS sound levels necessary to recognize the presence of an EV plying on road or approaching a crowded locality with pedestrians around. The study results may facilitate the necessary framework for regulations to be brought in for deployment of AVAS in electric vehicles in India. The research objectives include the following details:

1. What should be the dBA level when an EV is on but the velocity is zero?
2. What should be the dBA level of the vehicle running at a speed between 0 to 25 KMPH?
3. How should the AVAS sound fade out at velocities more than 35 KMPH?
4. Should the AVAS needs to produce any sound beyond 50 KMPH?
5. To identify the distance at which the presence of an approaching ICE is felt to human.
6. Similarly, to identify the distance at which the presence of an approaching EV is felt.
7. To identify the safe distance at which a person should identify an approaching vehicle.

The answers to the above questions will help in understanding the overall landscape of AVAS deployment that would be most appropriate in an Indian context. Through the literature review we may observe that similar tests have been conducted in other countries such as Europe, USA, Japan, Korea and China to avert potential accidents due to silent EVs. However, the same needs to be conducted for India.

1.4 Contributions

The contributions of this doctoral research thesis are:

- An analytical model for the results of a survey conducted within commuters owning EVs and ICEs conferring the essence of implementation of AVAS in the silent electric vehicles plying on the Indian road.
- A fundamental investigation into the study of the city ambient noise at various cities of India based on the sound dBA levels of roads and areas nearby to the traffic.
- Experimental results of actual distance (Meters) from which an approaching ICE vehicle can be identified by a pedestrian or a passerby verses the time duration (Seconds) available for the pedestrians to be alert in such situations.
- The experimental implementation and evaluation of the proposed optimum or minimum acoustic noise levels (dBA) that an EV should produce to feel its presence by the pedestrian in a moving traffic.

1.5 Significance of the research

As per a study on the adoption of electric vehicles in India by (Khurana et al., 2020), pollution of the environment is currently a global concern. Toxic emission from internal combustion engines is one of the primary air pollutants. In order to mitigate the effects of fossil fuel emission and address environmental concerns (ECs), electric vehicles (EVs) are being promoted aggressively all over the world. Various governments are encouraging people to switch to EVs by incentivizing the transition. Previous studies indicate that the high cost of the electric car, non-availability of charging infrastructure, time and range anxiety act as impediments to consumer adoption. The over-a-century-old automobile industry is now gearing up for transformation. The fossil fuel price spike and the impact of its emission on the environment have called for a change in individual transportation habits. The sector, propelled by internal combustion engines, is gravitating gradually towards electric vehicles (EVs). As per (Khurana et al., 2020), The different categories of EVs are as follows:

HEV: Hybrid electric vehicles (HEVs) are powered by fuel and electricity and have an engine and an electric motor. Electricity generated by the braking system charges the battery.

PHEV: Plug-in hybrid electric vehicles (PHEVs) are like HEV except that they have a small engine and larger batteries. The batteries recharging is either by the braking system or by plugging into an external electric charging point.

BEV: They have no engine and they use electric motors for propulsion with batteries as the energy storage device. They depend on external power points for charging the battery. These vehicles are also known as plug-in vehicles, EVs or the battery electric vehicles (BEVs).

The transportation sector contributes about a quarter of GHG emissions. Automobiles are the primary source of GHG emission world over with China emitting 25.9 per cent, the USA 13.87 per cent followed by India 7.45 per cent. The Eighth Clean Energy Ministerial in 2016, in its campaign, adopted the slogan ‘The EV30@30’. The member countries reaffirmed their commitment to EV adoption. The aim was to attain a total market share of 30 per cent for EVs, with 10 per cent market share for the respective categories, namely passenger cars, light commercial vehicles, buses and trucks by 2030 (IEA, 2016). Resonating to the emerging needs, the Government of India has given a call for ‘only Electric Vehicles’ on Road by 2030. On the other hand, vehicles powered by electric machines offer the advantage to be more silent than vehicles equipped with an internal combustion engine. Though, the reduced noise levels enable an improvement of the inner-city noise pollution, at the same time, quiet vehicles entail risks not to be acoustically detected by surrounding pedestrians and cyclists in the lower speed range. The emitted noise can easily be masked by the urban background noise (Fortino et al., 2016).

In the given scenario is it quite evident that identifying the presence of a silent electric vehicle is very important for the pedestrians under the urban noise and can be a potential cause for increasing road accidents. As per the study conducted by (Pardo-Ferreira et al., 2020), Sales of electric and hybrid electric vehicles are increasing steadily worldwide, and consequently their presence increases in city areas. At low speeds, the low levels of noise produced by these vehicles could become a new risk factor for road users. However, the magnitude of the risk has not been accurately determined. In addition, its inclusion in the work environment could pose a new risk that should be managed. Thus, in relation to low noise levels of electric and hybrid vehicles, their study aimed to characterize the risk situations and determine the risk perception of workers as pedestrians and internal combustion engine vehicle drivers coming into contact with these vehicles. The data were extracted from 417 questionnaires filled out by the employees of public service companies who come into contact with electric and hybrid vehicles during their working day in the city of Málaga, in the region of Andalusia, Spain. According to the experiences reported, it seems that the risk due to the low noise levels of electric vehicles is moderate and does not reach alarming levels. These risk situations usually occurred in low-speed urban areas, particularly when crossing the road, or in semi-pedestrian areas. Almost half the respondents considered that the electric vehicle poses a risk to other road users because it is more difficult to hear, and they believe it likely that other road users could be injured. Despite that risk, pedestrians did not change their way of walking or moving around the parking areas and other areas of the company. Electric and hybrid electric cars are now required to produce sound when travelling at low speeds. As per (Pardo-Ferreira et al., 2020), road traffic noise in urban environments is generated by vehicles and is mainly due to the friction of the tires and the noise of the engine. At speeds of over 30 km/h, the noise of tire friction overcomes the noise of the engine. However, at low speeds, the predominant noise is that of the engine. Specifically, EVs and hybrid electric vehicles (HEVs), which operate in electric mode at low speeds, have quieter engines at these speeds. This, coupled with the increased use of low noise road surfaces, could pose a threat to the safety of vulnerable road users who rely on their senses of sight and hearing to navigate road traffic safely in urban environments, since the paucity of auditory cues associated with the approach of these vehicles at low speeds increases the risk of pedestrian accidents. As per a recent study by (Liu et al., 2022) in Norway, safety performance is a vital factor of influencing the expansion of EVs. The primary safety concern to EVs is their threat to pedestrians and bicyclists due to their silent engines, especially for visually impaired ones under low-speed scenarios. When ICEVs are approaching pedestrians/bicyclists, the engine noise is expected to effectively provide alerts. However, the silent operation of EVs with electric motors, which is an advantage in terms of comfort, augments the odds of conflicts between EVs and pedestrians/bicyclists. In a study called "Incidence Rates of Pedestrian and Bicyclist Crashes by Hybrid Electric Passenger Vehicles: An Update. (DOT HS 811 526). Washington, DC: National Highway Traffic Safety Administration, conducted by (Wu et al., 2011), they analyzed the pedestrian and bicyclist crashes involved in some HEVs and ICEVs in 12 states of the U.S., and found that HEVs had a higher incident rate in pedestrian or bicyclist crashes than ICEVs. Later, (Wu et al., 2011) updated the study conducted on a total of 24,297 HE and 1,001,000 ICE Honda and Toyota selected vehicles in 16 States. A total of 186 and 5,699 HE and ICE vehicles respectively were involved in pedestrian crashes, and a total of 116 and 3,052 HE and ICE vehicles respectively were involved in bicycle crashes. Overall, the odds ratios indicate that the odds of an HE vehicle being in either a pedestrian or bicycle crash are greater, 35 percent and 57 percent respectively, than the odds of an ICE vehicle being in a similar crash.

Further, an interesting analysis done by (Roan et al., 2020), on the probability of detection as a function of distance and the results suggest that although the test sounds provide an average detection distance that exceeds the NHTSA minimum at the two test speeds, detection probability is not always 100% at those distances particularly at the 10 kmph. At the higher speed of 20 kmph, the tire-road interaction noise becomes dominant, and the detection range is 16 greatly extended. This is an important input that suggests that AVAS sound levels (dBA) needs to be modulated as the vehicle speeds and probably needs to be more at lower speeds specially between 10 to 20 Kmph.

Another study conducted by (Kosuge et al., 2019) based on approach information sound (AIS) concluded that pedestrians who did not recognize AIS noticed the approach of a quiet vehicle and felt danger not through AIS but through other, familiar sounds, such as wind noise and road noise, which are also emitted by vehicles having internal combustion engines. After providing the opportunity to hear and recognize AIS (in the design of awareness), half the participants began using AIS in noticing the approach of quiet vehicles. However, others reported that AIS was not enough to inform them of the approach of quiet vehicles, and they thus did not use it. Therefore, as per (Kosuge et al., 2019), further studies on the design of AIS, including designing awareness, would contribute to and improve the recognition of AIS.

Through various other literature reviews, it has been observed that AVAS should be adopted in each EV by the EV manufacturing OEMs also in India. Therefore, a deep study should to be carried out for India to carve out suitable specifications for AVAS as the city traffic noise for India is not similar to that of other countries.

1.6 Regulations around the world

As per (Misdariis and Pardo, 2017), Japan is the first country in the world to have considered and addressed how to improve the detectability of silent vehicles. Indeed, it was in this country that devices emitting sometimes very exotic warnings emerged (for example a “beep beep” followed by “Excuse me. Car is coming!” or a tune from a cartoon). Japan issued guidelines for such warning devices in January 2010[6]. The vehicle must make a continuous noise level of at least 56 dBA (within 2 meters) if the car is going 20 km/h (12 mph) or slower, and a maximum of 75 dBA. It is also here that a guide has already been produced and its application recommended for any device mounted on a vehicle.

The United States was also a pioneer in the field, taking the issue to national level with the publication of the Pedestrian Safety Enhancement Act of 2010, for which FMVSS regulation 141 [Minimum Sound Requirements for Hybrid and Electric Vehicles] was published in 2017. Pursuant to the Pedestrian Safety Enhancement Act of 2010 (PSEA), NHTSA [3] issued a new FMVSS regulation setting minimum sound level requirements for low-speed operation of hybrid and electric light vehicles.

Based on the NHTSA guidelines, the European Union introduced a similar voluntary guide [UNECE Consolidated Resolution on the Construction of Vehicles (R.E.3)], which was then taken up by the European Union in a regulation (540/2014/EC) [Regulation (EU) No.540/2014[4] of the European Parliament and the Council of 16 April 2014 on the sound level of motor vehicles and of replacement silencing system. In 2016, the United Nations published a regulation transcribing these recommendations into specifications requiring the performance of tests for vehicle approval. In 2017, the European Union introduced these same criteria in regulation 540/2014/EC, making it obligatory to fit a sound device on all electric or hybrid vehicles by 2019.

In sync with USA & Europe, China also drafted regulation No. GB/T 37153[7] to standardize AVAS. The Chinese regulation is fully aligned with UNECE regulation 138 except that all minimum noise levels are 2 dB higher and implemented in September'2019.

In Canada, The Motor Vehicle Safety Regulations (MVSR) are amended to introduce Canada Motor Vehicle Safety Standard (CMVSS) 141[8] — Minimum Sound Requirements for Hybrid and Electric Vehicles (CMVSS 141). The safety standard includes requirements to testable acoustic parameters when the vehicle is about to move or is moving at low speeds. As per Canada Gazette, Part II, Volume 156, Number 26, Motor Vehicle Safety Act P.C. 2022-1263 December 2, 2022, Every hybrid or electric passenger car, multi-purpose passenger vehicle, truck, bus and low-speed vehicle with a GVWR of 4 536 kg or less shall conform to

- the requirements set out in paragraph 6 of Regulation No 138 of the Economic Commission for Europe of the United Nations, entitled Uniform provisions concerning the approval of Quiet Road Transport Vehicles with regard to their reduced audibility, as amended from time to time, and shall be tested in accordance with the conditions and test procedures set out in Annex 3 of that Regulation, as amended from time to time; or
- the requirements set out in provision S5 of section 571.141, subpart B, part 571, chapter V, Title 49 of the Code of Federal Regulations of the United States, entitled Standard No. 141; Minimum Sound Requirements for Hybrid and Electric Vehicles, as amended from time to time, and shall be tested in accordance with the conditions and test procedures set out in provisions S6 and S7 of that section, as amended from time to time.

Other countries such as Taiwan and Korea are also considering legislation based on the United Nations regulation. Korea published a draft KMVSS 53.3[9] on minimum sound emission, which is based on UN R138.00. Application date is under consideration, proposal for 2 years after official release. As per (Misdariis and Pardo, 2017), several criteria are necessary to provide a solution to the problem. To achieve this, the vehicle must be detectable, recognizable and possible to situate whilst at the same time generating low noise nuisance. The main relevant criteria taken into account are the content and frequency level, and the modulation and spectral variation according to speed. These regulatory requirements are broken down into two regulations: UN-ECE R138 and FMVSS 141.

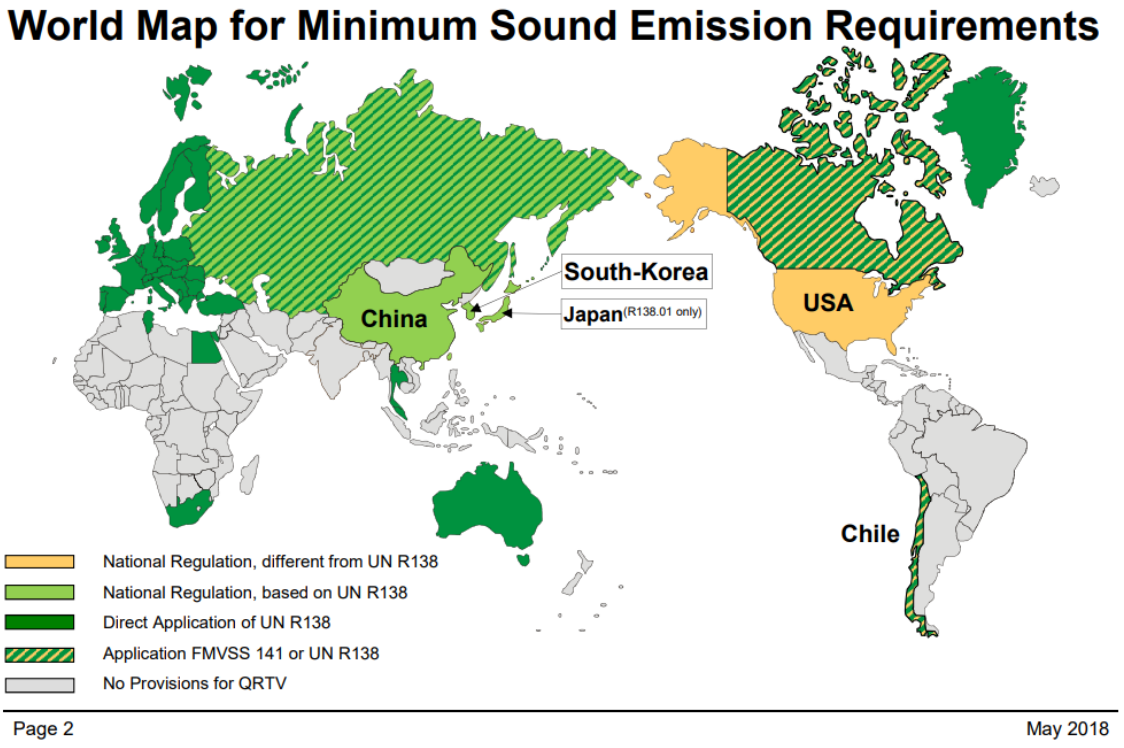
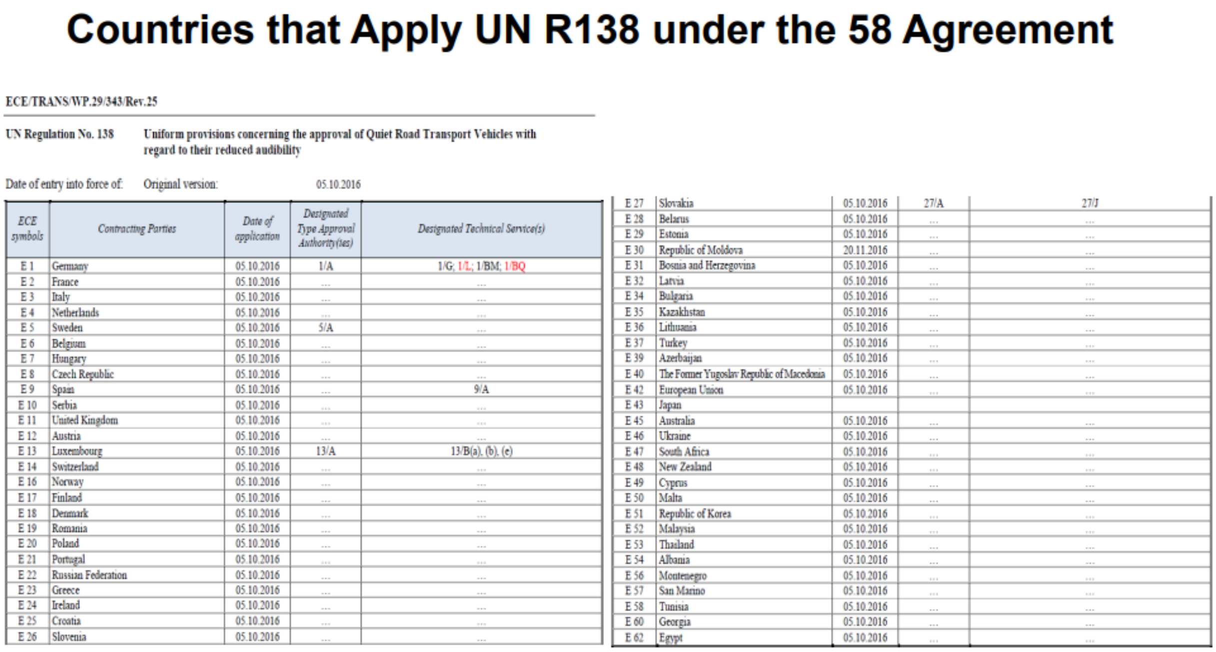


Figure 1: Regulations Worldwide on Minimum Sound Emission of Quiet Vehicles UN-ECE GRB GTR Working Group QRTV May 2018 – Baltimore as per international organization of motor vehicle manufacturers



Countries that Apply UN R138 under the 58 Agreement

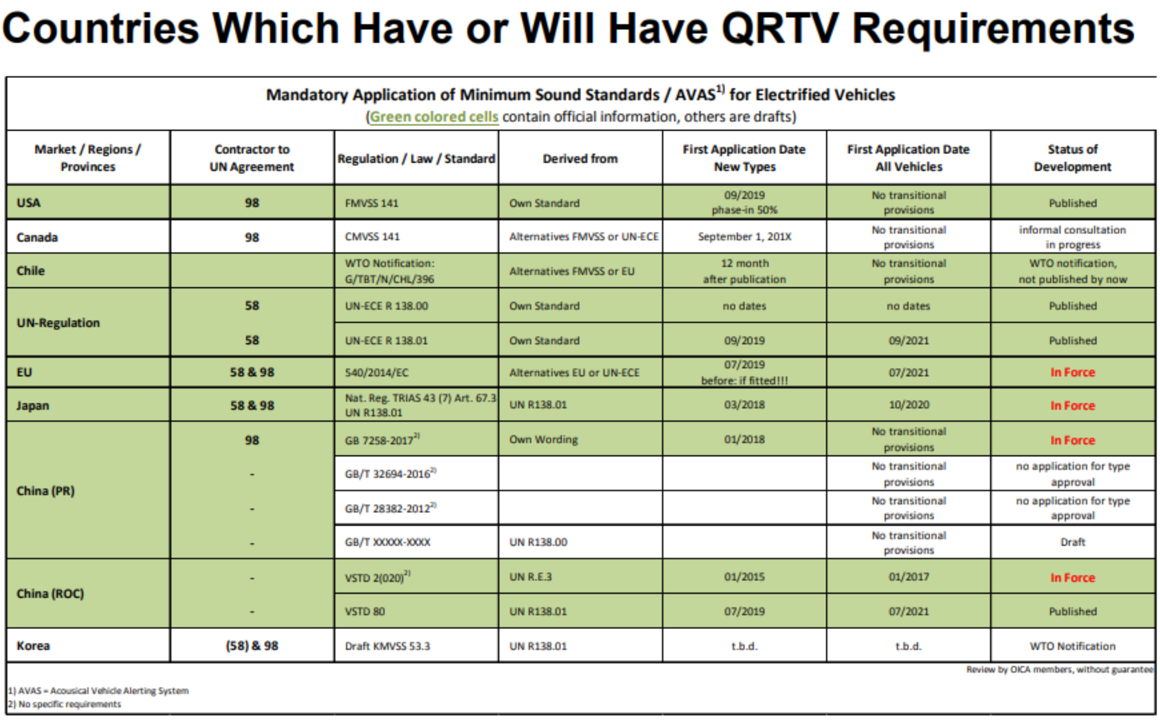
ECE/TRANS/WP.29/343/Rev.25

UN Regulation No. 138 **Uniform provisions concerning the approval of Quiet Road Transport Vehicles with regard to their reduced audibility**

Date of entry into force of: Original version: 05.10.2016

ECE symbols	*Contracting Parties*	*Date of application*	*Designated Type Approval Authority(ies)*	*Designated Technical Service(s)*
E 1	Germany	05.10.2016	1/A	1/G; 1/L; 1/BM; 1/BQ
E 2	France	05.10.2016	...	...
E 3	Italy	05.10.2016	...	...
E 4	Netherlands	05.10.2016	...	...
E 5	Sweden	05.10.2016	5/A	...
E 6	Belgium	05.10.2016	...	...
E 7	Hungary	05.10.2016	...	...
E 8	Czech Republic	05.10.2016	...	...
E 9	Spain	05.10.2016	...	9/A
E 10	Serbia	05.10.2016	...	...
E 11	United Kingdom	05.10.2016	...	...
E 12	Austria	05.10.2016	...	...
E 13	Luxembourg	05.10.2016	13/A	13/B(a), (b), (e)
E 14	Switzerland	05.10.2016	...	...
E 16	Norway	05.10.2016	...	...
E 17	Finland	05.10.2016	...	...
E 18	Denmark	05.10.2016	...	...
E 19	Romania	05.10.2016	...	...
E 20	Poland	05.10.2016	...	...
E 21	Portugal	05.10.2016	...	...
E 22	Russian Federation	05.10.2016	...	...
E 23	Greece	05.10.2016	...	...
E 24	Ireland	05.10.2016	...	...
E 25	Croatia	05.10.2016	...	...
E 26	Slovenia	05.10.2016	...	...
E 27	Slovakia	05.10.2016	27/A	27/J
E 28	Belarus	05.10.2016	...	...
E 29	Estonia	05.10.2016	...	...
E 30	Republic of Moldova	20.11.2016	...	...
E 31	Bosnia and Herzegovina	05.10.2016	...	...
E 32	Latvia	05.10.2016	...	...
E 34	Bulgaria	05.10.2016	...	...
E 35	Kazakhstan	05.10.2016	...	...
E 36	Lithuania	05.10.2016	...	...
E 37	Turkey	05.10.2016	...	...
E 39	Azerbaijan	05.10.2016	...	...
E 40	The Former Yugoslav Republic of Macedonia	05.10.2016	...	...
E 42	European Union	05.10.2016	...	...
E 43	Japan			
E 45	Australia	05.10.2016	...	...
E 46	Ukraine	05.10.2016	...	...
E 47	South Africa	05.10.2016	...	...
E 48	New Zealand	05.10.2016	...	...
E 49	Cyprus	05.10.2016	...	...
E 50	Malta	05.10.2016	...	...
E 51	Republic of Korea	05.10.2016	...	...
E 52	Malaysia	05.10.2016	...	...
E 53	Thailand	05.10.2016	...	...
E 54	Albania	05.10.2016	...	...
E 56	Montenegro	05.10.2016	...	...
E 57	San Marino	05.10.2016	...	...
E 58	Tunisia	05.10.2016	...	...
E 60	Georgia	05.10.2016	...	...
E 62	Egypt	05.10.2016	...	...

Figure 2: Countries that Apply UN R138 under the 58 Agreement as per international organization of motor vehicle manufacturers



Countries Which Have or Will Have QRTV Requirements

Mandatory Application of Minimum Sound Standards / AVAS[1)] for Electrified Vehicles

(Green colored cells contain official information, others are drafts)

Market / Regions / Provinces	Contractor to UN Agreement	Regulation / Law / Standard	Derived from	First Application Date New Types	First Application Date All Vehicles	Status of Development
USA	**98**	FMVSS 141	Own Standard	09/2019 phase-in 50%	No transitional provisions	Published
Canada	**98**	CMVSS 141	Alternatives FMVSS or UN-ECE	September 1, 201X	No transitional provisions	informal consultation in progress
Chile		WTO Notification: G/TBT/N/CHL/396	Alternatives FMVSS or EU	12 month after publication	No transitional provisions	WTO notification, not published by now
UN-Regulation	**58**	UN-ECE R 138.00	Own Standard	no dates	no dates	Published
	58	UN-ECE R 138.01	Own Standard	09/2019	09/2021	Published
EU	**58 & 98**	540/2014/EC	Alternatives EU or UN-ECE	07/2019 before: if fitted!!!	07/2021	**In Force**
Japan	**58 & 98**	Nat. Reg. TRIAS 43 (7) Art. 67.3 UN R138.01	UN R138.01	03/2018	10/2020	**In Force**
China (PR)	**98**	GB 7258-2017[2)]	Own Wording	01/2018	No transitional provisions	**In Force**
	-	GB/T 32694-2016[2)]			No transitional provisions	no application for type approval
	-	GB/T 28382-2012[2)]			No transitional provisions	no application for type approval
	-	GB/T XXXXX-XXXX	UN R138.00		No transitional provisions	Draft
China (ROC)	-	VSTD 2(020)[2)]	UN R.E.3	01/2015	01/2017	**In Force**
	-	VSTD 80	UN R138.01	07/2019	07/2021	Published
Korea	**(58) & 98**	Draft KMVSS 53.3	UN R138.01	t.b.d.	t.b.d.	WTO Notification

Review by OICA members, without guarantee

1) AVAS = Acousical Vehicle Alerting System
2) No specific requirements

Figure 3: Countries which have or will have QRTV requirements as per international organization of motor vehicle manufacturers

AVAS Guidelines

In one of research conducted by Kournoutos (Kournoutos, 2020), the majority of EV manufacturing countries form their legislation on the matter under the standards of the AVAS, and as a result, the warning sound systems that are currently being developed are designed and evaluated following the guidelines given by the AVAS regulations. It is therefore useful to provide an overview of these guidelines prior to the presentation of existing warning sound systems and the suggestion for development of novel systems. The AVAS is evaluated using the system fully integrated within an EV, with sound pressure level measurements performed outdoors and indoors. Two microphones, standing at 1.2 m above the ground and at a distance of 2 m from the centerline of the vehicle at each side are used to measure any noise produced by the vehicle. Outdoor measurements involve the vehicle moving forward at a constant speed of 10 km/h and at 20 km/h as well as a reversing test with no specific speed defined. Figure 4 shows the positions from which measurements are to be taken. In the forward tests the measurement begins at the point in time the front plane of the vehicle crosses the line AA' until the point in time the rear plane crosses the line BB', following a straight course as set by line CC'. Lines AA' and BB' are both distanced 10 m from the plane PP' defined by the placement of the two microphones. The reversing test is similarly performed, with the measurements being taken between the points in time the rear plane crosses the line BB' until the front plane crosses the line AA'.

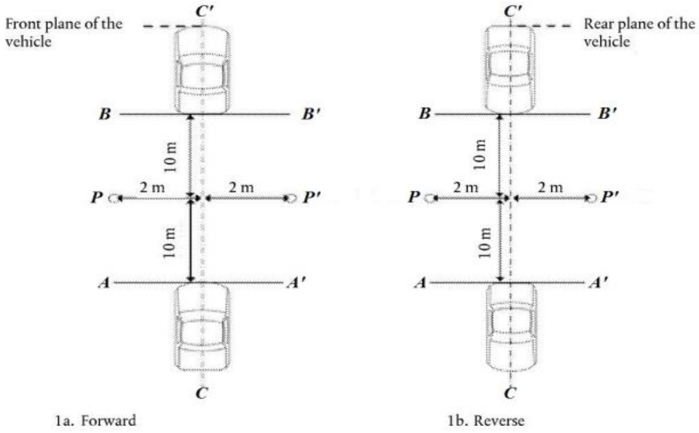


Figure 4: Measuring positions for vehicles in motion outdoor in accordance with UNECE guidelines for the AVAS, presented in (UNECE, 2017).

Indoor measurements are intended to be taken within a semi-anechoic environment with the vehicle in standstill condition; a constant speed is instead simulated for a minimum of 5 seconds. Figure 5 shows how the front plane of the car is positioned to coincide with the plane PP’ defined by the two microphones for the forward tests, and the rear plane is likewise used for the reversing test. Table 1 below shows the minimum sound pressure levels required to be achieved at specific frequency bands for each type of test. UNECE Regulations specify that a warning sound must have components covering at least two of the 1/3rd octave frequency bands included in the table, with at least one of them below or within the 1600 Hz 1/3rd octave band.

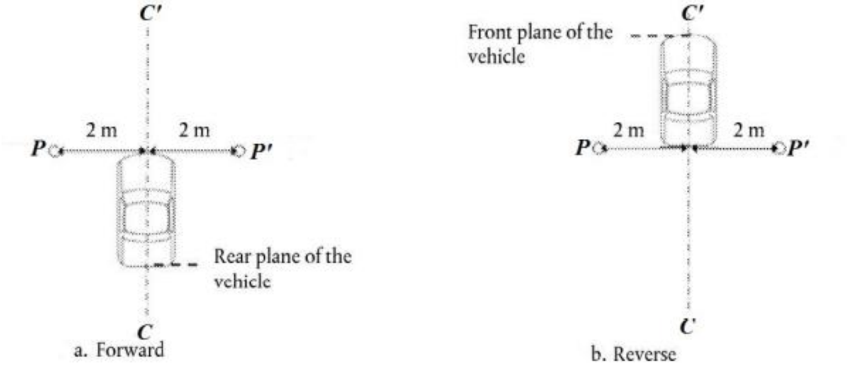
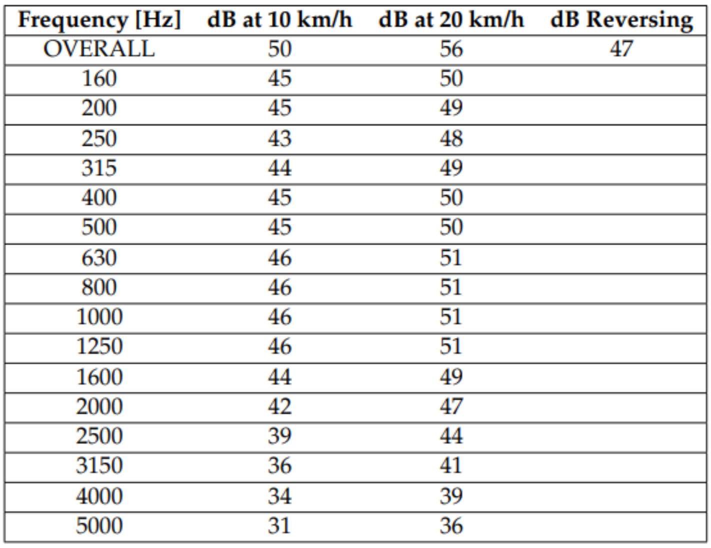


Figure 5: Measuring positions for vehicles in standstill for indoor testing in accordance with UNECE guidelines for the AVAS, presented in (UNECE, 2017).

As with other regulations regarding EVs and HEVs, the AVAS guidelines have undergone a number of revisions since they were first presented, due to the rapid development of technologies around warning sounds in the last few years. It could therefore be expected that the guidelines for AVAS presented in this section may be subject to change in the face of new findings, or if novel relevant technologies become available for wide implementation within the vehicle industry.

As per Kournoutos (Kournoutos, 2020), the short presentation of legislation on mandatory auditory warnings for EVs in this section showed that, although initial efforts were taken by each country individually, there has been a tendency towards a global standard in the last few years. The point of convergence can be considered to be in the regulations proposed for the AVAS guidelines. Under these guidelines, the bandwidth in which warning sounds are expected to operate, and the minimum SPL necessary at each frequency band are dictated. Also included are instructions on the measurements for the evaluation of the warning sounds. However, as EV technologies progress, the exact form of such regulations is expected to change in the near future.



Frequency [Hz]	dB at 10 km/h	dB at 20 km/h	dB Reversing
OVERALL	50	56	47
160	45	50	
200	45	49	
250	43	48	
315	44	49	
400	45	50	
500	45	50	
630	46	51	
800	46	51	
1000	46	51	
1250	46	51	
1600	44	49	
2000	42	47	
2500	39	44	
3150	36	41	
4000	34	39	
5000	31	36	

Table 1: Minimum Sound Level Requirements, overall and at specific 1/3rd octave bands, in dB(A) for the AVAS in accordance with UNECE Regulation 138 (UNECE, 2017), for constant forward speed tests at 10 km/h and 20 km/h, and reversing.

1.7 Thesis Structure

Chapter 2 constitutes an introduction to the subject of Acoustic Vehicle Alerting System (AVAS) in the form of a literature review. Results of published studies are used to show the overall essence to the implementation of AVAS for EVs in India. How the conditions in India in terms of various factors like population density, traffic density, road infrastructure, type of vehicles, city ambient noise etc. makes it different than other countries. Also, other factors like e-2wheelers and e-3wheelers plying in small lanes and sub-lanes of crowed streets affects the severity of silent vehicles plying without the implementation of an AIS (approach information sound) both for the pedestrians and EV drivers in India.

Chapter 3 focuses on the various methodologies adopted to conduct surveys and road tests to achieve the objectives of this research. It will outlay the survey formats distributed among EV owners and general commuters to understand their perspectives based on their daily life experiences. Further, it will elaborate on methodology of investigating into the study of the city ambient noise at various cities of India based on the sound dBA levels of roads and areas nearby to the traffic. Methodology of experiments that are carried out to understand the actual distance (Meters) from which an approaching ICE vehicle can be identified by a pedestrian or a passerby verses the time duration (Seconds) available for the pedestrians to be alert in such situations. The experimental test setups and evaluation of the proposed optimum or minimum acoustic noise levels (dBA) that an EV should produce to feel its presence by the pedestrian in a moving traffic.

Chapter 4 presents all the experiments conducted to achieve the objectives of this study. The results of the survey are mathematically modelled to derive conclusions. It presents the test conditions and their corresponding results thereby simulating the evident theories to arrive on logical conclusions.

Chapter 5 summarizes the results of the studies conducted within the project and lists the conclusions of this research. In addition, ideas for future work and the further development of the concepts investigated are presented.

Chapter 2

Preliminary Literature Review & Hypothesis

This chapter constitutes an introduction to the subject of Acoustic Vehicle Alerting System (AVAS). This is done in the form of a literature review, which aims to present the reasoning behind the conceptualization of AIS *(approach information sound)* for EVs and HEVs, the regulation mandating the content of such AIS system, and existing research on the development of AIS. The section 2.1 presents the population demography of India that has a critical significance to the traffic density. Section 2.2 presents the traffic noise and city ambient noise analysis done by previous researchers in India. This segment creates a preliminary understanding about the intensity of ambient noise and its masking effect of proposed AIS system. Section 2.3 covers the prior experiments conducted to carve out suitable sound level for EVs & HEVs across many other countries. While many researchers tried to understand the impact of silent electric vehicles on road for the pedestrians, they conducted surveys among EV owners and pedestrians. Similar insights on the earlier surveys are covered in Section 2.4. Further, many field tests on suitable artificial acoustics and related sound frequencies were conducted by researchers. They also conducted the approach distance audibility test and passerby noise test for EVs and traditional ICE vehicles. These experiments and their results are captured in Section 2.5. Section 2.6 presents the sounds and nature of noise generated by EVs and HEVs, and the way in which these differ from internal combustion engines. The results from studies on the effects and potential risks this difference in noise emissions possess, and the advantages of artificial warning sounds are presented in Section 2.7. An overview of research performed for the development of AIS systems currently in use is given in Section

2.8. The concept of AIS that aims to minimize environmental noise emissions, and a number of proposed systems aiming to achieve this objective are presented in Section 2.9. Finally, the overview of all these prior arts is summarized in the Section 2.10.

2.1 Understanding the population demography of India

As per (Agarwal et al., 2020), India’s population of 1.31 billion, the second largest globally, comprises 17% of the world’s total (United Nations 2015), and the United Nations Population Division estimates that India’s population will in fact overtake China’s by 2028. As per (Balk et al., 2019a), the average population density of Urban India is around 10,359 persons/Sq. km. This is an important parameter to be considered while understanding the specific need of a country like India.

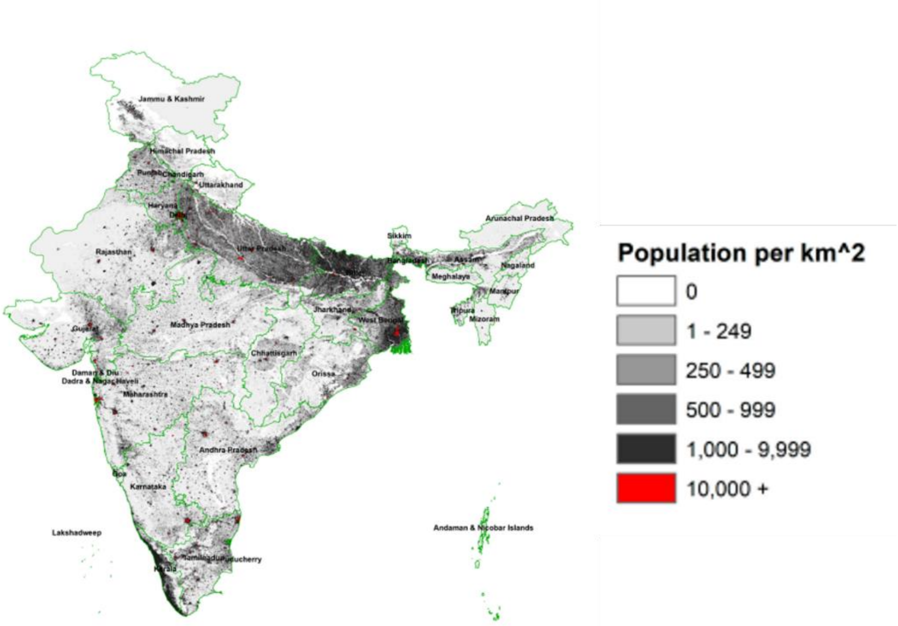


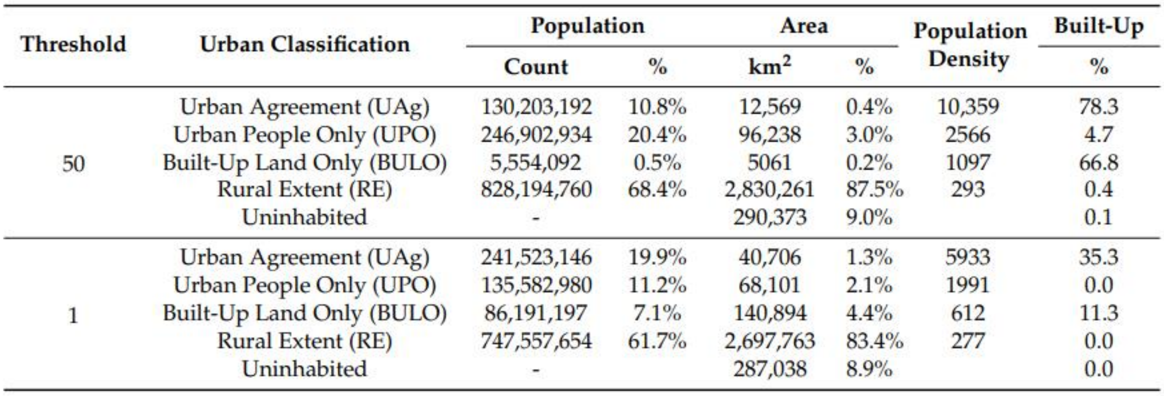
Figure 6: Population Density India 2011, (Balk et al., 2019b)

Census Classification	Population		Area		Population Density	Built-Up
	Count	%	km^2	%		%
Statutory Town	318,562,520	26.3%	80,109	2.5%	3977	14.4
Census Town	54,280,980	4.5%	26,234	0.8%	2069	10.2
Outgrowth	4,264,979	0.4%	3436	0.1%	1241	8.7
Village	833,746,498	68.9%	2,850,979	87.2%	292	0.6
Uninhabited	0	0.0%	307,377	9.4%	-	0.1

Table 2: Population, area, and population density (2011), and estimates of percentage built-up (2014), by official census classifications, India. (Balk et al., 2019a)

NB: These summaries were produced from the underlying vector data. Statistics based on the gridded products will differ slightly due to rounding and the majority-rule assignment of each class to a given grid cell.

The above table shows how the statutory towns and census towns are densely populated having an average population ranging up to 3977 numbers and 2069 numbers respectively per square kilometer. The onward effect of such population density in absence of adequate road infrastructure is further magnified with increased average traffic density on roads.



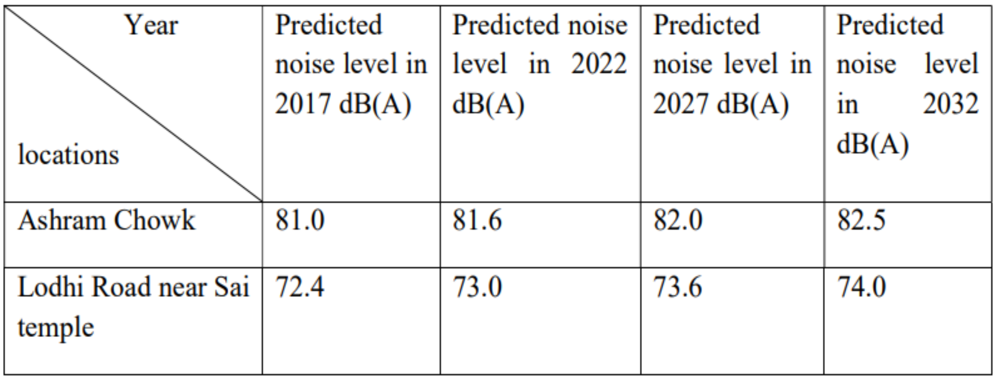
Threshold	Urban Classification	Population		Area		Population Density	Built-Up
		Count	%	km^2	%		%
50	Urban Agreement (UAg)	130,203,192	10.8%	12,569	0.4%	10,359	78.3
	Urban People Only (UPO)	246,902,934	20.4%	96,238	3.0%	2566	4.7
	Built-Up Land Only (BULO)	5,554,092	0.5%	5061	0.2%	1097	66.8
	Rural Extent (RE)	828,194,760	68.4%	2,830,261	87.5%	293	0.4
	Uninhabited	-		290,373	9.0%		0.1
1	Urban Agreement (UAg)	241,523,146	19.9%	40,706	1.3%	5933	35.3
	Urban People Only (UPO)	135,582,980	11.2%	68,101	2.1%	1991	0.0
	Built-Up Land Only (BULO)	86,191,197	7.1%	140,894	4.4%	612	11.3
	Rural Extent (RE)	747,557,654	61.7%	2,697,763	83.4%	277	0.0
	Uninhabited	-		287,038	8.9%		0.0

Table 3: Population, Area, And Population Density (2011), and Estimates of Percentage Built-up (2014), According to Urban classification based on Census + GHSL (satellite-derived) Built-up Area Data, India (BALK AL, 2019)

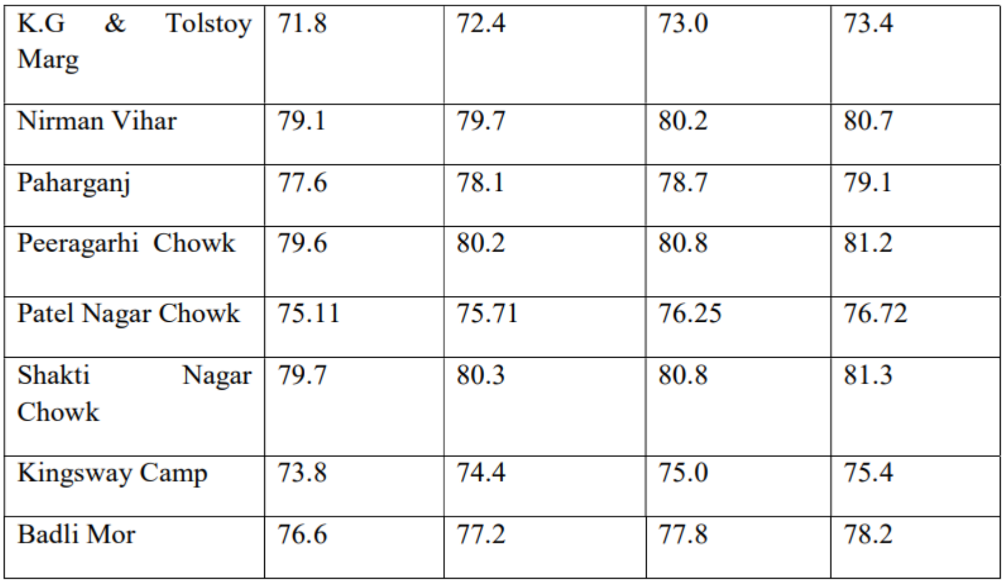
As per the study conducted by Singh et al., (2021), the traffic flow was found to vary between 1000 and 1200 vehicles per hour for the Chatram direction, whereas for the Palpannai direction, it varied between 700 and 1000 vehicles per hour. This study was conducted in Tiruchirappalli (Trichy) city, which is one of the major urban areas in Tamil Nadu, India, with a population of around 1.63 million, and an area of 167.23 Sq. km. Similarly, a topography of type of vehicle per hour is also important as the density of 2-wheelers and 3-wheelers can be significantly higher compared to passenger cars (PC) or heavy commercial vehicles (HCV). Another fact that affects is the presence of huge semi towns and suburban that is laid in the outskirts of all the major metro cities. In fact, it counts for a considerable area and mostly constitutes of small roads (galis) without any footpaths and steep turns. These are absolute accident-prone destinations for these silent electric vehicles and the pedestrians.

2.2 Traffic Noise Analysis in Indian Urban Cities

As per (Mishra et al., 2019), traffic noise is considered as one of the important source of noise pollution and its contribution is approximately 75% of the total noise pollution in urban areas. Delhi is considered as second noisiest city in the world. Before narrowing down to most suitable sound levels that an AVAS need to generate in urban India, it is very important to make an in-depth study of traffic noise in Indian urban cities. To study the effect and to control the noise, different type of models like Federal highway administration (FHWA) model in USA, Calculation of road traffic noise (CORTN) model in UK, Stop and Go model in Bangkok and Richtlinien für den Lärmschutz an Straben (RLS-90) model in Germany, are used in different countries. In the research conducted by (Mishra et al., 2019), they have adopted RLS-90 Model to monitor the traffic noise level at selected locations of New Delhi. These models are used to predict the noise level and help in the designing of noise barrier. As per (Mishra et al., 2019), prediction of road traffic noise level by using RLS -90 model is found best suitable model in Indian heterogeneous traffic conditions. The same model has been used to forecast the traffic noise level for the year 2022, 2027 and 2032. Following are the results concluded by (Mishra et al., 2019), after their details study that can be used while designing the noise level for AVAS suitable for India.



Year locations	Predicted noise level in 2017 dB(A)	Predicted noise level in 2022 dB(A)	Predicted noise level in 2027 dB(A)	Predicted noise level in 2032 dB(A)
Ashram Chowk	81.0	81.6	82.0	82.5
Lodhi Road near Sai temple	72.4	73.0	73.6	74.0

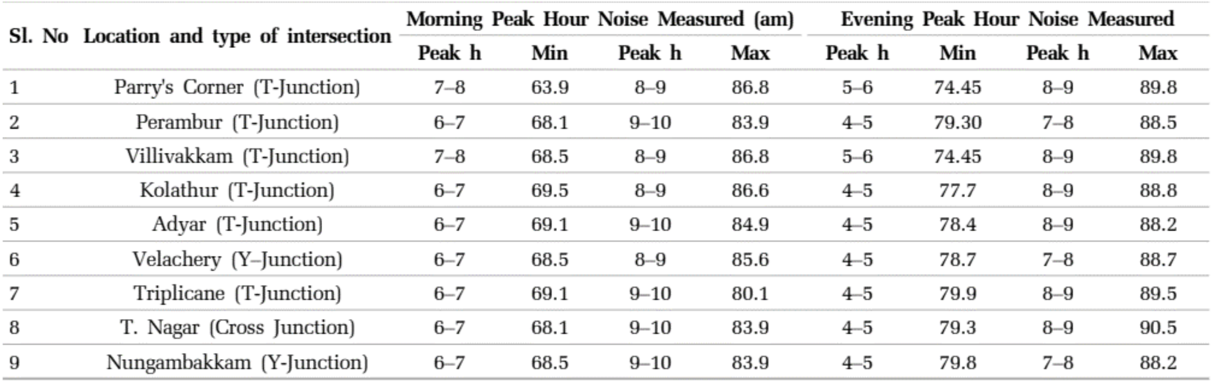


K.G & Tolstoy Marg	71.8	72.4	73.0	73.4
Nirman Vihar	79.1	79.7	80.2	80.7
Paharganj	77.6	78.1	78.7	79.1
Peeragarhi Chowk	79.6	80.2	80.8	81.2
Patel Nagar Chowk	75.11	75.71	76.25	76.72
Shakti Nagar Chowk	79.7	80.3	80.8	81.3
Kingsway Camp	73.8	74.4	75.0	75.4
Badli Mor	76.6	77.2	77.8	78.2

Table 4: Forecasting of traffic noise level for different years (Mishra et al., 2019)

Taking 2017 as a base year, road traffic noise has been predicted for different years i.e., 2022, 2027 and 2032. The forecasting of the traffic noise level at Ashram Chowk varied from 81 dB (A) to 82.5 dB(A) in 2017 to 2032 year, predicted traffic noise level much above the prescribed level due to heavy traffic flow and covered by high rise building on both sides of roads. Prediction of the traffic noise level at Lodhi road and K.G & Tolstoy Marg are varying from 72.4 to 74 and 71.8 to 73.4 dB (A) respectively, both locations consider as silence zone by CPCB. At Nirman Vihar traffic noise level predicted 79.1 to 80.7 dB(A) in 2017 to 2032 year. Paharganj Chowk which is near the New Delhi railway station, the traffic noise level has been predicted 77.6 to 79.1 dB (A). The developed model, i.e., RLS-90 gave very close results to the measured values. Percentage difference between predicted noise level and monitored noise level was found between 0.5 to 5.75%, which indicates the best suitability and applicability of this model in city like Delhi, whereas heterogeneous kind of traffic is found. The forecasted noise level at all the locations were found much more than the permissible noise level, which indicates the mitigatory measure like noise barriers would be required at all the locations to curb the noise pollution and its associated adverse health problems.

In another study conducted by (Partheeban et al., 2022), in Chennai city on urban road traffic noise using geospatial technology, the collected data includes traffic volume, speed, and noise level in lateral and vertical directions. Noise levels were measured in 9 locations using a noise level meter. It is observed that the noise levels vary from 50 dBA to 96 dBA. The table below shows the minimum and maximum noise levels observed in all 9 locations concerning peak hours in the morning and evening. The noise observed changes according to locational characteristics of intersection and types of intersection. The maximum noise level is observed at the T. Nagar intersection, which is due to the four-arm type intersection with the value of 90.5 dBA. Mostly, noise levels were recorded maximum during morning 9.00 – 10.00 AM and evening 8.00 –9.00 PM. Road intersections are very important in noise generators in the study area compared to along the length of the road.



Sl. No	Location and type of intersection	Morning Peak Hour Noise Measured (am)				Evening Peak Hour Noise Measured			
		Peak h	Min	Peak h	Max	Peak h	Min	Peak h	Max
1	Parry's Corner (T-Junction)	7–8	63.9	8–9	86.8	5–6	74.45	8–9	89.8
2	Perambur (T-Junction)	6–7	68.1	9–10	83.9	4–5	79.30	7–8	88.5
3	Villivakkam (T-Junction)	7–8	68.5	8–9	86.8	5–6	74.45	8–9	89.8
4	Kolathur (T-Junction)	6–7	69.5	8–9	86.6	4–5	77.7	8–9	88.8
5	Adyar (T-Junction)	6–7	69.1	9–10	84.9	4–5	78.4	8–9	88.2
6	Velachery (Y–Junction)	6–7	68.5	8–9	85.6	4–5	78.7	7–8	88.7
7	Triplicane (T-Junction)	6–7	69.1	9–10	80.1	4–5	79.9	8–9	89.5
8	T. Nagar (Cross Junction)	6–7	68.1	9–10	83.9	4–5	79.3	8–9	90.5
9	Nungambakkam (Y-Junction)	6–7	68.5	9–10	83.9	4–5	79.8	7–8	88.2

Table 5: Measured Minimum and Maximum Noise Levels (dBA) in Chennai City (Partheeban et al., 2022)

In another interesting study conducted by (Garg et al., 2016), the long-term noise monitoring shows that ambient noise levels have marginally increased since past three years in the 35 locations under study in which 14 locations are in commercial zone, 5 in Industrial, 7 in residential and 9 in silence zones. The study is very helpful in ascertaining the magnitude of annual average ambient noise levels, planning for noise abatement action plans and formulation of revised ambient noise standards in Indian scenario. As per (Garg et al., 2016), automatic Data Collecting Remote Stations comprising of noise monitoring sensor, data logger, internal

Global Positioning System (GPS), microprocessor, protection circuits, communication modem, power source including battery and charge regulator for solar panel or mains AC power supply were used to monitor the city ambient noise at various locations. Below Fig. 5 shows the pictorial view of typical remote noise monitoring station installed at a commercial zone in Delhi city. The noise monitoring data can be viewed on the website http://www.cpcbnoise.com developed exclusively for showing the daily ambient sound levels for all the 35 sites under consideration. For dissemination of the real-time information to public, bright LED display boards are installed at various locations. Fig. 6 shows one such LED display installed outside the CPCB, Delhi office.

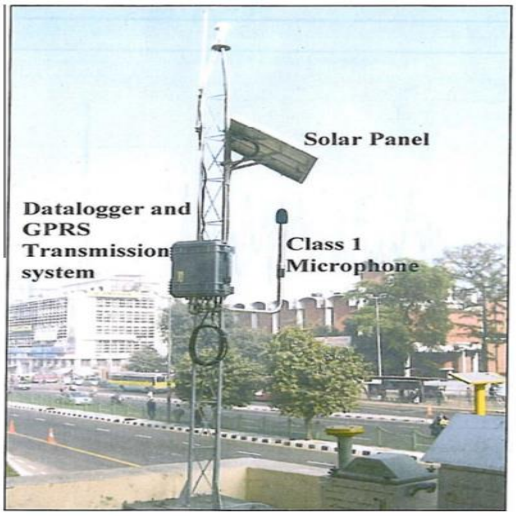
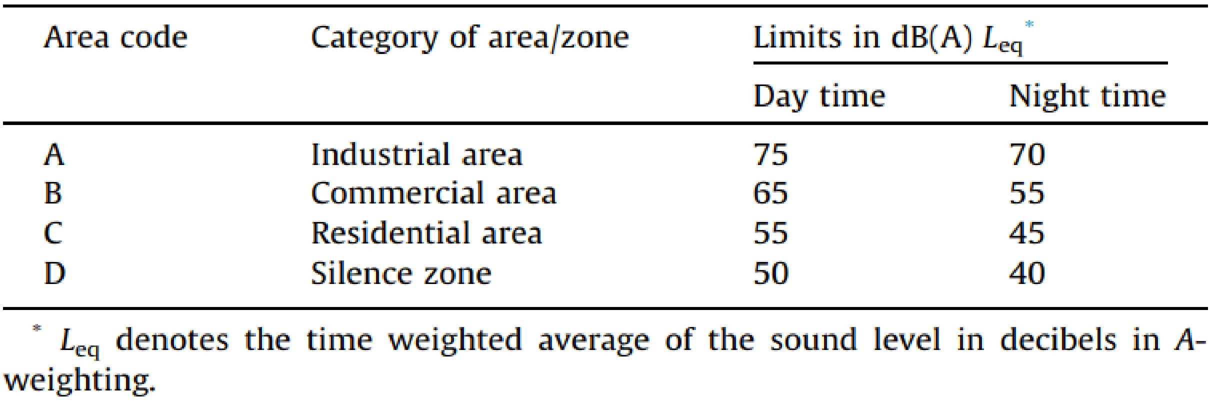


Figure 7: Typical remote noise monitoring station for CPCB NANMN (National Ambient Noise Monitoring Network) project (Garg et al., 2016)

Figure 8: LED display outside CPCB office in Delhi showing the ambient sound levels (dBA) (Garg et al., 2016)

The Day equivalent level, L_{Day} and $_{Night}$ equivalent level, L_{night} is calculated from the 24 h noise data for each day of the year. The day-time means from 6.00 a.m. to 10.00 p.m., while the night time means from 10.00 p.m. to 6.00 a.m. It may be noted that the ambient air quality standards in respect of noise recommended in terms of L_{day} and L_{night} as enlisted in Table 5. The silence zone is an area comprising not less than 100 m around hospitals, educational institutions, courts, religious places or any other area which is declared as such by the competent authority. Mixed categories of areas may be declared as one of as one of the four mentioned categories in Table 5 by the competent authority.

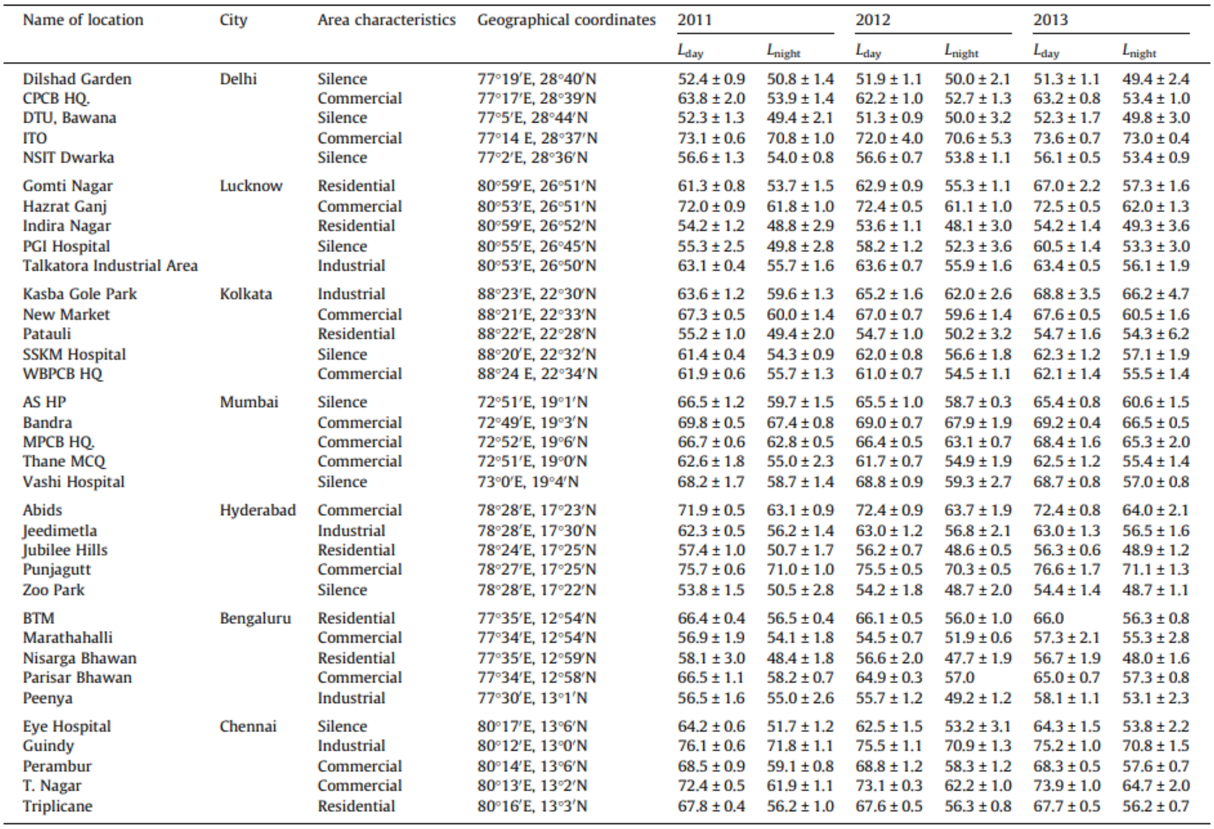


Area code	Category of area/zone	Limits in dB(A) L_{eq} *	
		Day time	Night time
A	Industrial area	75	70
B	Commercial area	65	55
C	Residential area	55	45
D	Silence zone	50	40

* L_{eq} denotes the time weighted average of the sound level in decibels in A-weighting.

Table 6: Ambient noise level standards in respect of noise in India (Garg et al., 2016)

The level of significance for assessing noise impacts has been identified as a L_{dn} of 65 dB(A); whereby a 65 dB(A) L_{dn} is described as the onset of a normally unacceptable zone. Table 6 enlists the annual average ambient levels, L_{day} and L_{night} for three years (2011–2013) for 35 noise monitoring stations installed under NANMN program across the seven major cities in India. These observations are thus helpful in analyzing the status of ambient noise levels exclusively in terms of city and zone wise and the comparison of ambient noise levels with the standards.



Name of location	City	Area characteristics	Geographical coordinates	2011		2012		2013	
				L_{day}	L_{night}	L_{day}	L_{night}	L_{day}	L_{night}
Dilshad Garden	Delhi	Silence	77°19′E, 28°40′N	52.4 ± 0.9	50.8 ± 1.4	51.9 ± 1.1	50.0 ± 2.1	51.3 ± 1.1	49.4 ± 2.4
CPCB HQ.		Commercial	77°17′E, 28°39′N	63.8 ± 2.0	53.9 ± 1.4	62.2 ± 1.0	52.7 ± 1.3	63.2 ± 0.8	53.4 ± 1.0
DTU, Bawana		Silence	77°5′E, 28°44′N	52.3 ± 1.3	49.4 ± 2.1	51.3 ± 0.9	50.0 ± 3.2	52.3 ± 1.7	49.8 ± 3.0
ITO		Commercial	77°14 E, 28°37′N	73.1 ± 0.6	70.8 ± 1.0	72.0 ± 4.0	70.6 ± 5.3	73.6 ± 0.7	73.0 ± 0.4
NSIT Dwarka		Silence	77°2′E, 28°36′N	56.6 ± 1.3	54.0 ± 0.8	56.6 ± 0.7	53.8 ± 1.1	56.1 ± 0.5	53.4 ± 0.9
Gomti Nagar	Lucknow	Residential	80°59′E, 26°51′N	61.3 ± 0.8	53.7 ± 1.5	62.9 ± 0.9	55.3 ± 1.1	67.0 ± 2.2	57.3 ± 1.6
Hazrat Ganj		Commercial	80°53′E, 26°51′N	72.0 ± 0.9	61.8 ± 1.0	72.4 ± 0.5	61.1 ± 1.0	72.5 ± 0.5	62.0 ± 1.3
Indira Nagar		Residential	80°59′E, 26°52′N	54.2 ± 1.2	48.8 ± 2.9	53.6 ± 1.1	48.1 ± 3.0	54.2 ± 1.4	49.3 ± 3.6
PGI Hospital		Silence	80°55′E, 26°45′N	55.3 ± 2.5	49.8 ± 2.8	58.2 ± 1.2	52.3 ± 3.6	60.5 ± 1.4	53.3 ± 3.0
Talkatora Industrial Area		Industrial	80°53′E, 26°50′N	63.1 ± 0.4	55.7 ± 1.6	63.6 ± 0.7	55.9 ± 1.6	63.4 ± 0.5	56.1 ± 1.9
Kasba Gole Park	Kolkata	Industrial	88°23′E, 22°30′N	63.6 ± 1.2	59.6 ± 1.3	65.2 ± 1.6	62.0 ± 2.6	68.8 ± 3.5	66.2 ± 4.7
New Market		Commercial	88°21′E, 22°33′N	67.3 ± 0.5	60.0 ± 1.4	67.0 ± 0.7	59.6 ± 1.4	67.6 ± 0.5	60.5 ± 1.6
Patauli		Residential	88°22′E, 22°28′N	55.2 ± 1.0	49.4 ± 2.0	54.7 ± 1.0	50.2 ± 3.2	54.7 ± 1.6	54.3 ± 6.2
SSKM Hospital		Silence	88°20′E, 22°32′N	61.4 ± 0.4	54.3 ± 0.9	62.0 ± 0.8	56.6 ± 1.8	62.3 ± 1.2	57.1 ± 1.9
WBPCB HQ		Commercial	88°24 E, 22°34′N	61.9 ± 0.6	55.7 ± 1.3	61.0 ± 0.7	54.5 ± 1.1	62.1 ± 1.4	55.5 ± 1.4
AS HP	Mumbai	Silence	72°51′E, 19°1′N	66.5 ± 1.2	59.7 ± 1.5	65.5 ± 1.0	58.7 ± 0.3	65.4 ± 0.8	60.6 ± 1.5
Bandra		Commercial	72°49′E, 19°3′N	69.8 ± 0.5	67.4 ± 0.8	69.0 ± 0.7	67.9 ± 1.9	69.2 ± 0.4	66.5 ± 0.5
MPCB HQ.		Commercial	72°52′E, 19°6′N	66.7 ± 0.6	62.8 ± 0.5	66.4 ± 0.5	63.1 ± 0.7	68.4 ± 1.6	65.3 ± 2.0
Thane MCQ		Commercial	72°51′E, 19°0′N	62.6 ± 1.8	55.0 ± 2.3	61.7 ± 0.7	54.9 ± 1.9	62.5 ± 1.2	55.4 ± 1.4
Vashi Hospital		Silence	73°0′E, 19°4′N	68.2 ± 1.7	58.7 ± 1.4	68.8 ± 0.9	59.3 ± 2.7	68.7 ± 0.8	57.0 ± 0.8
Abids	Hyderabad	Commercial	78°28′E, 17°23′N	71.9 ± 0.5	63.1 ± 0.9	72.4 ± 0.9	63.7 ± 1.9	72.4 ± 0.8	64.0 ± 2.1
Jeedimetla		Industrial	78°28′E, 17°30′N	62.3 ± 0.5	56.2 ± 1.4	63.0 ± 1.2	56.8 ± 2.1	63.0 ± 1.3	56.5 ± 1.6
Jubilee Hills		Residential	78°24′E, 17°25′N	57.4 ± 1.0	50.7 ± 1.7	56.2 ± 0.7	48.6 ± 0.5	56.3 ± 0.6	48.9 ± 1.2
Punjagutt		Commercial	78°27′E, 17°25′N	75.7 ± 0.6	71.0 ± 1.0	75.5 ± 0.5	70.3 ± 0.5	76.6 ± 1.7	71.1 ± 1.3
Zoo Park		Silence	78°28′E, 17°22′N	53.8 ± 1.5	50.5 ± 2.8	54.2 ± 1.8	48.7 ± 2.0	54.4 ± 1.4	48.7 ± 1.1
BTM	Bengaluru	Residential	77°35′E, 12°54′N	66.4 ± 0.4	56.5 ± 0.4	66.1 ± 0.5	56.0 ± 1.0	66.0	56.3 ± 0.8
Marathahalli		Commercial	77°34′E, 12°54′N	56.9 ± 1.9	54.1 ± 1.8	54.5 ± 0.7	51.9 ± 0.6	57.3 ± 2.1	55.3 ± 2.8
Nisarga Bhawan		Residential	77°35′E, 12°59′N	58.1 ± 3.0	48.4 ± 1.8	56.6 ± 2.0	47.7 ± 1.9	56.7 ± 1.9	48.0 ± 1.6
Parisar Bhawan		Commercial	77°34′E, 12°58′N	66.5 ± 1.1	58.2 ± 0.7	64.9 ± 0.3	57.0	65.0 ± 0.7	57.3 ± 0.8
Peenya		Industrial	77°30′E, 13°1′N	56.5 ± 1.6	55.0 ± 2.6	55.7 ± 1.2	49.2 ± 1.2	58.1 ± 1.1	53.1 ± 2.3
Eye Hospital	Chennai	Silence	80°17′E, 13°6′N	64.2 ± 0.6	51.7 ± 1.2	62.5 ± 1.5	53.2 ± 3.1	64.3 ± 1.5	53.8 ± 2.2
Guindy		Industrial	80°12′E, 13°0′N	76.1 ± 0.6	71.8 ± 1.1	75.5 ± 1.1	70.9 ± 1.3	75.2 ± 1.0	70.8 ± 1.5
Perambur		Commercial	80°14′E, 13°6′N	68.5 ± 0.9	59.1 ± 0.8	68.8 ± 1.2	58.3 ± 1.2	68.3 ± 0.5	57.6 ± 0.7
T. Nagar		Commercial	80°13′E, 13°2′N	72.4 ± 0.5	61.9 ± 1.1	73.1 ± 0.3	62.2 ± 1.0	73.9 ± 1.0	64.7 ± 2.0
Triplicane		Residential	80°16′E, 13°3′N	67.8 ± 0.4	56.2 ± 1.0	67.6 ± 0.5	56.3 ± 0.8	67.7 ± 0.5	56.2 ± 0.7

Table 7: Annual average ambient levels, L_{day} and L_{night} for three years for 35 noise monitoring stations installed under NANMN program across seven major cities in India (Garg et al., 2016)

The study shows that out of 35 sites under consideration across the seven major cities of India, the 9 sites including four commercial and five industrial meets the ambient noise standards. It can be observed that Lday levels varied from 60 to 70 dB(A) for 19 sites, while 18 sites experienced Lnight levels between 50 and 60 dB(A). The continuous monitoring since past three years shows that no site lying under residential and silence zone meets the ambient noise standards.

2.3 Various Experiments Conducted to Carve Out Suitable Sound Level

Many experiments were conducted across the world to find out the most suitable sound levels (dB) that would be helpful to identify the presence of EVs. The approach taken to define the levels can be broadly classified in two groups. First, by doing survey among EV owners and second by conducting various field tests.

In the ECE regulation, the minimum sound level at 10 km/h is set to 50 dB and 56 dB at 20 km/h at 2m distance from the center line of the driving lane. The maximum sound level (of AVAS) shall never exceed 75 dB, independent of speed. These requirements are set so that the sound from these quiet vehicles shall not be higher than ICE vehicles, but at the same time give enough sound to warn pedestrians/bicyclists, especially when the background sound levels are low (Berge and Haukland, 2019). The regulations define AVAS, with respect to the minimum sound required in the 1/3rd octave bands from 160 to 5000 Hz. The pitch of the sound shall also increase with increasing speed, simulating the increase in tonality of a combustion engine with increasing rpms. A different sound when the vehicle is in reverse mode is also required. The European Blind Union (among several other) has expressed concern of the present UN ECE regulation. The main objections are: - the present allowance of a pause switch should be abandoned - the AVAS should be active up to 30 km/h (as in the US) - AVAS should be mandatory also when the vehicle is stationary. The removal of the pause switch has already been proposed, both by EU and in Geneva (UN ECE) and it is likely that this option will be removed before the introduction of the regulations (Berge and Haukland, 2019).

In another study conducted by (Fagerlönn et al., 2018) was to investigate whether AVAS following the UNECE requirements affect people’s acceptance of EVs. The approach of the study was the construction of an immersive experience where people could experience potential future traffic scenes. Thirty-nine participants (15 females and 24 males), divided into five groups, participated in the experiment. Their mean age was 40.1 years (SD = 10.3). Two people reported some form of hearing impairment (weak tinnitus), and 20 participants reported that they worked with vehicle development in some form. The experiment was conducted in a listening room at Scania in Sweden. The listening room is equipped with a multi-channel system with seven satellite speakers (Genelec 8260) and a subwoofer (Genelec 7271A). Two of the satellite speakers in the front of the room played sounds from the EV and ICE vehicles used in the study, while the remaining satellite speakers were used to play ambient city noises.

Figure 9: Listening room used for the Evaluation (Fagerlönn et al., 2018)

Designing the sounds based on different strategies allowed the project to investigate whether different types of AVAS have different effects.

Audibility: This group consists of design concepts with clear tonal components. The design strategy corresponds to some existing AVAS solutions in the European market, such as the one used in the Nissan Leaf.

Operation: These AVAS sounds were designed to resemble the natural operating sounds of an electric car. These are designed to feel less like artificial (added) sounds.

Engine: These AVAS sounds were designed to remind people of an ICE. The strategy was promoted by the Swedish Association of the Visually Impaired.

Temporal: These AVAS sounds use sound bursts (pulsations) to represent speed changes at low speeds. The intervals between bursts changed according to the speed of the vehicle (faster speed – shorter interval).

In another interesting experiment conducted by (Kosuge et al., 2019), the experiments were divided in two portions whilst experiment-1 being sound used in recognizing the approach of a quiet vehicle and experiment-2 being effect of designing awareness. The experiment was conducted on a traffic comprehensive test road at Nihon University on 16 October 2017 using a Prius (TOYOTA) as an example of a quiet vehicle. The positions of the quiet vehicle and participants are shown in Fig. 8. The quiet vehicle traveled from line AA′ to line BB′ at a constant speed of 15 km/h, which was within the operational speed range of the AVAS and ensured the safety of participants. The vehicle speed was measured using a speed gun. The participants stood 2 m from the center line of the quiet vehicle near line PP′ in Fig. 8, forming a line with 1-m intervals. The experimental scene is shown in Fig. 9. So that the participants paid attention to the sound emitted from the quiet vehicle, the participants stood with their backs to the vehicle and closed their eyes during the experiment. The quiet vehicle passed behind the participants three times. The participants were 11 male students and one female student attending Nihon University and having an average age of 21.7 years. The experiment was recorded using a video camera.

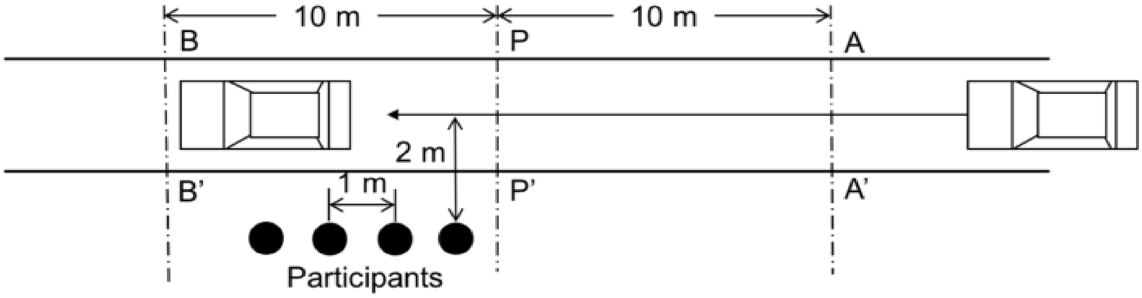
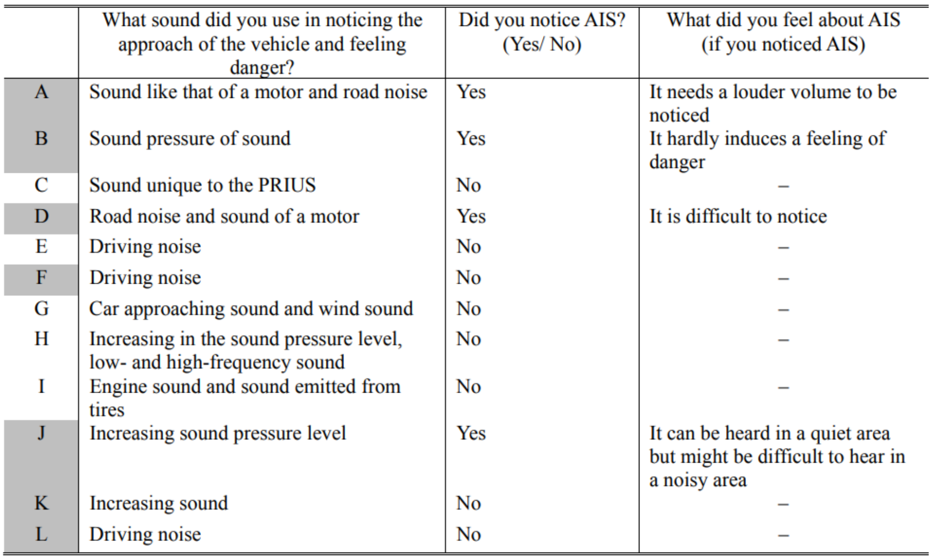


Figure 10: Positions of participants and the quiet vehicle (Kosuge et al., 2019)

Figure 11: Experimental Scene (Kosuge et al., 2019)

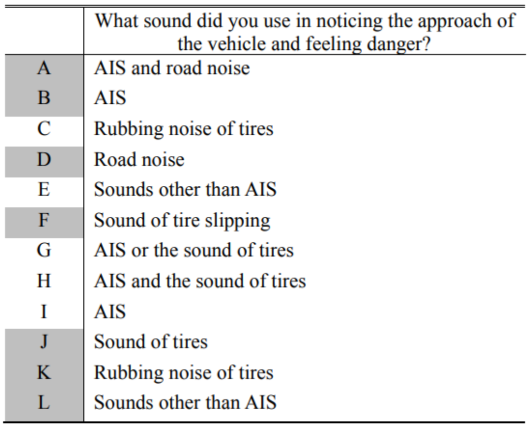
To avoid the participants intentionally directing their attention to the AIS *(approach information sound)*, the experimenters explained that “This experiment aims to measure the distance at which pedestrians sense the danger of an approaching vehicle”. The participants were required to raise their hand when they felt they were in danger from the approaching vehicle. The experiment was conducted twice with the emitting of AIS. The experimenter then conducted an interview in which participants were asked what sound they used in noticing the approach of the vehicle and feeling danger. Experimental results obtained from the interview are given in Table 7. Each participant is indicated by a letter. Those who knew about AIS before participating in the experiment are indicated by colored cells. Table 7 shows that no participant answered that he or she noticed the approach of the quiet vehicle and felt danger because of the AIS, and rather, they used other sounds, such as the sound of the motor, road noise, and wind noise. One participant referred to an "engine sound" even though the quiet vehicle did not drive with an engine. The sounds listed by participants are emitted from not only quiet vehicles but also vehicles with internal-combustion engines. The results suggest that the participants might use these familiar sounds as clues to the approach of the quiet vehicle. Participants who did not notice the AIS reported that "I did not recognize the sound as a notification sound" and "I noticed sounds such as road noise and running noise other that the AIS". As reported in a previous study, it might be difficult for people to notice the AIS without recognizing the sound. However, participants who knew about AIS before participating in the experiment also reported that they did not use AIS in noticing the approach of the quiet vehicle but other sound emitted by the vehicle. The recognition of the AIS might not affect the use of sound in noticing the approach of vehicles and feeling the danger posed by vehicles. To address this point, the same experiment was conducted after providing the opportunity for participants to recognize and hear the AIS as Experiment 2.



	What sound did you use in noticing the approach of the vehicle and feeling danger?	Did you notice AIS? (Yes/ No)	What did you feel about AIS (if you noticed AIS)
A	Sound like that of a motor and road noise	Yes	It needs a louder volume to be noticed
B	Sound pressure of sound	Yes	It hardly induces a feeling of danger
C	Sound unique to the PRIUS	No	–
D	Road noise and sound of a motor	Yes	It is difficult to notice
E	Driving noise	No	–
F	Driving noise	No	–
G	Car approaching sound and wind sound	No	–
H	Increasing in the sound pressure level, low- and high-frequency sound	No	–
I	Engine sound and sound emitted from tires	No	–
J	Increasing sound pressure level	Yes	It can be heard in a quiet area but might be difficult to hear in a noisy area
K	Increasing sound	No	–
L	Driving noise	No	–

Table 8: Results of an interview conducted after the experiment (Kosuge et al., 2019)

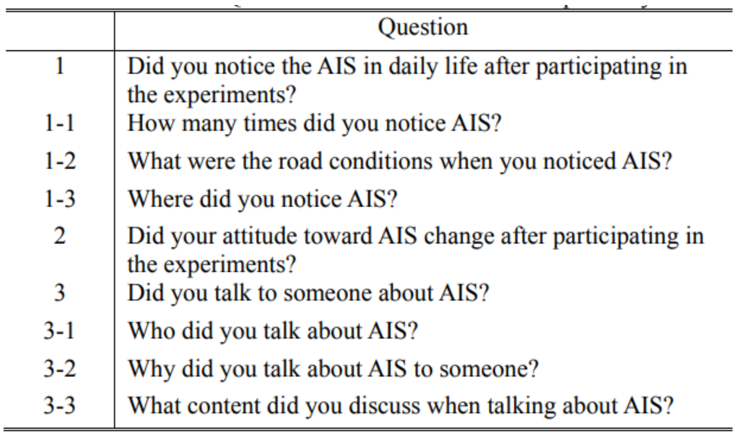
In the experiment 2: Effect of designing awareness, the experimental conditions and method were the same as those in Experiment 1. The experimenters explained the AIS to the participants and the participants heard the AIS repeatedly until they could recognize it before the experiment began. Experimental results are given in Table 8. As in Table 7, each participant is assigned a letter and those who knew about the AIS before participating in the study are indicated by colored cells. Half of the participants answered that they used the AIS in noticing the approach of the quiet vehicle and feeling danger, and three of them (participants G, H, and I) did not know about the AIS before participating in the study. This result suggests that providing the opportunity to hear and recognize the AIS (referred to as the design of awareness in a previous study) can contribute to the use of the AIS in noticing the approach of a vehicle. In Experiment 1, physical quantities such as the volume of sound and abstract sounds such as driving noise were reported as factors used in recognizing the approach of a quiet vehicle and feeling danger. Meanwhile, specific sounds such as the AIS and sound of tires were reported as factors in Experiment 2. As observed in Experiment 1, other participants in Experiment 2 did not use the AIS. These participants reported that the AIS did not notify them of the approach of a vehicle enough to feel danger. They therefore use familiar sounds such as road noise rather than the AIS in noticing the approach of a quiet vehicle. Further studies on various aspects of the design of AIS are required.



	What sound did you use in noticing the approach of the vehicle and feeling danger?
A	AIS and road noise
B	AIS
C	Rubbing noise of tires
D	Road noise
E	Sounds other than AIS
F	Sound of tire slipping
G	AIS or the sound of tires
H	AIS and the sound of tires
I	AIS
J	Sound of tires
K	Rubbing noise of tires
L	Sounds other than AIS

Table 9: Sounds that participants used to notice the approach of a quiet vehicle (Kosuge et al., 2019)

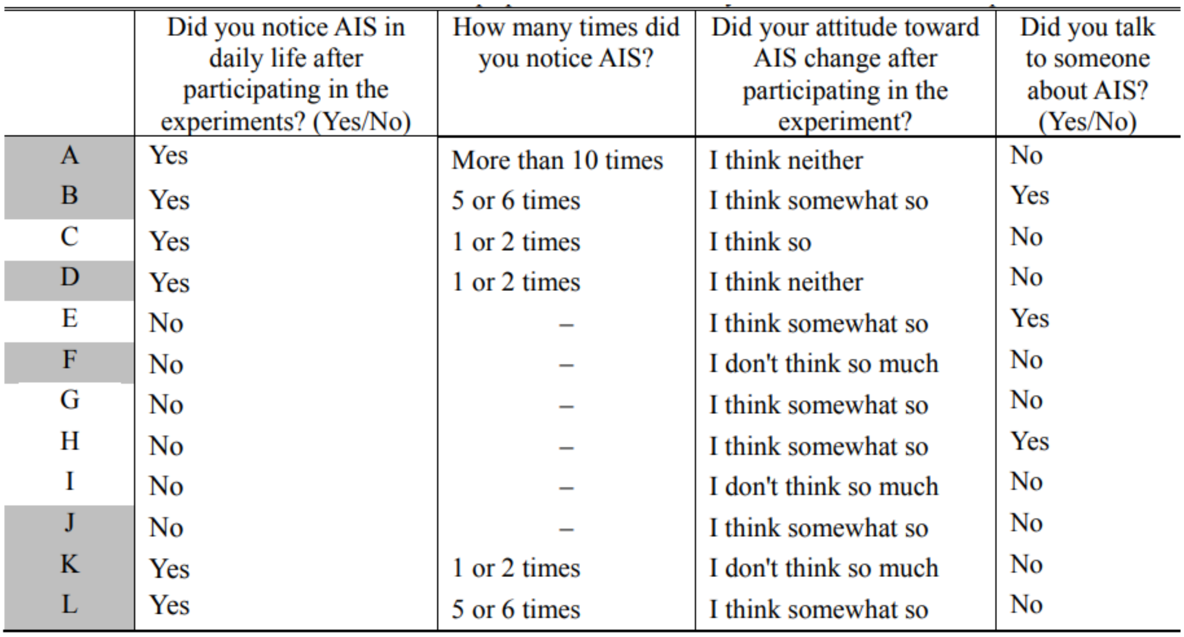
The results of Experiments 1 and 2 reveal that the design of awareness is effective in improving the recognition of AIS and changing pedestrians' attitude toward sound. To discuss the long-term effect of this design of awareness, the following survey was conducted 1 and 3 months after the experiments. The questionnaire survey was conducted using Google Form provided by Google. The experimenters sent the URL of the Google Form by e-mail and required participants to complete the questionnaire survey via the Internet. The survey questions are given in Table 9. Up to nine questions were asked according to the answers given.



	Question
1	Did you notice the AIS in daily life after participating in the experiments?
1-1	How many times did you notice AIS?
1-2	What were the road conditions when you noticed AIS?
1-3	Where did you notice AIS?
2	Did your attitude toward AIS change after participating in the experiments?
3	Did you talk to someone about AIS?
3-1	Who did you talk about AIS?
3-2	Why did you talk about AIS to someone?
3-3	What content did you discuss when talking about AIS?

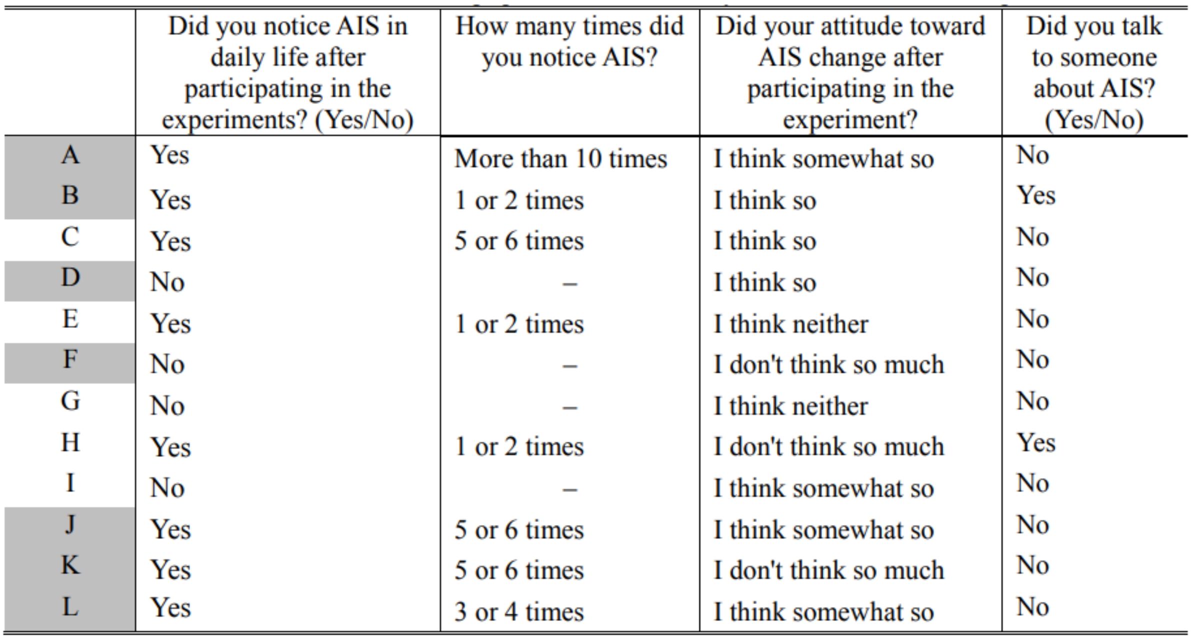
Table 10: Questions asked in the follow-up survey (Kosuge et al., 2019)

Results of the questionnaire survey completed 1 month after the experiments are given in Table 10. Each participant is indicated by a letter and those who knew about the AIS before participating in the study are indicated by colored cells. The table shows that six participants (A, B, C, D, K, and L) noticed and heard the AIS in daily life (i.e., under noisy conditions), whereas the experiment was conducted under quiet conditions. However, only some reported that their attitude toward the AIS changed and that they consciously listened to the sound. A change in attitude toward the AIS might not necessarily affect the participants' awareness of the AIS. Meanwhile, participants who were not aware of the AIS in daily life reported that their attitude toward the AIS changed after participating in the experiment (participants E, G, H, and J). Their participation in the experiment and opportunity to recognize and hear the AIS affected the participants’ attitude toward the AIS. Furthermore, three participants (B, E, and H) reported that they had talked to friends or someone about AIS after participating in the experiment. A previous study showed that information from other people is most effective in terms of recognizing AIS. Therefore, participating in the experiment and the effect of designing awareness could improve the recognition of AIS. These results again confirm the effect of designing awareness on AIS reported in a previous study. The design of awareness contributed to improving the recognition of and changing the attitude toward AIS. Results of the questionnaire survey completed 3 months after the experiments are given in Table 11. Again, each participant is indicated by a letter and those who knew about the AIS before participating in the study are indicated by colored cells. Three participants (E, H, and J) reported that they noticed AIS in daily life even though they did not 1 month after the experiments. The number of times that five participants (C, E, H, J, and K) noticed AIS increased from that reported 1 month after the experiment. As observed in Table 10, more than half the participants stated that their attitude changed in that they consciously heard AIS. The design of awareness thus has a long-term effect. In the interview conducted after Experiment 2, few participants answered that they noticed the approach of the quiet vehicle and felt danger through AIS. However, six participants (C, D, E, J, K, and L) reported that they noticed AIS in daily life 1 or 3 months after participating in the experiment. Two of them (participants C and E), who did not know about AIS before participating in the study, also reported that their attitude toward AIS changed after the experiments. The results show that providing the opportunity to recognize and hear AIS, or in other words, the design of awareness, can change the participants’ recognition of and attitude toward AIS over the long term and contribute to improving others' recognition of AIS.



	Did you notice AIS in daily life after participating in the experiments? (Yes/No)	How many times did you notice AIS?	Did your attitude toward AIS change after participating in the experiment?	Did you talk to someone about AIS? (Yes/No)
A	Yes	More than 10 times	I think neither	No
B	Yes	5 or 6 times	I think somewhat so	Yes
C	Yes	1 or 2 times	I think so	No
D	Yes	1 or 2 times	I think neither	No
E	No	–	I think somewhat so	Yes
F	No	–	I don't think so much	No
G	No	–	I think somewhat so	No
H	No	–	I think somewhat so	Yes
I	No	–	I don't think so much	No
J	No	–	I think somewhat so	No
K	Yes	1 or 2 times	I don't think so much	No
L	Yes	5 or 6 times	I think somewhat so	No

Table 11: Results of the follow-up questionnaire survey: 1 month after the experiment (Kosuge et al., 2019)



	Did you notice AIS in daily life after participating in the experiments? (Yes/No)	How many times did you notice AIS?	Did your attitude toward AIS change after participating in the experiment?	Did you talk to someone about AIS? (Yes/No)
A	Yes	More than 10 times	I think somewhat so	No
B	Yes	1 or 2 times	I think so	Yes
C	Yes	5 or 6 times	I think so	No
D	No	–	I think so	No
E	Yes	1 or 2 times	I think neither	No
F	No	–	I don't think so much	No
G	No	–	I think neither	No
H	Yes	1 or 2 times	I don't think so much	Yes
I	No	–	I think somewhat so	No
J	Yes	5 or 6 times	I think somewhat so	No
K	Yes	5 or 6 times	I don't think so much	No
L	Yes	3 or 4 times	I think somewhat so	No

Table 12: Results of the follow-up questionnaire survey: 3 months after the experiment (Kosuge et al., 2019)

The two experiments conducted in this study revealed that pedestrians who did not recognize AIS noticed the approach of a quiet vehicle and felt danger not through AIS but through other, familiar sounds, such as wind noise and road noise, which are also emitted by vehicles having internal combustion engines. After providing the opportunity to hear and recognize AIS (in the design of awareness), half the participants began using AIS in noticing the approach of quiet vehicles. However, others reported that AIS was not enough to inform them of the approach of quiet vehicles, and they thus did not use it. Further studies on the design of a more noticeable AIS are needed. Surveys conducted 1 and 3 months after the experiments showed the long-term effect of designing awareness. About a half of participants noticed AIS in daily life and recognized that their attitude toward AIS had changed such that they listened to the sound consciously after participating in the experiments. Further studies on the design of AIS, including designing awareness, would contribute to and improve 7185 the recognition of AIS.

2.4 Survey Among EV Owners

As per Berge and Haukland, 2019, in 2017, the Association of electric cars in Norway conducted a survey among their members on behalf of SINTEF. The main purpose was to investigate their views on AVAS as a safety issue for pedestrians/bicyclists. A questionnaire was sent out to 6728 owners of EVs and a total of 3280 (48,8%) responded to the questions. The main findings were: -

1. Approximately 1/3rd of the EVs were delivered with AVAS installed. For some of the EVs, AVAS could be chosen as optional equipment to a price of around 100 €. Most of the EVs with AVAS were delivered with a "pause switch", allowing the driver to disengage AVAS during driving. However, the AVAS was always turned on, when restarting the car.
2. 56 % of the respondents have had their EV less than 2 years.
3. 49 % were introduced to AVAS and the "pause" function when they bought the car, and 41 % were not (the rest did not remember).
4. About 19 % were motivated NOT to use the pause switch during operation, while 60 % were not given such motivation.

5. 64 % do not consider AVAS as annoying from the driver's seat, while 31 % found the sound annoying.

On the question if they ever had experienced any dangerous situation with pedestrians/bicyclists due to lack of sound (or very low sound level) from their car, the response was as follows:

1. 83 % said no, never 11 % yes, more than once, and 6 % yes, once. This is quite similar response to an investigation made by the association in 2012, where the numbers were 81, 13 and 6 %. It is interesting, however, to see the results when they are grouped into two: those who have AVAS and those who do not have. For the group with AVAS, 18 % answer that they have experience dangerous situations more than once, while only 6 % of those without AVAS have experience this more than once. It is also a clear majority (87 %) of those without AVAS who never have experienced any dangerous situations, compared to 75 % of those who have AVAS. This may indicate that AVAS, as implemented, do not have any major influence on the safety situation for pedestrians.
2. 66 % of the dangerous situations occurred in an urban street with very little traffic. About 40 % in a parking area/house and 30 % in a busy city street.
3. 46 % believed that AVAS is not a good technology to warn vulnerable groups, while 36 % approved the technology. 18 % had no opinion.
4. About 70 % were positive to an alternative technology, such as a system where AVAS was engaged only when needed, for example based on input from other driver assistant systems (camera, GPS, etc.). 20 % were negative.
5. A majority (49 %) were also positive to a technology where a signal was given only to those who wanted a warning, for example through an audible signal to or a vibration of a smart phone. 41 % were negative.

In addition to the defined questions, there was also a possibility to comment on the issue of AVAS and silent vehicles. This opportunity was used by many of the respondents. Obviously, a topic of interest! The comments can be summarized as follows: -

1. Most of the respondents claimed that their driving style had changed driving an electric car. They are more conscious that their car is creating less sound at low speeds for pedestrians/bicyclists and adopt their driving behaviour to this fact. They claimed that (young?) people with headphones listening to music were the most important people to be aware of not hearing their car. Patience from the driver could avoid most dangerous situations.
2. Many of the car owners would like to have a possibility to use a warning signal such as the bell of a bicycle to warn people. One person suggested a change in the behaviour
3. of the car horn: A short pressure could give a low volume warning signal, while a long pressure could give the normal sound. As a general comment to the survey, the association said that this investigation indicated that AVAS could be a false safety issue (make the car owner to believe that AVAS always could prevent accidents). The survey shows that there is no indication that cars without AVAS are more involved in accidents than cars with AVAS. For example, 92 % of Tesla owners answered that they never have been in any dangerous situations with pedestrians/bicyclists.

2.5 Field Tests Conducted

Many researchers have tried to understand the best possible acoustic noise that a silent EV should generate at various vehicle speeds. However, to understand it well it’s important to also consider the ambient traffic noise especially with the co-existence of ICE vehicles. Under these conditions the test results should suggest the necessary sound dB(A) required to be generated by the vehicle AVAS at various vehicle speeds. Other parameters that influence the recommendations are human experiences of various age groups and also pedestrians with visual impairment. The type of sounds that are considered is also another important aspect that needs to be researched to identify the suitable ones.

In a field test conducted by (Berge and Haukland, 2019), A panel of 4 test persons were placed along the road at a defined distance from the 0 m-line, as shown in the figure 10. At the 0 m-line, a lidar and a microphone was placed. The microphone at 2 m distance from the center line of the road, measured the sound level continuously when the car approached the test area.

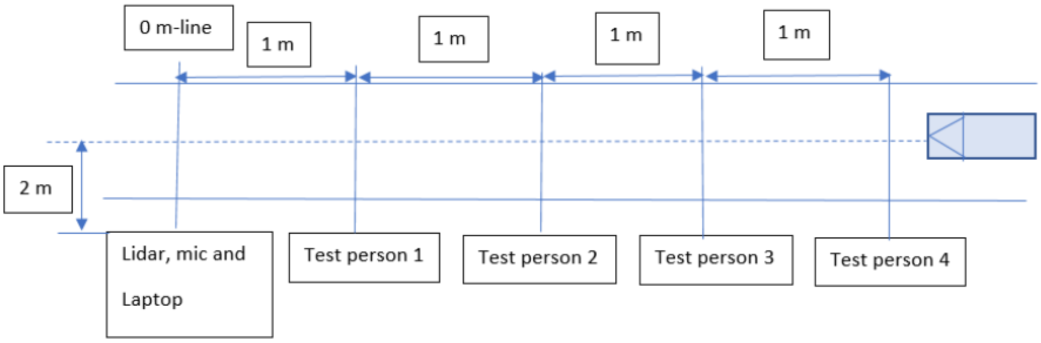


Figure 12: Layout of test area (Berge and Haukland, 2019)

The lidar works like a radar, except using the reflection and spread of a light signal instead of radio waves. The lidar does not require a reflection mirror, as needed for a laser-based system. The lidar gives information about location and speed of the car. All test persons were equipped with a button to be activated whenever they could hear the car approaching. All signals from these buttons, the signal from the lidar and the microphone signal was recorded to the same data file on the laptop, using a program made with LabVIEW. This simplified the post-analysis of the measurement data. The signal from the button, corrected for the individual position of the test person (figure 12) defines the detection distance of the car from the 0 m-line.

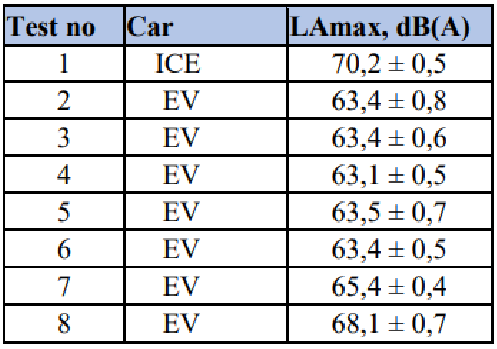
Figure 13: Test persons located on the road side (Berge and Haukland, 2019)

Table 13 below gives and overview of the test persons, gender, age and their visual ability used by (Berge and Haukland, 2019). All the normal seeing people had sleep shades during the test. Since only the hearing was used to detect the vehicle, it would have been interesting also to include a hearing test of all the participants.

Test person no	Gender	Age	Visual condition
1	M	75	Normal
2	F	55	Blind
3	F	58	Visually impaired (ca.5 %)
4	M	62	Normal
5	M	67	Normal
6	M	54	Blind
7	M	28	Normal
8	M	28	Normal

Table 13: Overview of the test persons, gender, age and their visual ability (Berge and Haukland, 2019)

Two cars were used for the test. As an ICE reference car: a VW Caddy, with a diesel engine and manual transmission. During the test, only 2nd gear was used at the speed of 20 km/h. The electric vehicle (EV) was Nissan e-NV 200. This is a rather large EV with 7 seats. Tires on the EV: Goodyear Efficient Grip 185/65 R15. The Nissan car was equipped with standard AVAS from the manufacturer, including a pause switch allowing a test of the car without AVAS engaged. It is not known if this AVAS fulfill the UN ECE or the US regulations. The sound level of the car was measured during the pass-by for each test. The maximum A-weighted sound level and the standard deviation is given in table 14, as the average of 5 runs.



Test no	Car	LAmax, dB(A)
1	ICE	70,2 ± 0,5
2	EV	63,4 ± 0,8
3	EV	63,4 ± 0,6
4	EV	63,1 ± 0,5
5	EV	63,5 ± 0,7
6	EV	63,4 ± 0,5
7	EV	65,4 ± 0,4
8	EV	68,1 ± 0,7

Table 14: Maximum weighted sound level LAmax dB(A) with standard deviation, Speed : 20km/h (Berge and Haukland, 2019)

The requirements in the regulations for minimum sound level at 10 km/h are 50 dB and 56 dB at 20 km/h. This was met for all test conditions, as shown in the above table. The ICE car has a maximum sound level approximately 7 dB higher than the EV, when the EV has no AVAS engaged. Using the buttons, the detection time/distance to the 0 m-line was recorded for each of the test persons. This detection time/distance can then be an indicator on the margin of the time needed for a person to decide if it safe to cross a street or not. The distance could also be a measure for the time needed for a car to break and completely stop, in order to avoid a collision with a person. In the US regulation, this safety distance is set to 5 m, when a car is driving at 10 km/h and 11 m when the car is driving at 20 km/h. 11 m is equivalent to a safety margin of approximately 2 seconds when the car is driving at 20 km/h (~5,6 m/s). In (Berge and Haukland, 2019) analysis, they have set the safety margin to 11 m. If any of the test persons activated their button less than 2 seconds before the car crossed the 0 m-line, it would mean a possible dangerous situation. An example of the resulting analysis is shown in figure 14. In this case, the AVAS signal is set to 50 dB and background noise level to 50 dB. 0 second is at the 0 m-line in figure 10. The location of the points of detection for the 4 test persons is only related to the x-axis (time) and not to the level of sound (y-axis).

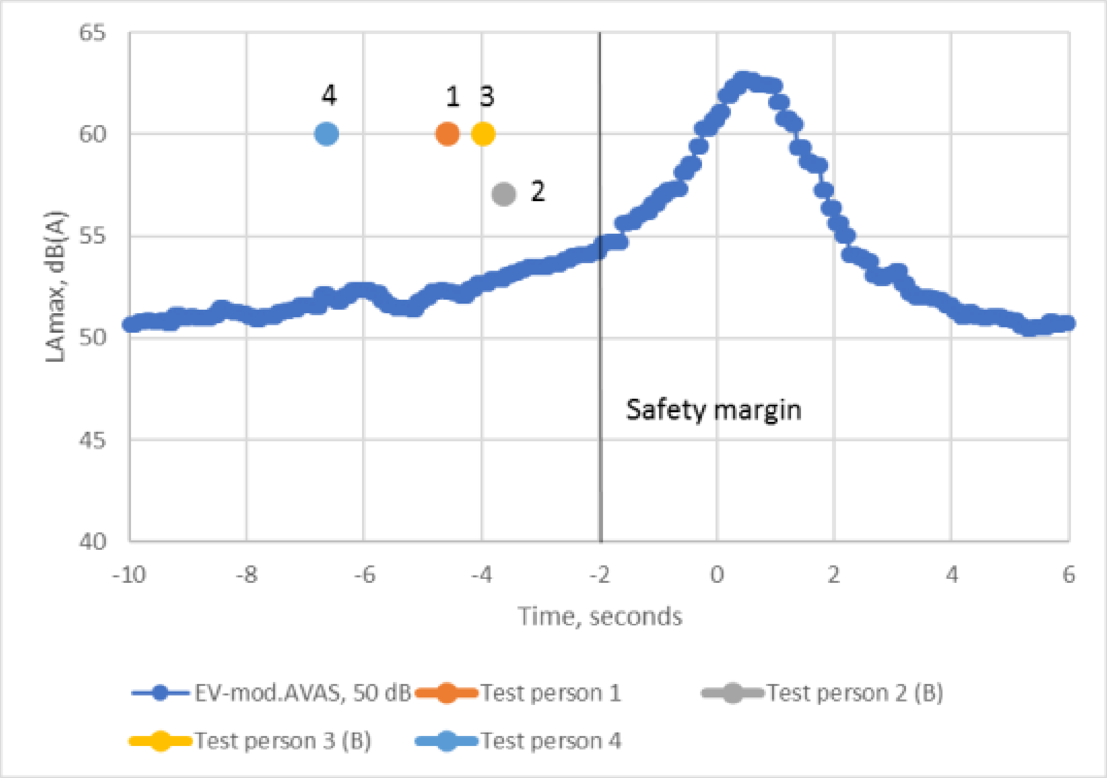


Figure 14: Example of analysis and results of one run persons 2 and 3 are visually impaired (Berge and Haukland, 2019)

In this specific example, all test persons could hear the car before reaching the 2 seconds (11 m) safety margin. In figure 15, the combined results for all 8 test persons and 8 test conditions are presented. For each of the 8 test conditions, the average value (5 repetitions) of the detection distance is shown, together with the 95 % confidence interval. This interval indicates that it is 95 % probability that the average detection distance lies within this interval. It is an indication of the overall spread in detection distance. The safety margin of 11 m is also shown. During tests 1 to 4, the natural background noise level at the site was used, while an artificial background noise level from the loudspeaker was used during tests 5 to 8.

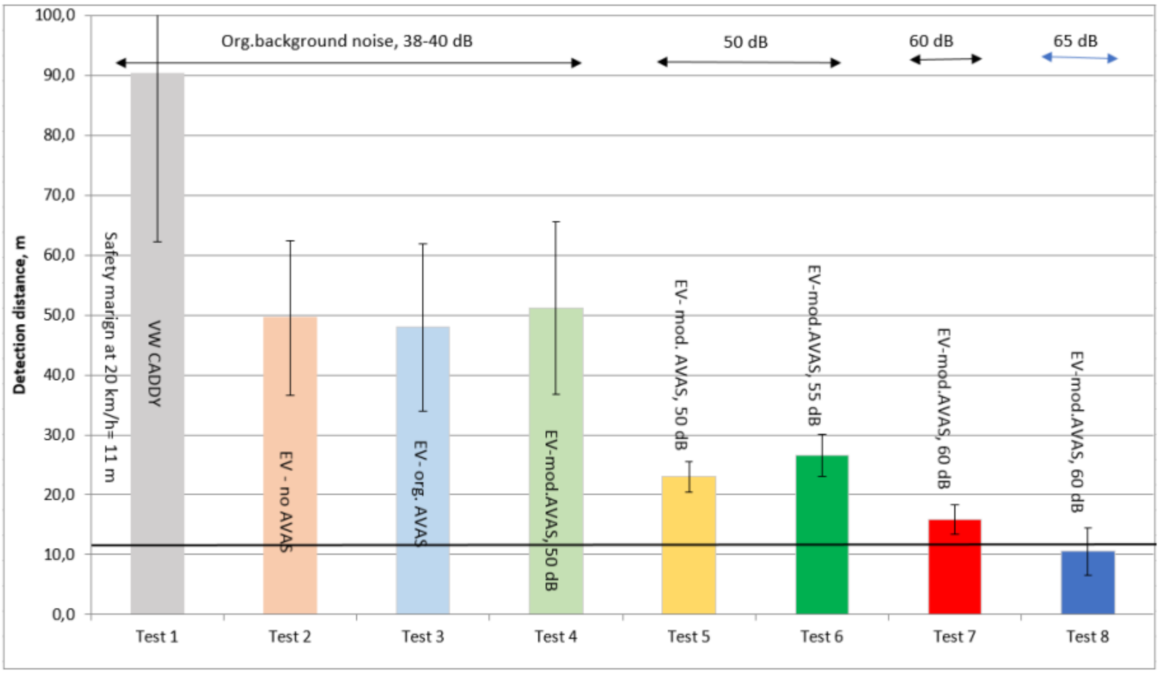


Figure 15: Average detection distance and 95 % confidence interval (Berge and Haukland, 2019)

In table 15, the numbered values for detection distance in figure 15 are listed, together with the standard deviation.

Test no	Car	Detection distance m	Standard deviation, m
1	ICE	90,3	40,6
2	EV	49,5	18,7
3	EV	47,9	20,2
4	EV	51,2	20,8
5	EV	23,0	3,6
6	EV	26,6	5,1
7	EV	16,0	3,5
8	EV	10,6	5,8

Table 15: Detection distance and standard deviation. Speed = 20 km/h (Berge and Haukland, 2019)

As shown in both figure 15 and table 15, there is a large variation in the detection distance of the ICE car (VW Caddy). However, all test persons did hear this car clearly in a larger distance than the EV, independent on the sound level of the AVAS. Reviewing seeing these results, we would have liked to repeat the test with the ICE car, also when the background noise was high. However, this was not feasible within the time and budget for the project. Even if the maximum recorded sound level in tests 4 and 5 are almost identical (63,1 and 63,4 dB(A) in table 13), the detection distance is considerably reduced in test 5, approximately with 55 %. The artificial background noise level is in test 5 about 10-12 dB higher than the natural background noise level at the location and this clearly masks the sound of the vehicle when it is at a longer distance from the test panel. When AVAS is increased to 55 dB (test 6), the detection distance is somewhat increased, however, it is within the statistical variation. Figure 13 shows that for all test conditions from 1 to 6, the detection distance is well above the safety margin of 11 m. When the background noise level is of the same order as the AVAS signal (60 dB in test 7), the detection distance is much closer to the 11 m margin, but still slightly above. When the background noise level is approximately 5 dB higher than the AVAS signal (test 8), they had a situation where several of the test persons could not hear the car within the safety margin. These tests indicated that in a very common urban situation, with a traffic noise level in the order of 65 dB (or higher), AVAS as used in this test, seems useless as a safety device. For example, the average traffic noise level in the city center of Copenhagen was found to be 64 dB_{10}. In such a situation, the sound level of AVAS should be increased, if the intention is to warn pedestrians. Alternative warning techniques should be considered, like direct communication between the car and the blind person. Another possibility is to completely rely on sensors on the vehicle to avoid dangerous situations, even if many blind people are against such alternative solutions. In the test panel, 3 were blind/visually impaired persons and 5 with normal seeing abilities. It is known that blind people to a much higher degree than normal seeing people rely on their hearing to orientate in a traffic environment. They should then be much more trained to observe and to make decisions on what there are hearing, than the normal seeing people. In a listening test like conducted in this project, one could then expect that the visually impaired group in general would detect the car earlier than the other group, especially when the background noise level is high. The project conducted and presented by (Berge and Haukland, 2019) has some clear limitations concerning conclusions:

- The tests were conducted with only one electric car (in addition to the ICE reference car). For this car, the dominating noise source at 20 km/h was the tyre/road noise contribution. The original AVAS designed by the manufacturer had no influence on the detection of the car at the chosen test location. However, the average detection distance was well before the recommended distance of 11 m, when the speed of the approaching car was 20 km/h. It was planned to include a small set of other EVs (4-5), but this was unfortunately not possible, due to adverse weather conditions during the time of the measurements (only 3 days without rainfall in the period) and access to visually impaired persons for tests.
- When all the analysis of the results was available, it was clear that it had been valuable to include some tests also at 10 km/h, as the tyre/road noise would have been significantly lower at this speed. Then, the variation of the sound level of the AVAS signal would probably have had a greater influence on the detection distance, at different background noise levels, than at 20 km/h.
- One of the objectives of the projects was to see if it was possible to reduce the sound level of AVAS when the background noise level was low (as in a residential street during night time). However, due to the dominating tyre/road noise at 20 km/h (as for test 4 in Fig.13) it was not possible to investigate this. Additional tests at 10 km/h would have a way to do such an analysis.
- If the background noise level is in the range of 60 to 65 dB, commonly found in a busy city street, the AVAS signal seems unfit as a safety warning signal to pedestrians/bicyclists, unless the sound level is increased. However, this must be balanced against the needs to reduce road traffic noise in general.
- There were no significant differences in the detection distance between the two groups; blind/visually impaired and normal seeing persons.

It is not only the maximum sound level of AVAS which influence the potential detection by pedestrians. As part of the development of different AVAS sound design, the frequency content has been very important. In general, traffic noise has a peak around 800 - 1200 Hz, when tyre/road noise is dominating. In the regulations for AVAS and minimum noise levels, it is recommended that the frequency content is not masked by the tyre/road noise. The regulations have specific recommendations for minimum sound levels in the frequency spectra from 160 to 5000 Hz. Furthermore, it is required in the UN ECE regulation, that the pitch of the signal shall change with vehicle speed, simulation the change in tonality when the engine speed of an ICE vehicle is increasing. Within the scope of this project, it was not resources to do a frequency analysis and the effect of different types of AVAS signals. For example, the Renault Zoe is delivered with an option for the driver to choose within 3 different AVAS signals. Only one of these AVAS signals were recorded and chosen for our test program. If the project could be continued, such an analysis of differences in frequency and tonality would be of interest. Additional tests with different EVs, especially equipped with low noise tyres (like BMW i3) should also be included. The objective of their project was to investigate if an adaptive AVAS could be an improvement. Due to the influence of the tyre/road noise for the test car (and road surface) it was only partly successful. It was not possible to see if a reduced AVAS sound level (from the level set by the manufacturer) would be feasible, when the background noise level is low. An adaptive AVAS can be implemented in a way, for example with an external microphone mounted on the EV at a location where the noise from the car itself is minimized or corrected for. This signal from the external microphone could then control the sound level of the AVAS signal, for example in steps of 5 dB (to avoid unnecessary rapid fluctuation of the AVAS signal). A more advanced system could be to add a GPS signal only activating the AVAS at special locations, such as pedestrian crossing, kindergartens, schools, etc., to avoid unnecessary noise disturbances.

2.6 Comparison of Noise generated from EVs and ICEs

A detailed study conducted in 2020 by (Kournoutos, 2020) for University of Southampton clearly capture from earlier researchers the various sources of noise in road vehicles. As per (Kournoutos, 2020), the necessity of artificial warning sounds for EVs stems from the difference in the noise generated between EVs and HEVs and vehicles equipped with conventional internal combustion engines (ICEs). It is therefore important to have an understanding of how the noise coming from vehicles equipped with electric motors differs from that of ICE vehicles. This section presents results of studies performed on the sources of noise in road vehicles, how these are different depending on the type of vehicle, and their effect on the generated noise.

As per (Kournoutos, 2020), the noise generated by road traffic has been a concern since the adoption of the car as the most used means of transportation, and the identification of noise sources as well as strategies for its reduction have been the subject of research during the development of many generations of road vehicles. A comprehensive study on NVH (Noise, Vibration and Harshness) analysis techniques for design and optimization of HEVs and EVs supported by the European Cooperation in Science and Technology (Parizet et al., 2014) offers an identification and classification of the primary sources of pass-by noise found in a typical passenger vehicle. With the exception of the engine, which will be addressed separately, the following components are found in both ICE equipped vehicles and EVs, and constitute sources or important factors in the generation of pass-by noise.

Tyres: The tyres constitute the contact surfaces between the road and the vehicle, and contribute to the generation of noise in multiple ways. Firstly, the nature of the tyre surface in contact with the road is an important source of airborne noise, dependent on both the geometry of the tyre tread and its material composition. In addition, the dynamic behavior of the tyres allows for the transmission of forces between the road and the wheels, transmitting vibrations to the vehicle by means of the structure borne path. The tyre-road noise becomes an increasingly important factor of overall pass-by noise as the speed of the vehicle, and therefore the velocity at which the wheels rotate, increases (Heckl, 1986).

Suspensions: The suspension is the principal connecting component between the tyres and the vehicle body (Takahashi et al., 1987). It is therefore a crucial structure borne transmission path, transmitting vibrations produced by the tyre-road contact. Suspensions are normally engineered with the goal of minimizing this transmission, but there is a complicated trade-off between handling and NVH performance.

Aerodynamic Sources: The aerodynamics of the vehicle are the main source of airborne noise at high speeds, with the intensity of the aerodynamic noise being proportional to the sixth power of the speed (George, 1990). Aerodynamic sources can be distinguished into three types (Parizet et al., 2014) : a global flow which influences the low-frequency range; a local flow, mainly present at mid-to-high frequencies; and turbulence, which generates a broadband noise.

Other Sources: Vehicle components such as brakes and miscellaneous electrical and mechanical accessories can be considered as secondary sources of noise. Although their contribution to overall noise levels produced is minimal compared to the other sources listed, they should still be considered when studying the acoustic behavior of a vehicle. Noise Characteristics of the engine ICEs and electric motors display fundamental differences in their components and operation, and thus the characteristics of the resulting noise generated. In addition to the motor itself, each type also requires a different powertrain, also characterized by unique noise sources. ICE and powertrain: In ICE equipped vehicles, the reciprocating and rotational masses within the engine, such as the pistons, connecting rods and shafts, are the primary sources of vibration. Additional sources in the corresponding powertrain are the exhaust system, and the gearbox and differential when the vehicle is in motion.

Electric motors: Research into the noise produced by the operation of electric motors has found that the noise signature is characterized by tonal components mainly at frequencies above 2 kHz (Kournoutos, 2020). These components are speed dependent, resulting from the dominating electromagnetic harmonics and covering a wide rpm range.

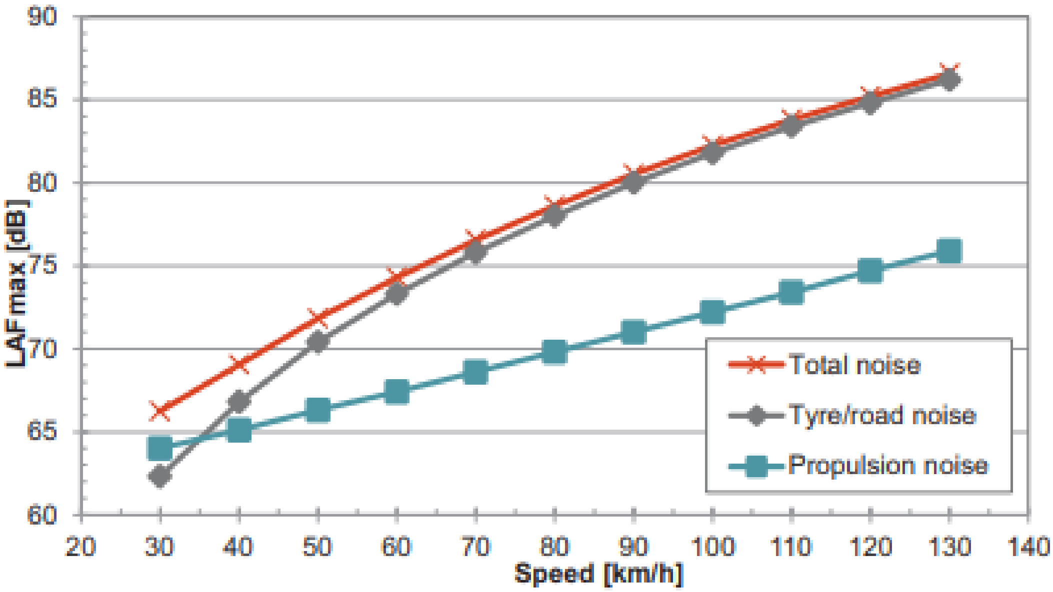


Figure 16: The propulsion noise, the tyre/road noise and the total noise from a passenger car calculated with the Nord 2000 noise prediction model (Kragh, 2011) as presented in (Kournoutos, 2020)

The most widely used type of electric motor is the permanent magnet synchronous motor. In this system, the battery provides a DC voltage. This is in turn converted to a magnitude and frequency-controlled AC voltage on the inverter via pulse-width modulation (PWM) as presented in (Kournoutos, 2020). The switching frequency for the PWM is located for the majority of EVs in the 5 kHz to 20 kHz range. This switching frequency is the primary contributor to the audible noise produced by an electric motor and powertrain system, followed by the magnet noise from the powertrain and the cooling system.

Noise Measure from ICE Vehicles

As per the research conducted by (Kournoutos, 2020), many of the different sources of noise presented above are dependent on the speed of the vehicle, and, in the case of the ICE, factors such as the rpm and the gear in which the vehicle is being driven. This means that the contribution of each source to the overall pass-by noise generated depends on the driving conditions. In particular, the main contributors to noise in an ICE vehicle are the engine and the tyre-road interaction. The latter becomes more influential as the speed of the vehicle increases. Figure 16 above shows a prediction of the noise generated by the propulsion system and the tyres of an ICE car, calculated using the Nord 2000 noise prediction model (Kragh, 2011). The term LAF_{max} denotes the maximum A-weighted and time weighted sound pressure level over the measured time period. The plot used has been presented as part of an existing literature survey on noise from EVs by Iversen and Marbjerg (Iversen et al., 2013).

It can be seen from this figure that at low speeds, the propulsion system, which consists of the ICE and the corresponding powertrain, is the primary source of noise. However, from speeds of around 35 km/h and up, the tyre-road interaction becomes the main source of noise, reaching a 10 dB difference at 50 km/h and up to 20 dB as the speed increases. For speeds above 90 km/h, both sources of noise rise linearly with speed. It is therefore apparent that differences in the engine will only yield a significant difference in the noise generated at speeds below the 35 km/h threshold, especially since an electric motor is generally understood to be quieter in operation than an ICE.

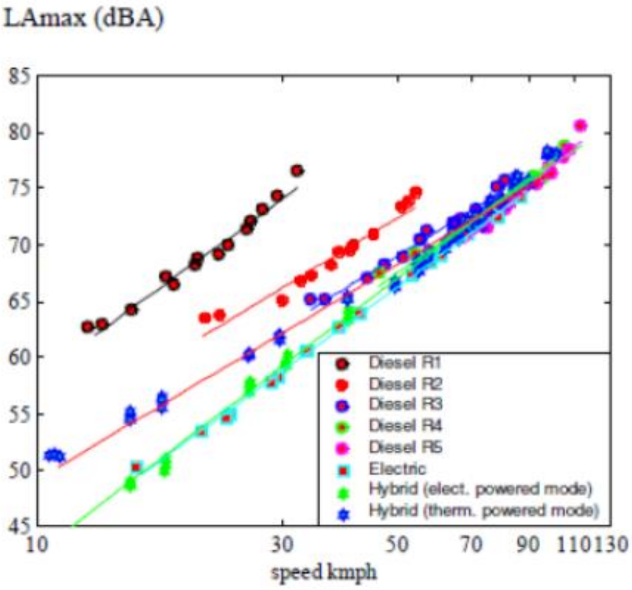


Figure 17: Overall noise levels at different speeds for an ICE vehicle, an EV and a HEV driven at different modes, as presented in (Lelong, 2001)

Comparison Between EV and ICE Vehicle Noise

A study conducted in 2001 by (Lelong, 2001) investigated noise at different speeds from an ICE vehicle, an EV and a HEV driven in electric and in conventional mode. The cars were driven at constant speed when the measurements were performed. No separation between the tyre-road interaction and the propulsion noise was considered, and it is worth noting that the ICE vehicle chosen for the study ran on diesel fuel. Figure 17 shows results of the study in terms of the overall noise generated by the vehicles at different speeds. Similarly, to the preceding figure, the term LA_{max} denotes the maximum A-weighted sound pressure level over the measured time period. The notations R1 to R5 in the figure stand for different gears. It is evident that at low speeds, the EV and HEV achieve an overall noise reduction of about 15 dB, and it is worth noting that the HEV driven in electrically powered mode displays the same noise behavior as the EV. Even when driven in conventional mode, the HEV still produces significantly less noise at low speeds. For increasing speeds above 35 km/h, the overall noise produced is similar for all of the measured vehicles, which suggests that the tyre-road interaction and aerodynamics become the dominant sources of noise instead of the engines, as suggested in the previous section (Kournoutos, 2020).

A more recent study conducted by the National Traffic Safety and Environment Laboratory and the Ministry of Land, Infrastructure, Transport and Tourism in Japan, compared the noise from a HEV operated in electric mode and from two ICE vehicles (Sakamoto et al., 2010). All vehicles were classified as small passenger cars. Pass-by measurements performed at different constant speeds were made, and the results are shown in Fig. 18. As this study is focused on low speeds up to 30 km/h, the difference between the noise produced by the HEV and the ICE vehicles is more prevalent. The HEV produces a noise level reduced by over 15 dB compared to the ICE vehicles when stationary, and remains quieter up to a speed of 20 km/h. The increase in noise measured at these low speeds for the HEV was interpreted as being caused by the tyre-road interaction (Kournoutos, 2020).

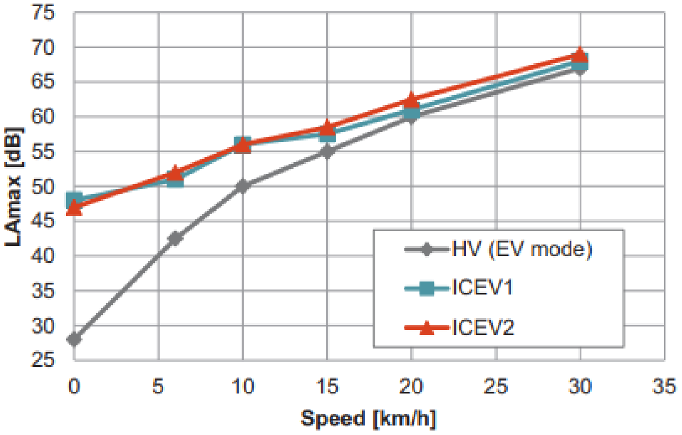
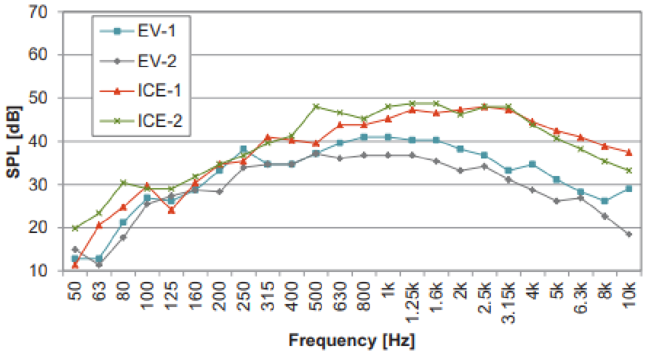


Figure 18: The maximum sound pressure level from two different ICE vehicles and one hybrid vehicle operated in electric mode when the cars pass-by at different constant speeds with the microphone at a distance of 2 m. Results from (Sakamoto et al., 2010).

The results of the two studies presented above are clear in showing that the quiet operation of electric motors results in EVs and HEVS being significantly quieter than ICE vehicles at low speeds. As measurements shown thus far have only considered the overall noise levels, it could be useful to have a picture of the sound pressure levels across frequency. The study presented in (Sakamoto et al., 2010) also provides an insight into the frequency spectrum of the noise produced by the investigated vehicles. An example is shown in Fig 19, which contains the A-weighted frequency spectra for the noise from the vehicles driven at constant speeds of 10 km/h and 20 km/h. In the 10 km/h case, the EVs generate a lower overall level of noise compared to the ICE vehicles. Only in the lower frequencies up to 315 Hz the levels of both types are similar. It was not elaborated to what extent the low frequency components were due to non-engine related factors, but the conclusion from this was that ICEs emit higher noise levels at all frequencies over 315 Hz compared to electric motors. At 20 km/h both types of vehicles display a very similar noise spectrum. This is indicative of how noise from tyres and aerodynamics overcomes the engine by a significant amount as the speed increases.



(A) Vehicles driven at a constant speed of 10 km/h.

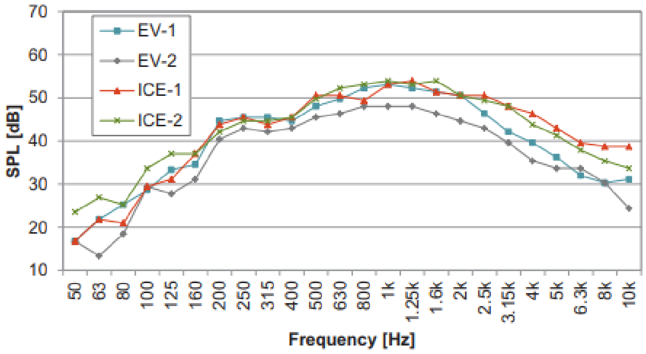


Figure 19: The A-weighted frequency spectra for vehicles driven at different constant speeds. From (Sakamoto et al., 2010), as presented by (Kournoutos, 2020)

The study results showcased in this section indicate that EVs and HEVs driven in electric mode are significantly quieter than conventional petrol vehicles. This is due to the quiet operation of the electric motor compared to the internal combustion engine. From a threshold of roughly 20 km/h and above, the noise generated by either type of vehicle tends to be similar, due to the prevalence of aerodynamic and tyre-related noise at such higher speeds (Kournoutos, 2020).

2.7 Electric Vehicles and Pedestrian Safety

As per the study of (Kournoutos, 2020), the fact that EVs have proven to be substantially quieter than ICE vehicles at low speeds has raised concerns over increased collision incidents involving pedestrians and other vulnerable road users, particularly during low speed maneuvers, due to the lack of auditory warning. The motivation of the two Japanese studies presented in the previous section (Sakamoto et al., 2012) (Sakamoto et al., 2010) was partly to determine whether these vehicles pose a safety risk to pedestrians due to their low noise level, especially in consideration of visually impaired people. Similarly, a number of studies have solely focused on determining the extent of this issue. This section presents the findings of studies regarding the increased risks that the quiet operation of EVs brings, and the resulting necessity for an artificial auditory warning system.

In a study on the risk of quiet vehicles to pedestrians and drivers by (Wogalter et al., 2001) as presented by (Kournoutos, 2020), one of the earliest mentions of the potential risks of wide EV use, which focused on a survey exploring interest and concerns over the then emerging technology of EVs. The study considered the pre-existing auditory alarms installed in automated guided vehicles (Egawa, 1988), as well as the effectiveness of alarms found in emergency vehicles (Robbins, 1995). Findings of the survey indicated that the public, though supportive of the adoption of EVs and HEVs, expressed worries over the reduced auditory cues to the presence of a moving vehicle. Aside from the issue of detection by pedestrians and other vulnerable road users, the study also addressed factors crucial to the evaluation of danger and collision avoidance, such as speed estimation, which are heavily dependent on sound (Evans, 1970). In addition, the importance of auditory cues to aid the performance of the driver of the vehicle was considered (Nelson and Nilsson, 1990). Lastly, the study offered suggestions for the nature of potential artificial warning sound sources to be installed in EVs. One of the earliest mentions of the potential risks of wide EV use was in a 2001 study by Wogalter (Wogalter et al., 2001), which focused on a survey exploring interest and concerns over the then emerging technology of EVs. The study considered the pre-existing auditory alarms installed in automated guided vehicles (Egawa, 1988), as well as the effectiveness of alarms found in emergency vehicles (Robbins, 1995). Findings of the survey indicated that the public, though supportive of the adoption of EVs and HEVs, expressed worries over the reduced auditory cues to the presence of a moving vehicle. Aside from the issue of detection by pedestrians and other vulnerable road users, the study also addressed factors crucial to the evaluation of danger and collision avoidance, such as speed estimation, which are heavily dependent on sound (Evans, 1970). In addition, the importance of auditory cues to aid the performance of the driver of the vehicle was considered (Nelson and Nilsson, 1990). Lastly, the study offered suggestions for the nature of potential artificial warning sound sources to be installed in EVs (Kournoutos, 2020).

In another study cited by Kournoutos (Kournoutos, 2020) in their research is an investigation of probability of pedestrian crash based on auditory recognition distance due to a quiet vehicle in motor mode conducted by (Hong et al., 2013) which included diesel and petrol ICE vehicles, EVs and HEVs, based around two experiments. The first experiment was conducted at speeds of 20 km/h and 30 km/h on a public road, while the second experiment was performed using an idle engine setting in an underground car park. In both cases, the objective was to determine the maximum distance at which the vehicle could be reliably perceived through noise. The participants were split into two age groups, those below 60 years and those above. Results indicated that the younger group could more easily recognize the EVs and HEVs driving at a speed of 30 km/h. The study estimated the collision probability of the younger group to be 20% lower than the older group regardless of vehicle type. Overall probability of collision for EVs and HEVs were increased by 31% compared to the ICE vehicles. Lastly, during the static experiment 80% of participants were unable to perceive the HEV at a distance greater than 0.1 m, while the percentage was as high as 97% for the case of the EV (Hong et al., 2013).

In another study captured by Kournoutos (Kournoutos, 2020) in their research conducted by R. Hanna (Hanna, 2009) on incidence of pedestrian and bicyclist crashes by hybrid electric passenger vehicles in USA, the sample was limited to vehicles which had both ICE and Hybrid-Electric versions. A total of 8,287 HEVs and 559,703 ICE vehicles were included. Incidence rates were calculated as the number of a given vehicle type involved in an incident divided by the total number of vehicles of its type in the sample. The findings of the survey are summarized as follows:

- A total of 0.9% of HEVs and 0.6% of ICE vehicles were involved in incidents with pedestrians.
- For cyclists the rates were 0.6% with HEVs and 0.3% with ICE vehicles.
- Regarding incidents recorded at speeds below 35 mph, the rates were 1.8% for HEVs and 1.2% for ICE vehicles. There were substantially fewer incidents with pedestrians for speeds above 35 mph.
- For speeds under 35 mph, incidence rates with cyclists were: HEV:1.0%, ICE: 1.6%.
- Collisions that occurred while the vehicle was travelling straight were the most common manoeuvres, although no significant difference between the incidence of HEV and ICE vehicle crashes was shown in the data.
- The second most common manoeuvres prior to a pedestrian involving collision were making a turn, with incidence at 1.8% for HEVs and 0.6% for ICE vehicles.
- Low speed manoeuvres such as slowing down, stopping, reversing and entering or leaving a driveway were grouped together. Pedestrian incidence rates were found to be 1.2% for HEVs and 0.6% for ICE vehicles.
- The same types of manoeuvres showed for cyclists the incidence rates of 0.8% for HEVs and 0.4% for ICE vehicles.

The study concluded that HEVs were more likely to be involved in collisions with pedestrians or cyclists than ICE vehicles at speeds below 35 mph. However, as the small sample size, in part due to the newly emerging market presence of HEVs during the years investigated, the results were deemed questionable. A second survey under the same guidelines was performed in 2011, with a sample of 24,297 HEVs and 1,001,000 ICE vehicles (Wu et al., 2011). Its summarized results are as follows:

- Total incidence rates for pedestrian collisions were 0.77% with HEVs and 0.57% with ICE vehicles.
- For cyclists, the total rates were 0.48% against 0.30% with HEVs and ICE vehicles respectively.
- At speeds under 35 mph, the HEV incidence rate was 1.39% and the ICE vehicle rate was 1.01%.
- For the low-speed manoeuvres defined as in the previous study, rates were 1.24% for HEVs and 0.75% for ICE vehicles.

As per Kournoutos (Kournoutos, 2020), overall, this repetition came to verify the initial conclusions that at lower speeds, HEVs tend to be less safe for pedestrians as well as cyclists. These surveys, however, have been subject to criticism for their methodology by published literature. Namely, the neglect of mileage for each vehicle, of the population composition between car owners and the fact that the studies do not indicate whether the HEV was being driven in electric mode at the time of the incident are factors stressed in question of the above conclusion (Verheijen and Jabben, 2010).

As per Kournoutos (Kournoutos, 2020), a 2009 study by the Japan Automobile Standards Internationalization Center (JASIC, 2009) mentioned that no accidents resultant from lack of audible warning had been recorded until then in Japan; however no further information on the methods under which this survey was conducted were provided. Also mentioned was the lack of difference between the noise produced by EV/HEVs and ICE vehicles at speeds above 20 km/h.

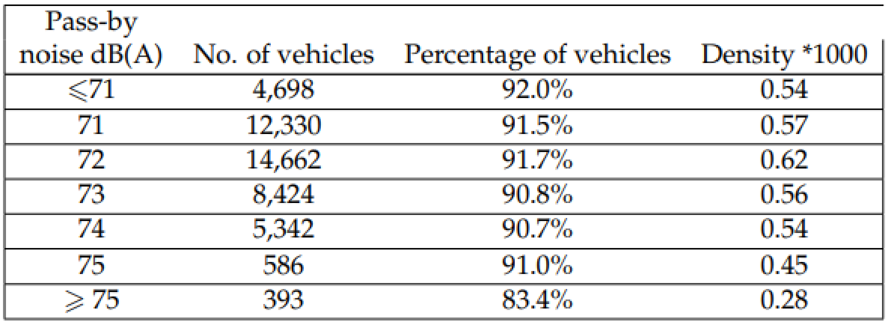
The Transport Research Laboratory (TRL) performed a statistical study for the UK Department for Transport based on police reports of pedestrian-vehicle collisions between the years 2005 and 2008 (Morgan et al., 2011). Among these results it was found:

- Pedestrian-vehicle involvement density in per 10,000 registered vehicles was overall between 2005-2008: 4.9 incidents for EV/HEVs and 5.5 incidents for ICE vehicles.
- Regardless of vehicle type, the majority of incidents involving pedestrians occur at speeds below 30 mph, with both categories of vehicles displaying similar rates when it comes to injuries sustained.
- Considering relative rates of vehicles sampled, it was deduced that EV/HEVs were less likely to be involved in a general collision by 30%.

The study also conducted surveys with vision impaired participants in vehicle detection during drive-by scenarios such as moving straight, turning and parking; manoeuvres for which EV/HEVs showed a high rate of incidence in the NHTSA report (Hanna, 2009). The TRL report concludes that although EV/HEVs might pose an increased risk for pedestrians, not enough data is included in the statistics, such as mileage of each vehicle, and whether an HEV involved was operating in electric or ICE mode. A further point for consideration was that during the sound level measurements conducted, it was found that differences in the noise produced by EV/HEVs and contemporary ICE equipped vehicles is negligible, even at these rather low speeds (Morgan et al., 2011).

As per Kournoutos (Kournoutos, 2020), TRL subsequently conducted a complementary study with extra focus on the correlation of sound levels emitted from the vehicle and the likelihood of incidents involving pedestrians (Muirhead and Walter, 2011). Results, as seen in Table 15, show that apart from vehicles with exceptionally high noise levels, the proportion of vehicles involved in incidents with pedestrians at lower speeds is fairly constant at the order of 91%.

The conclusion of both UK based studies is that the evidence for the increased risk to pedestrians posed by EV / HEVs is insufficient to reach a verdict. A noteworthy point put forth is the fact that as newer ICE models display similar sound levels to EVs even when at low speed, the use of warning sounds might as well be considered for all quiet cars regardless of propulsion system.



Pass-by noise dB(A)	No. of vehicles	Percentage of vehicles	Density *1000
⩽71	4,698	92.0%	0.54
71	12,330	91.5%	0.57
72	14,662	91.7%	0.62
73	8,424	90.8%	0.56
74	5,342	90.7%	0.54
75	586	91.0%	0.45
⩾ 75	393	83.4%	0.28

Table 16: Vehicles involved in pedestrian accidents at speeds below 30 mph, as presented in (Muirhead and Walter, 2011)

Another study considered by Kournoutos (Kournoutos, 2020) was conducted in 2012 by Kim (Kim et al., 2012) to investigate the difference that an artificial warning sound makes in the perceptibility of a HEV by vision impaired adults. Fourteen participants with visual impairments attempted to detect three different vehicles: a HEV without any artificial warning sounds, a HEV with a Vehicle Sound for Pedestrians (VSP) installed (Konet et al., 2011), and a comparable ICE vehicle. The characteristics of the VSP warning sound system will be presented in more detail in Section 2.8. Two test sites were used, a parking lot and a road way, which provided an overall background sound level difference of roughly 10 dBA. Results indicated that the HEV with the added VSP system was detected at a distance greater than that corresponding to the HEV without the artificial warning sound by over 10 m, and on occasion even surpassed that corresponding to the ICE vehicle. The study concluded that equipping

HEVs and EVs with a sound system that emits an alerting sound in certain low-speed manoeuvres is crucial for the safety of blind pedestrians.

2.8 Development of AIS Systems

Artificial sounds have been designed and installed in EVs and HEVs even before the issue of pedestrian safety was officially addressed. Differences in the design philosophy of warning sounds can also be seen in the time between identifying their necessity and finalizing the guidelines for their attributes. This section gives an overview of studies on the identification of characteristics in warning sounds that may render them more efficient in their role, as well as investigations on the impact that warning sounds might have on the environment. In addition, warning sounds currently used by EV and HEV manufacturers are presented, to the extent that such information has been openly published (Kournoutos, 2020).

Research on type of AIS sounds and frequency modulation

As presented in the study of Kournoutos (Kournoutos, 2020), in a survey conducted by Wogalter (Wogalter et al., 2001), intended to obtain an insight into the type of sounds that the public associated with road vehicles, and would prefer to characterize the sound of an EV or HEV. Results of this survey indicated an overwhelming preference for the sound of a conventional ICE, followed by sounds like wide band noise and humming. The least preferred sound was that of an ICE vehicle exhaust.

Another similar study was performed in 2008 (Nyeste and Wogalter, 2008) with a focus on the evaluation of potential warning sounds. In this instance, the survey presented participants with the actual sound samples instead of their description. The results of this study showed high correspondence with the results of the earlier study, with a conventional engine noise being rated as the most preferable sound, followed by the sounds characterized as hum and white noise. For both studies, this preference was interpreted as a result of the familiarity the public has with such sounds, and the instinctive association with road vehicles. It is worth mentioning however, that other types of noise associated with ICE vehicles, such as the sound of an exhaust, were considered most undesirable. In general, the sounds that were least preferred were characterized by strong tonal components, especially at higher frequencies.

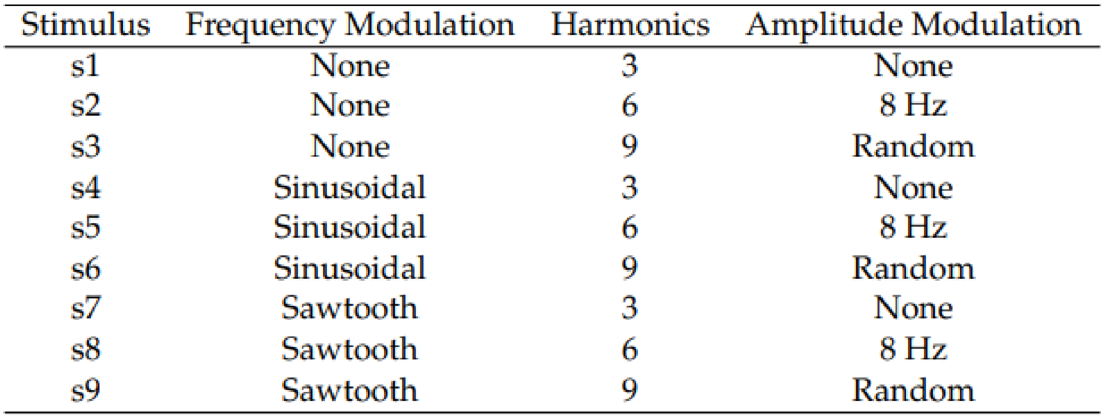
With the concept of artificial EV warning sounds established and the planning of regulations in progress, researchers in the Technical University of Denmark (DTU) conducted a survey in 2013 to determine which types of sound were most appropriate for use as warning sounds (Petiot et al., 2013). The survey separated participants in two subgroups, one consisting of 34 “novice users” and the other of six “experts” with technical knowledge in the subject of EVs and artificial warning sounds. In the first part of the survey participants were asked their opinion on the matter of warning sounds for EVs with results indicating an approval of warning sounds as a safety measure, and a preference of sounds that would be associated with ICE vehicles to be used.

The experimental part of the survey had the participants evaluate different synthesized sounds on the bases of appropriateness and pleasantness. 17 different sounds were designed and put to evaluation. The tests also simulated the movement of the car by adjusting the frequencies and amplitudes of the sounds to recreate a pass-by effect. Upon analysis of the quantitative ratings on pleasantness and appropriateness, it was found that little agreement (28.4%) existed between the subjects. The researchers' explanation for this was the fact that still few propositions exist on the market for EV sounds, and the absence of context for judgement.

A survey conducted by researchers from the University of Warwick (Singh et al., 2021b) considered both the detectability, as well as the subjective evaluation and suitability of different warning sounds. The study employed simulation software to recreate visual and audio stimuli of EVs moving through an urban environment and carrying out different manoeuvres, as would have been heard by a pedestrian. Although the published results from this study did not provide details on the characteristics of each sound, nor did the conclusions point out a trend in the qualities that render a warning sound more detectable, a finding that is worthy of note was that the A-weighted SPL of the warning sound did not show association with its detectability. Such a finding suggests that pass-by SPL measurements might be insufficient as the sole means for the assessment of the effectiveness of warning sounds. The conclusions from this research pointed out the necessity of evaluating warning sounds through more subjective criteria such as familiarity and association of the sound with a vehicle, as well as annoyance (Kournoutos, 2020).

Between 2011 and 2014, the European Commission and a number of EV manufacturers in part funded the eVADER project (electric Vehicle Alert for Detection and Emergency Response), which aimed to develop a next generation warning sound system solution for EVs and HEVs (Quinn et al., 2014). The key objective for this system was to achieve the communication of an auditory warning to a vulnerable road user while minimizing the overall contribution of the vehicle to environmental noise. An overview of the complete system that was developed is given in Sec. 2.5. In the scope of warning sound design within the project, the work of Parizet (Parizet et al., 2014) aimed to develop warning sounds that are effective at being easily detectable by a recipient, without causing annoyance. On the topic of determining the qualities that would make the warning sounds themselves suitable, a series of psychoacoustics experiments were performed (Parizet et al., 2014). The survey involved a sample of 100 normal vision and 53 visually impaired participants. A drive-by scenario was simulated in order to evaluate each sound. Warning sounds were synthesized according to a three-factor design, for each of which three levels of variation were defined. Therefore, each sound used was characterized by three indices, corresponding to a specific level for each factor; these were:

- Number of components: Each component referring to a “harmonic” frequency, with the lowest fixed at 300 Hz. Three frequencies were separated by 300 Hz for level 1, “six harmonics” were separated by 150 Hz for level 2 and nine “harmonics” at 150 Hz apart were generated for level 3, all at the same initial level.
- Frequency modulation: At level 1 all components had fixed frequencies. At level 2 the frequencies of the higher two components were modulated at 5 and 4 Hz respectively. Level 3 included level 2 with a saw tooth modulation applied to the rest of the components.



Stimulus	Frequency Modulation	Harmonics	Amplitude Modulation
s1	None	3	None
s2	None	6	8 Hz
s3	None	9	Random
s4	Sinusoidal	3	None
s5	Sinusoidal	6	8 Hz
s6	Sinusoidal	9	Random
s7	Sawtooth	3	None
s8	Sawtooth	6	8 Hz
s9	Sawtooth	9	Random

Table 17: Characteristics of warning signals that were used in the experiment of (Parizet et al., 2014)

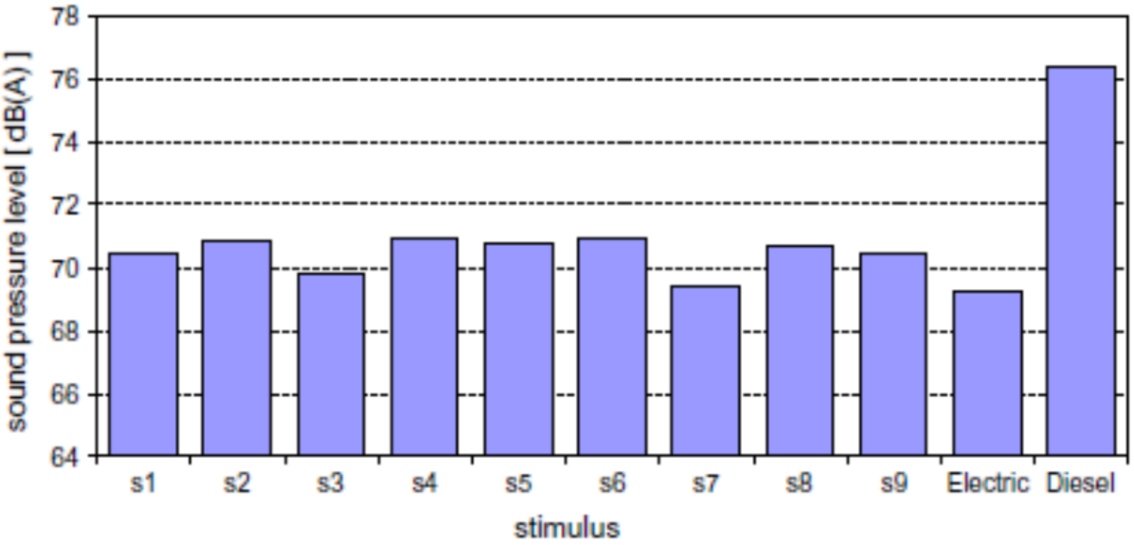


Figure 20: Peak level (A-weighted SPL) of the vehicle sounds with (s1–s9) and without added warning signals (the two rightmost bars), as presented in (Parizet et al., 2014)

Amplitude modulation: No amplitude modulation was applied for level 1. At level 2, the signal amplitude was sinusoidally modulated at 8 Hz. At level 3, the lower two components were modulated with a variable modulation frequency of unspecified range. This last level was designated as “random” amplitude modulation.

Table 17 contains the list of sounds that were evaluated in the survey and their characteristics. The sound pressure level (SPL) of the synthesized sounds is shown in Fig. 20. It can be seen that compared to a diesel ICE, all synthesized sounds maintained a lower level, and in certain cases the levels were comparable to the operation of an EV without a warning sound system installed (Kournoutos, 2020).

The evaluation of the effectiveness of each sound was performed in a simulated environment, where participants attempted to identify by sound the approaching vehicles. The measured reaction times of participants were converted to the corresponding distance of the vehicle in the simulated scenario. Figure 21 depicts the mean distance at which the vehicle was detected using each synthesized sound. It is evident that certain synthesized sounds worked efficiently enough to be just as detectable as a standard ICE. Added to the fact that the overall sound level for all the samples was 5 to 7 dB lower than that of the conventional engine, the successful sound types offer an ideal solution that combines both detectability and lower noise emissions.

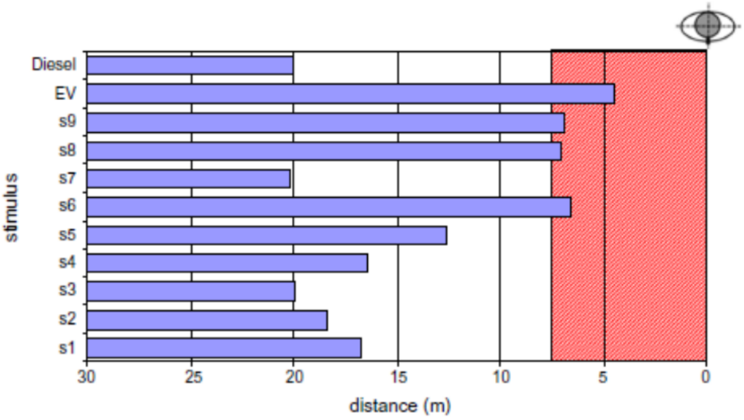


Figure 21: Distance in m at which the vehicles were detected in the virtual scenario, as presented in (Parizet et al., 2014). The shaded area corresponds to unsafe distances.

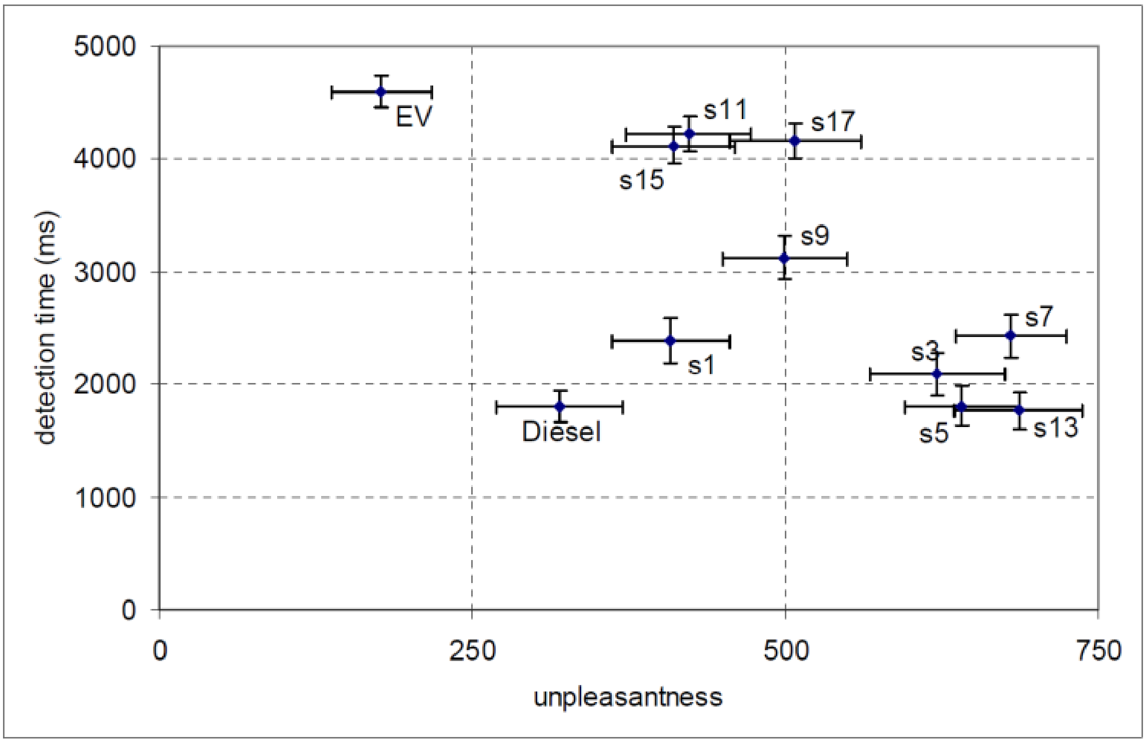


Figure 22: Mean detection time and rated unpleasantness for various synthesized warning sounds, as presented in (Parizet et al., 2016)

An extended presentation of the same study, published in (Parizet et al., 2016), provides a view of the effectiveness of each synthesized sound in relation to the annoyance caused by its perception. Figure 22 shows this in terms of the mean detection time versus the perceived unpleasantness as rated by the participants. The figure includes warning sounds for which details were not explicitly presented in the paper. For sounds with the naming convention s1 to s7, the characteristics defined in Table 17 apply. It is apparent that synthesized sounds that are more easily detectable are also characterized by a high unpleasantness factor, therefore necessitating a compromise when choosing the optimum sound. As the study concludes, s1, which consists of three tonal components and no frequency or amplitude modulation offers a satisfactory combination of detectability and limited annoyance caused.

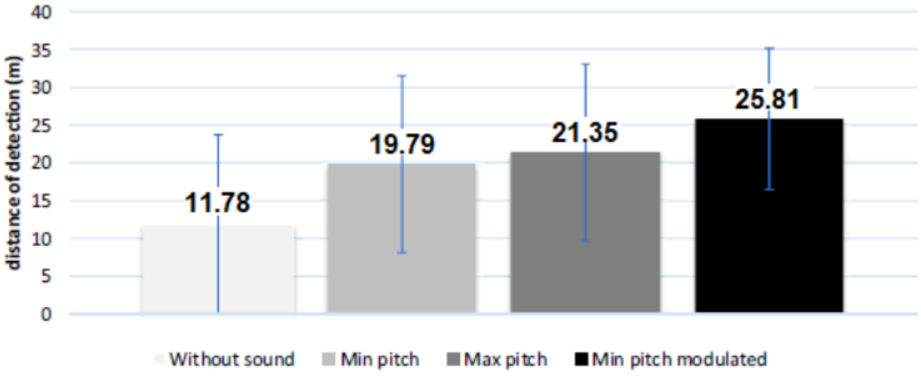


Figure 23: Mean detection distances and standard deviations for the four types of sounds tested in (Fleury et al., 2016), as presented in the published article.

In another study presented by Kournoutos (Kournoutos, 2020) of a publication by Fleury (Fleury et al., 2016) investigated the effect that the pitch of a warning sound had on its detectability. Three sample sounds were used for the test: two static sounds that were characterized by a difference in pitch, and a third one based on the lower pitched sound, with added frequency modulation. In the first study, blindfolded participants had to detect an approaching EV with either no warning sounds at all or one of three types of sound tested. The second study aimed to replicate the results of the first in an ecological setting; for that purpose, the EV was driven along a road as conductors of the experiment counted the number of people who turned their heads towards its direction. Figure 23 shows the results of the first study with the mean distance of detection for each of the warning sounds investigated. It can be seen that raising the pitch of a sound made it detectable from a greater distance; however, a modulated pitch proves even more effective in that regard, as its distance of detection increases despite its base pitch being lower. The second study was unique in comparison to existing ones at featuring the sounds tested in a natural context. Participants were unaware of their involvement in a survey, and therefore could not concentrate their perceptual and cognitive resources on detection. Overall, results showed that when the vehicle was travelling at 10 km/h, it was detected 2.88 s earlier for the minimum pitch sound (which corresponds to a safety margin of 6.02 m), and 5.05 s earlier in the modulated pitch (8.01 m).

AIS Under the City Ambient Noise

The above studies are mainly focused on warning sounds in an isolated environment. However, such systems are expected to operate under the masking effect of city ambient noise. Therefore, detectability of EVs through their warning sounds in presence of existing background noise, and the contribution of such warning sounds to the overall environmental noise levels is a very important aspect that needs to be studied. Below work presented from the Kournoutos study covers the various prior arts of researchers on the masking effect of city ambient noise on AIS system.

A 2014 study by researchers from the University of Nagasaki (Yamauchi, 2014) is presented by Kournoutos (Kournoutos, 2020) reviewed the issue of EV and HEV quietness, with focus on the design of feasible warning sounds. Attention was given to the impact of environmental sounds to the perceptibility of the warning signals, including the factors such as the variability in time of said interfering sounds. Examples were given of warning sounds evaluated as reliably detectable proving inaudible when used in environments significantly louder than the testing tracks. A characteristic example is displayed in Fig. 24, where the minimum required levels for the warning sound are shown to be well below the estimated levels necessary for a reliable detection of the sound over a background noise. The variation in detecting capabilities by persons of different age was also addressed. The study concluded that revisions on the guidelines for warning sounds are necessary if auditory warnings are to be the solution to vehicle detectability, otherwise non-acoustical measures should be considered.

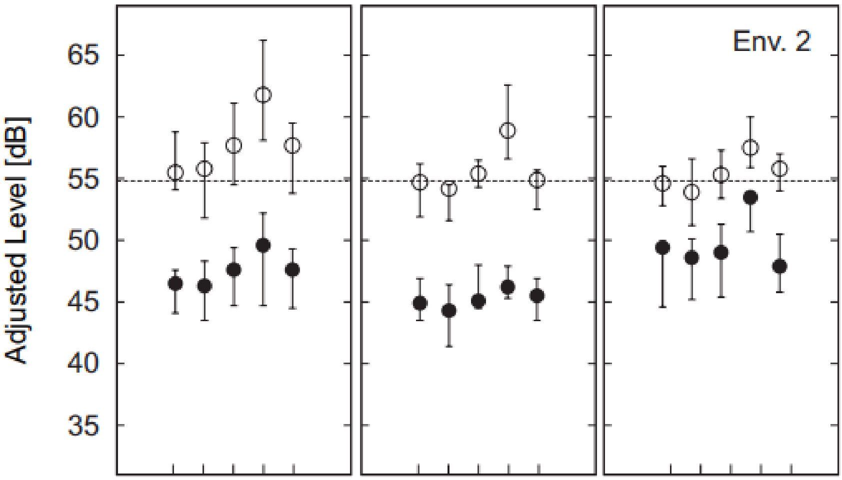


Figure 24: Minimum level requirements for warning sounds (dark points), and levels necessary for a reliable detection given a background noise, as estimated using different methods (white points). The level of the background noise is marked by the horizontal line. From (Yamauchi, 2014)

Poveda-Martinez et al. (Poveda-Martinez et al., 2017) analyzed in detail the characteristics of a number of warning sounds proposed by the industry and conducted a comparative study to determine their effectiveness in different urban environments. Soundscapes from static traffic, a busy pedestrian area and the vicinity of a playground were used. 8 warning sound samples were used, classified into four groups based on their characteristics: flat/tonal spectrum, unmodulated/modulated. As can be seen in Fig. 25, the A-weighted level of these sounds varies, but in all cases is lower than that of the ICE in operation. Figure 26 shows the distance at which the vehicle was detected using each warning sound, within the different simulated environments. The minimum safe distance is also marked with a horizontal dashed line. The results revealed a significant difference between detection errors committed depending on the sonic environment. The noisiest urban areas with the presence of idling vehicles (Environment 1) led to a higher number of detection errors, while in the pedestrian area (Environment 2) and especially the playground area (Environment 3) the vehicle can be more reliably detected at a greater distance. Regarding the warning sound features, reaction time was reduced in the presence of stimuli with a small number of harmonic components. The incorporation of modulation, either in amplitude or in frequency, did not significantly improve the reaction time. However, it is noted that incorporation of pure tonal components may also result in an increase in annoyance from the sound. The study concludes that warning sounds more similar to those generated by traditional vehicles, where high spectral density bands are combined with pronounced tonal components, can offer the most successful solution to the problem. Overall, the sound that proved to be most successful is an engine simulation characterized by a main wide band component in the 100 Hz to 300 Hz range, with additional narrow band components at 275, 550 and 800 Hz, with no amplitude or frequency modulation (Kournoutos, 2020).

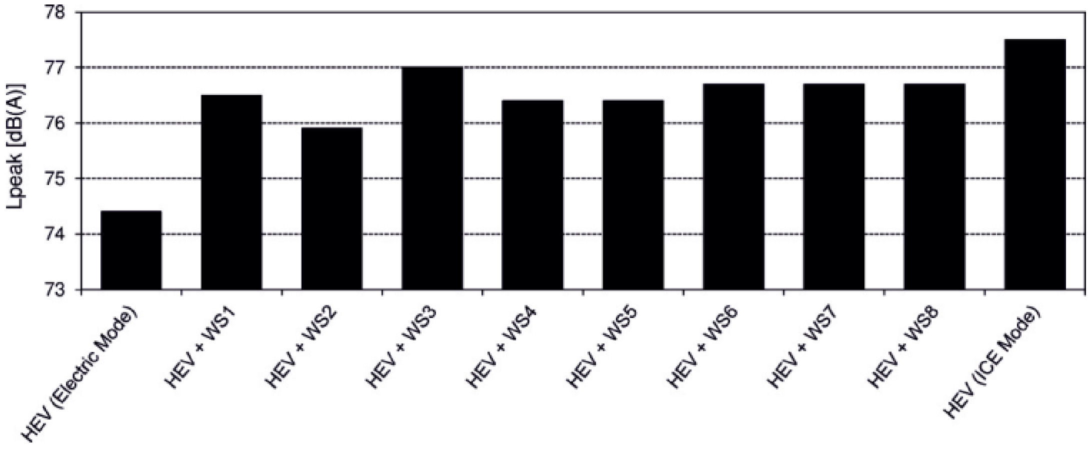


Figure 25: Overall A-weighted sound pressure levels generated by the different warning sounds, and HEVs in ICE mode and in electric mode without artificial noise. From (Poveda-Martinez et al., 2017)

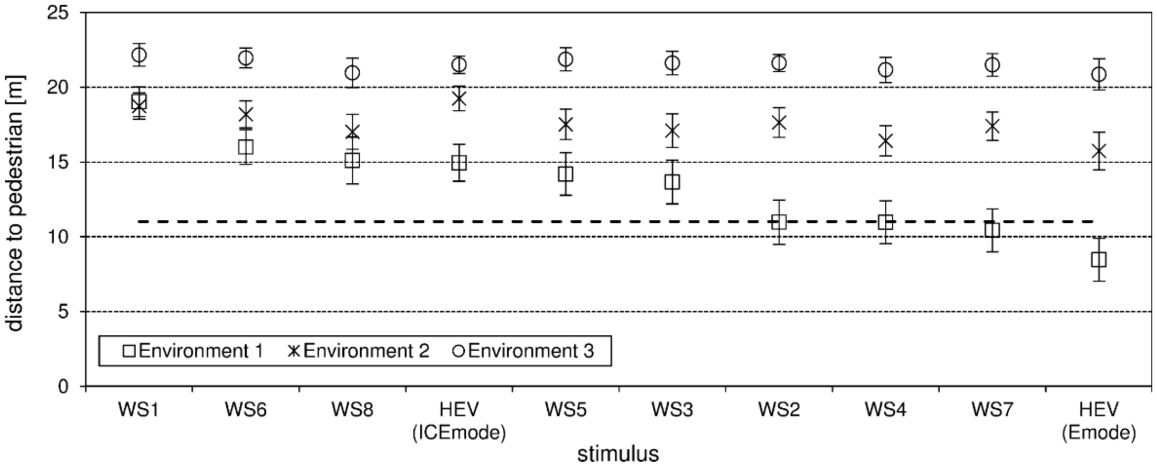
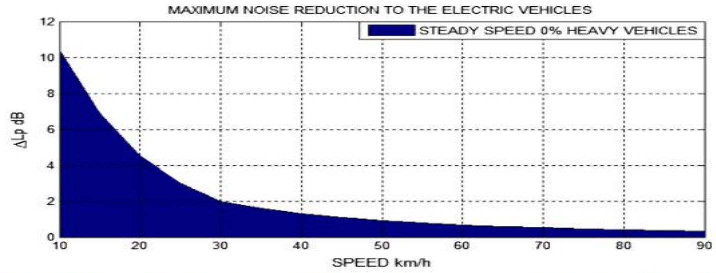
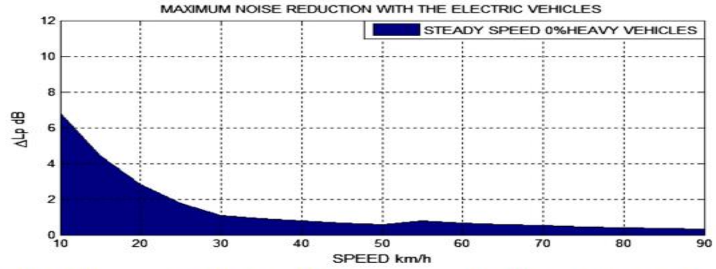


Figure 26: Distance at which the vehicle was detected using different warning sounds at the three environments. The dashed line denotes the minimum safe distance. From (Poveda-Martinez et al., 2017)

A Spanish study from 2017 (Campello-Vicente et al., 2017) investigated the expected noise effects of EVs and HEVs on noise maps in an urban environment through measurement and simulation. The noise emitted from the selected vehicles was measured and used in conjunction with the NMPB ROUTES noise prediction model (Besnard et al., 2009) to simulate a traffic environment and estimate the resulting noise levels and effects on the population. Results from the study displayed in Fig. 27 show the estimated noise reduction in dB at different speeds that is achieved by having a vehicle population of EVs with and without AVAS, compared to ICE vehicles. The difference in either case decreases with speed, as expected from the predominance of the tyre-road interaction and other noise sources at higher speeds. Between 10 km/h and 20 km/h, the EVs without AVAS achieve a noise reduction from 10 dB to 4 dB. The reduction is not as significant when AVAS is equipped, in which case it ranges from 7 dB to 3 dB. Figure 28 shows the results from the simulations regarding the number of citizens affected by high noise levels, given a street traffic consisting of EVs without warning sounds, EVs with AVAS, and ICE vehicles (Kournoutos, 2020).



(A) Difference between EVs with no warning sounds and ICE vehicles.



(B) Difference between AVAS equipped EVs and ICE vehicles.

Figure 27: Estimated difference in noise levels between a traffic consisting entirely of EVs with either no warning sound or equipped with AVAS, and of entirely ICE vehicles. As presented in (Campello-Vicente et al., 2017)

Though the results for the AVAS equipped EVs indicate that more people are exposed to higher noise levels than would be without AVAS, the situation still shows noticeable improvements compared to ICE vehicles. Thus, a reduction in noise pollution could still be achieved even with the current guidelines for AVAS in effect (Kournoutos, 2020).

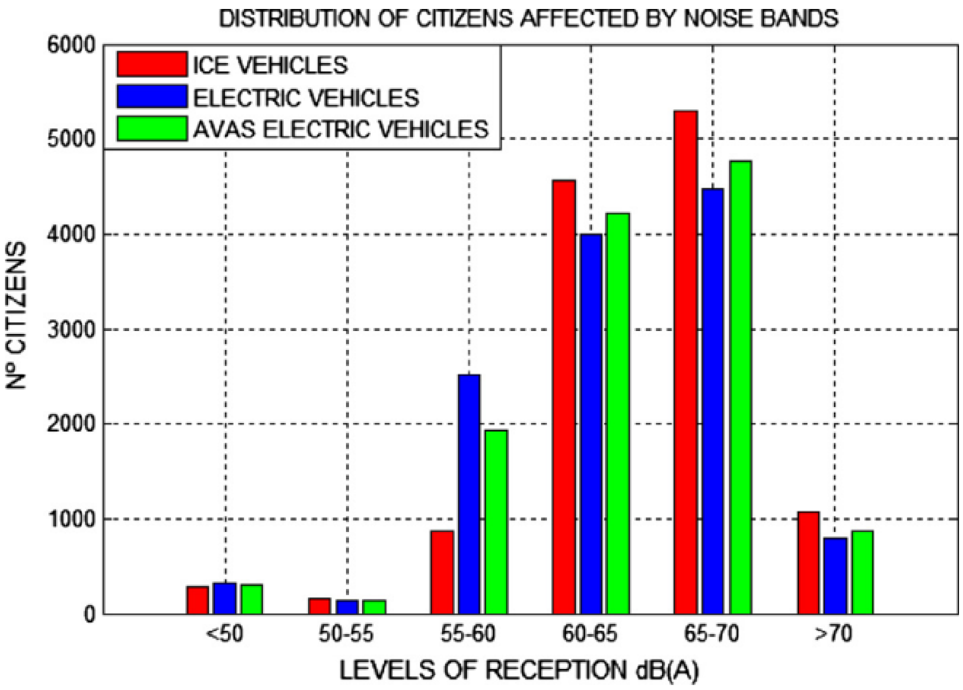


Figure 28: Number of citizens affected by different sound levels of the noise generated from EVs, EVs equipped with AVAS and ICE vehicles. From (Campello-Vicente et al., 2017)

AIS System for Commercial Vehicles

As the inclusion of artificial warning sounds has become mandatory in the majority of the world, manufacturers of EVs and HEVs produce their vehicles with preinstalled AVAS-compliant warning sound systems (Kournoutos, 2020). Currently, warning sound systems in wide production use either a single or a pair of loudspeaker drivers installed usually under the bonnet in a forward-facing orientation. Let us understand the number of characteristic examples of such systems that are being used, or exist at a stage of development as presented by Kournoutos (Kournoutos, 2020).

Nissan has so far been the first and only major EV manufacturer to openly publish the research around the development of the warning sound used for their vehicles (Konet et al., 2011) (Tabata, 2010). The system has been named Vehicle Sound for Pedestrians (VSP). The system uses a single speaker placed under the bonnet of the vehicle, which is used to emit the warning sound both when moving forward and reversing. Under compliance to AVAS regulations, the system remains active as long as the vehicle is in operation, and produces the sound up to a speed of 30 km/h. The VSP warning sound itself was designed with consideration to the frequency sensitivity of the human ear. For this reason, a peak in the spectrum of the sound was included at 2.5 kHz. An additional peak was added at 600 Hz for better detectability from persons with age related hearing loss. This lower frequency component also displays an amplitude modulation to enhance its detectability in the presence of ambient noise. The VSP sound spectrum is also characterized by a dip at 1 kHz, as the ambient noise of traffic was found to consistently peak near that frequency. The system generates a sound pressure level ranging from 50 to 54 dB, which is lower than the 55 to 58 dB produced from a typical ICE.

Similarly, the Hyundai Motor Company, jointly with Kia Motors Corporation, have patented a Virtual Engine Sound System (VESS) for use in their EVs and HEVs (You et al., 2020). Currently, EVs and HEVs from Hyundai and Kia use a single loudspeaker mounted to the front bumper of the vehicle to emit the warning sound. The VESS is planned to incorporate various sub-systems in the vehicle to identify vulnerable road users and emit the warning sound towards their location (Kournoutos, 2020).

Figure 29 shows the schematic of the main functional components for VESS. An on-board camera and radar are able to detect the presence of a pedestrian or other vulnerable road user in the path of the vehicle. Along with information on the status of the vehicle, such as speed and steering, this data serves to determine the characteristics of the warning sound, and also the direction at which it will be emitted to match the location of the target. This aims to achieve a precise warning without generating noise that affects the rest of the environment. Such a system requires at least six loudspeakers in order to effectively control the sound beam, and, as alleged by the authors of (You et al., 2020), such a configuration would result in an increased production cost for the vehicle. For this reason, the necessity to develop new methods and apparatuses that are capable of achieving the same results at reasonable costs is acknowledged.

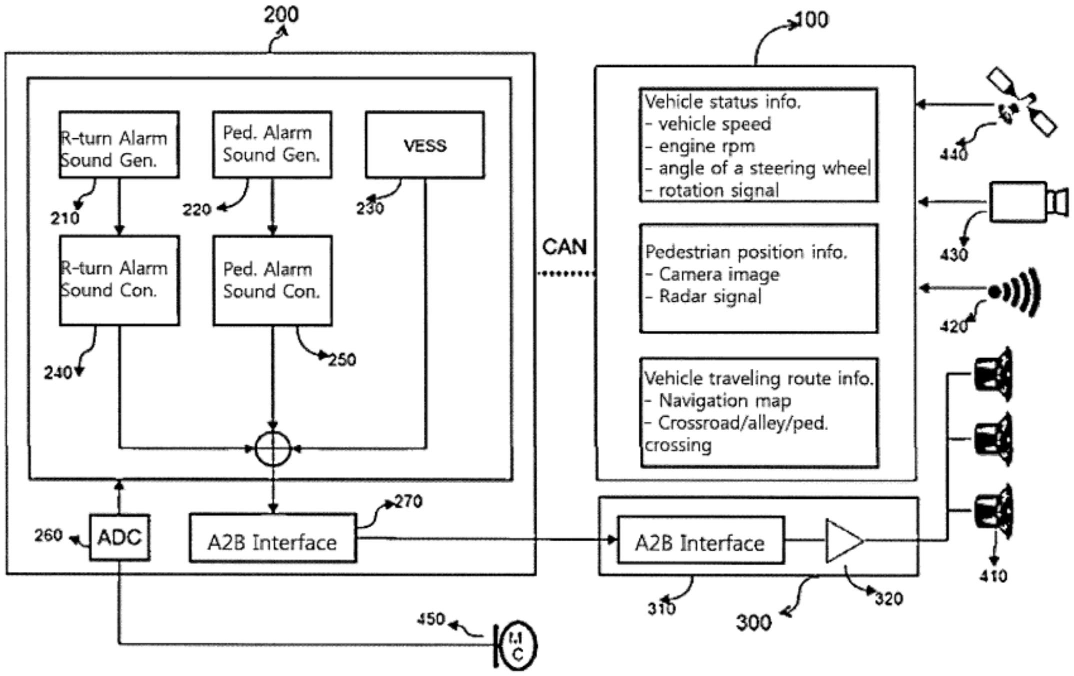


Figure 29: Schematic showing the components and operation sequence for VESS, as presented in (You et al., 2020)

Other AIS Systems

As presented by Kournoutos (Kournoutos, 2020) in their study, other EV and HEV manufacturers equip their vehicles with AVAS compliant warning sound systems, however no detailed information has been made publicly available regarding the composition of the sounds used or the particulars of their operation. The majority of systems that are currently used employ simple loudspeaker drivers, typically installed under the bonnet or near the front grille or bumper of the vehicle to emit the warning sound. EV sound systems had been developed in the past prior to the AVAS regulations being formed. Either as warning systems, in response to the concerns voiced over safety issues, or purely as means of enhancing the driving experience (Kournoutos, 2020).

- The Danish company EC Tunes developed a system capable of being retrofitted to a vehicle without an existing warning system (Kournoutos, 2020). Marketed both for the private users and automotive manufacturers the system used a control box with software, digital amplifiers and three external speakers, of which two mounted in the front and one in the rear of the vehicle. A selection of ICE simulating sound packs was available, which adapted with speed and acceleration of the vehicle.

- Lotus Engineering and Harman Becker, in cooperation, have been developing the HALOsonic system from an active noise control configuration used to cancel out intrusive noises inside a car (Kournoutos, 2020). The same system was adapted to simulate engine sounds to provide audible cues to the driver. This technology eventually shaped into the HALOsonic Internal and External Electronic Sound Synthesis system, which features a number of noise solutions, including an algorithm for pedestrian warning. The sounds are of simulated engines, and the option exists as above to have different settings externally and inside the car.
- Soundracer is a manufacturer of after-market electronic engine sound devices based in Sweden. Their EVEES product is aimed at providing a more enjoyable driving experience by incorporating actual recorded engine sounds instead of synthesized ones. For the latter reason, the system provides the option of being deactivated or not at speeds chosen by the driver (Soundracer AB, 2017).

However, as the AVAS regulations have imposed strict guidelines on the characteristics of warning sounds, systems like the ones presented above are either becoming abandoned or limited to use as alternative engine sounds solely for use in the interior of the vehicle.

2.9 Various types of Warning Sounds and Drive-by Noise

Studies presented in the previous sections as per Kournostos (Kournoutos, 2020) indicate that artificial warning sounds lead to a perceivable increase in traffic noise generated by EVs, which, although lower in level than that generated by ICEs, potentially negates the benefit of reducing noise pollution that would otherwise be achieved. Studies on the impact on environmental noise that artificial warning sounds on EVs and HEVs presented in the previous section indicate that the inclusion of AVAS technologies compromises the benefit of noise pollution reduction that quiet vehicles would otherwise bring. For this reason, concern and criticism over the mandatory use of auditory alarms has been voiced. This section gives an overview of such arguments, and presents solutions that have been suggested to achieve both objectives of safety and noise reduction (Kournoutos, 2020).

Concerns Over the Use of Warning Sounds

In the study made by Kournoutos (Kournoutos, 2020) various arguments concerning the use of warning sound has been meticulously captured. One of the aspects as per study of Govindswamy and Eisele in 2011 regarding the passer-by-noise comparison of a ICE Fiat 500 Car (Govindswamy and Eisele, 2011) with an EV called Liiondrive shows the difference between the electric and the ICE version of the Fiat 500 is very small, and in fact the Liiondrive is actually louder at high speeds. The details of the study by Kournoutos (Kournoutos, 2020) are as follows:

Since the prospect of installing artificial sound generators in EVs and HEVs was first discussed, and in the years prior to the finalization of the AVAS regulations, concerns have been voiced regarding the potential increase in noise pollution the measures might cause. From the results presented in Section 2.7 (Electric Vehicles and Pedestrian Safety), while the NHTSA study (Hanna, 2009; Wu et al., 2011) has found a significant relationship for incidents between quiet vehicles and pedestrians or cyclists, the studies from the UK (Muirhead and Walter, 2011) and Japan (JASIC, 2009) conclude that statistical evidence is too limited to identify such a relationship. A Dutch study on the effect of EVs on traffic noise and the environment (Verheijen and Jabben, 2010) stresses how artificial warning sounds will negate numerous of the benefits that would normally be associated with the wide adoption of EVs and HEVs. In particular, efforts to curb noise pollution in urban centers may be ultimately undone as the noise of ICEs will merely be replaced by artificial sounds, and adverse health effects caused by noise annoyance will remain. In this respect, the study recommends the investigation of safety measures other than imposing minimum noise levels or continuous warning sounds. A fact that has been addressed by Sandberg (Sandberg et al., 2010) is that the presence of quiet vehicles in traffic is not a phenomenon that first appeared with the arrival of HEVs. The study mentions that bicycles, another quiet means of transportation, are often cycled on pavements among pedestrians. In addition, trams and electrically powered trolley buses have also been present in urban environments for decades, and have developed to be increasingly quiet without sparking concern over the same issues. Lastly, as has been put forward in (Muirhead and Walter, 2011), ICE vehicles have for some time been comparably quiet. An example of particular relevance to this argument can be found in a 2011 study on the sound characteristics of EVs (Govindswamy and Eisele, 2011). Here, a measurement of the noise from a standard petrol Fiat 500 was compared to an electrified version of the car named Liiondrive. Figure 30 shows the measured pass-by noise from the electric and ICE versions. The rolling noise was also measured with the engine switched off and, since everything except for the propulsion was identical about the cars, it was assumed as the same for both versions of the vehicle. From the depicted example it can be seen that the difference between the electric and the ICE version of the Fiat 500 is very small, and in fact the Liiondrive is actually louder at high speeds. The latter observation can be explained by the fact that the electric version was fixed in second gear, which would mean an increase in noise at high speeds, as seen in the previously presented study by Lelong and Michelet (Lelong, 2001) shown in Fig. 17. The rolling noise seems also to dominate at all speeds. These results indicate that ICE vehicles are occasionally just as quiet as EVs and HEVs. The conclusion here could be that either additional warning sources are unnecessary, as ICE vehicles are already quiet without an observable increase in collision incidents, or necessary for all quiet vehicles, regardless of propulsion means.

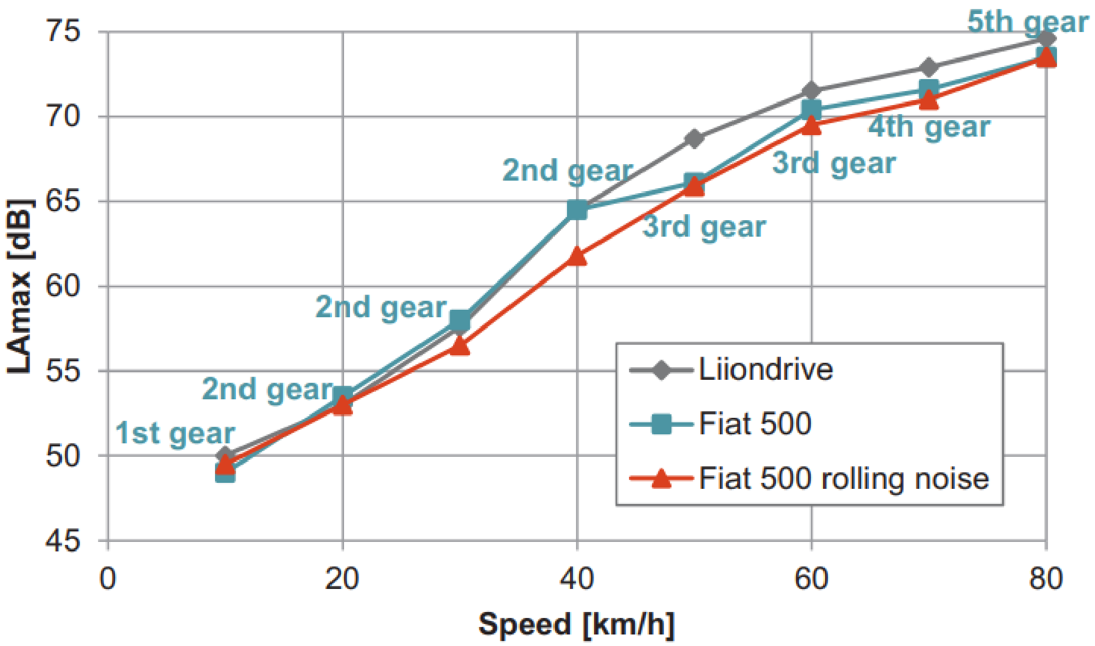


Figure 30: Exterior pass-by noise level of an electric car (Liiondrive) and a similar ICE car (Fiat 500). The Liiondrive is an electrified version of the Fiat 500 and is fixed in 2nd gear. The rolling noise of the two cars is assumed to be the same and the presented rolling noise is therefore for both vehicles. From (Govindswamy and Eisele, 2011), as presented in (Iversen et al., 2013)

One last argument against the mandatory use of warning sounds, presented in (Sandberg et al., 2010), is the fact that headphone or earphone use has become increasingly common for pedestrians, cyclists and drivers alike. These devices, especially if used with noise-cancelling technology, effectively isolate the users from their environment. Thus, any auditory warning produced by an oncoming vehicle will have no effect on these individuals. A study conducted in the Netherlands (Stelling-Konczak et al., 2017) focused on the impact that music listening and activities such as talking on the phone had on the incident involvement rates for Dutch cyclists. There was not any strong correlation found, however the study stresses that the majority of the cyclists seldom encountered quiet vehicles on the road. Therefore, as the number of EVs and HEVs is increasing, the question remains whether cyclists and pedestrians who listen to music or talk on the phone will sufficiently compensate for the limited auditory output of these vehicles. The arguments presented above can be considered valid as to how artificial warning sounds might have limited positive impact for the majority of the public, and even cause more annoyance than convenience due to the resulting noise pollution. However, citizen groups such as the visually impaired, who are reliant on auditory cues for their safety, should not be isolated. The same could hold true for animals, domesticated or wild, that often find themselves near roads, though at this point, research on the effects of quiet vehicles on animal safety remains limited. Lastly, auditory warnings should not be ruled out as a means of ensuring the safety of the wider public in specific circumstances, particularly starting and reversing manoeuvres. It is therefore important to continue working towards the development of warning sound systems that render the vehicle detectable to any vulnerable person that might be affected by its presence, while at the same time minimizing its contributions to environmental noise. The following sections present suggestions for warning sounds and warning sound system concepts that intend to achieve both of these objectives.

Adaptive Warning Sound Systems

Similarly, in the Kournoutos Study, the possibility of adopting an adaptive AVAS system has also been considered. As per (Kournoutos, 2020), current AVAS regulations specify inflexible minimum sound levels for the warning sounds regardless of the sonic environment that surrounds the vehicle. As seen in studies presented in this chapter (Poveda-Martinez et al., 2017; Yamauchi, 2014), the level and spectrum of background noise has an effect in the perceptibility of a auditory warning. It would therefore mean that the warning sound needs to be emitted at a higher level to overcome increased environmental noise, and thus, if a global minimum level is defined by guidelines, the warning sound would be unnecessarily loud and intrusive in quieter environments. A solution to this would be an adaptive warning sound, capable of amplifying or attenuating its signal depending on the current level of environmental noise. This has been investigated by SINTEF in Norway (Berge and Haukland, 2019) in a study that evaluated the effect in detectability of the vehicle that a variance in background noise levels brings. The study was performed with a jury consisting of participants with both normal or impaired vision, using an EV with a speaker that emitted a warning sound at an adjustable level. The speed at which the tests were performed was 20 km/h. The results indicated that at the chosen speed, tyre noise had already become the primary noise source instead of the warning sound. In addition, for a background noise level of 60 to 65 dB, indicative for a busy urban street, the intended minimum level for the AVAS was found too low for detection. This last finding suggests that an adaptive AVAS might be necessary in order to achieve safety and limit noise pollution at the same time, as the level required to render the vehicle detectable in a loud environment would be a major source of noise in a quieter situation. One thing worth noting about the above study is that the adaptation of the warning sound is performed by adjusting the gain on the overall signal. As the usual composition of AVAS sounds is of discrete frequency bands, the extent to which the sound is masked by the background noise may not be an issue of its overall level, but the level of a specific frequency component which is masked by a sound in the current environment, in a tone masked by wide band noise scenario (Zwicker and Fastl, 2013). Masking effects have been considered in the evaluation of warning sounds (Lee et al., 2017), but not as part of an adaptive system. An adaptive system that considers the above effects, and is capable of adjusting specific components of the warning sound to avoid masking effects could potentially constitute a more refined and precise solution to the problem and will be focused in next section. In any case, however, such a system would require the alteration of current AVAS regulations to consider different minimum levels depending on the environment.

Directional Warning Sound Systems

As shown in the Kournoutos study (Kournoutos, 2020), another important research that could influence the effect of AIS systems is the detectability of a vehicle by pedestrians and vulnerable road users, while keeping the overall sound emissions to a minimum, that could be achieved without interfering with the spectral content of the warning sound itself, would be to impose control over the shape of the radiated sound field. This would mean that the design of a warning sound emitting system that is capable of controlled directivity over a bandwidth sufficient to cover the contents of a warning sound. Directional warning sound solutions have been suggested, including the filing of patents, for systems consisting of arrays of multiple loudspeakers (Kim and Moon, 2014) or parametric drivers (Pompei, 2006). However, despite the investigations of such concepts, no directional systems have been implemented in production vehicles of any type at the time of this research.

eVADER

Another warning sound system aimed to maximize detectability and minimize its environmental impact was conducted and documented in the European project eVADER by Quinn (Quinn et al., 2014) that has been also covered by Kournostos (Kournoutos, 2020) in their literature review. The project partly focused on the development of a warning sound that could be easily detectable without causing annoyance (Parizet et al., 2014). The project utilized an Environmental Perception System (EPS) incorporating a windscreen-mounted stereo camera and front chassis-mounted radar. In addition to the EPS, a Location Based System (LBS) was used to support risk estimation based on GPS position, time of day and a database of hotspots, critical areas and speed limits. The components are displayed as positioned in the test vehicle in Fig. 31.

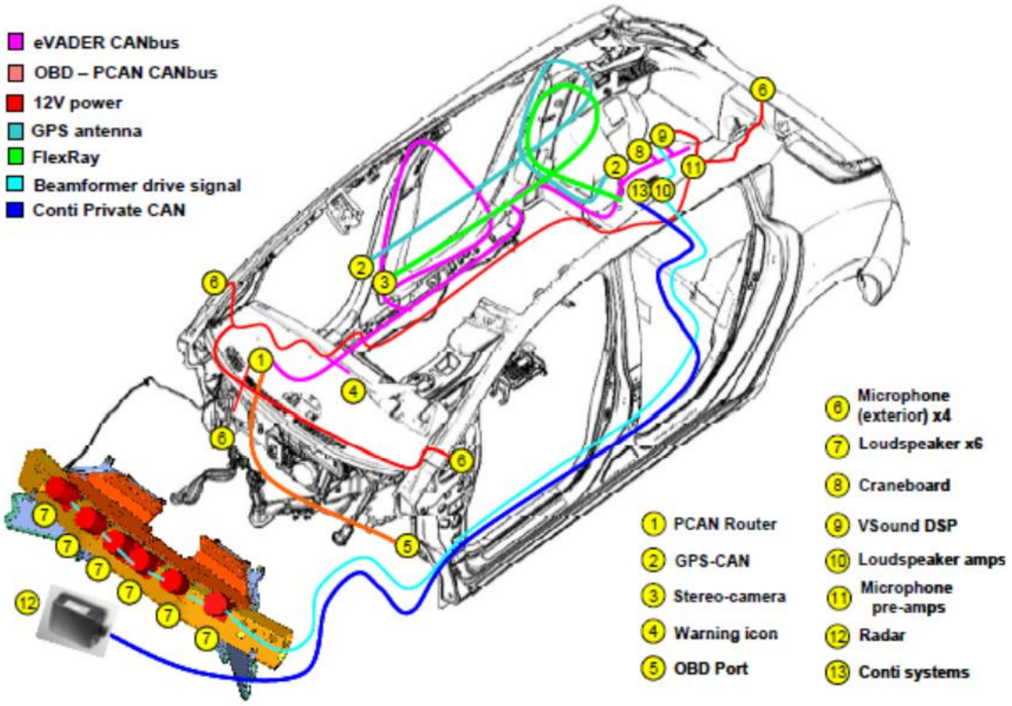


Figure 31: Schematic of the components comprising the full eVADER system. Note the six-loudspeaker array arranged along the forward bumper (7), used to achieve a directional sound field. Figure as presented in (Quinn et al., 2014).

Similar to other warning sound systems mentioned here, the eVADER system only emitted sound at speeds below 35 km/h. On-board microphones measured the prevailing ambient noise levels so the overall level of the warning sound could be adjusted in response. The default condition, when no vulnerable road users are detected, had the system emit a low-level sound in the general direction of travel of the vehicle. When a vulnerable road user was located, the warning sound was directed towards them, with the sound beam becoming spatially narrower and increasing in sound level, depending on the collision risk.

The eVADER system achieved directional sound radiation through a six-loudspeaker array installed in the forward bumper of the vehicle. This array could be controlled via adjusting the phase and amplitude of the signals sent to each loudspeaker in order to control the width of the sound beam and direct it towards specific locations. To achieve this control, a sound-power minimization algorithm was used, as presented in (van der Rots and Berkhoff, 2015). Figure

32 shows the beamforming performance of the array in terms of the resulting directivity patterns for settings directed forward and at angles of 30◦ and 60◦. The system is seen to be capable of amplifying the sound by at least 10 dB at the location of a vulnerable road user, though the width of the beam increases at higher steering angle settings.

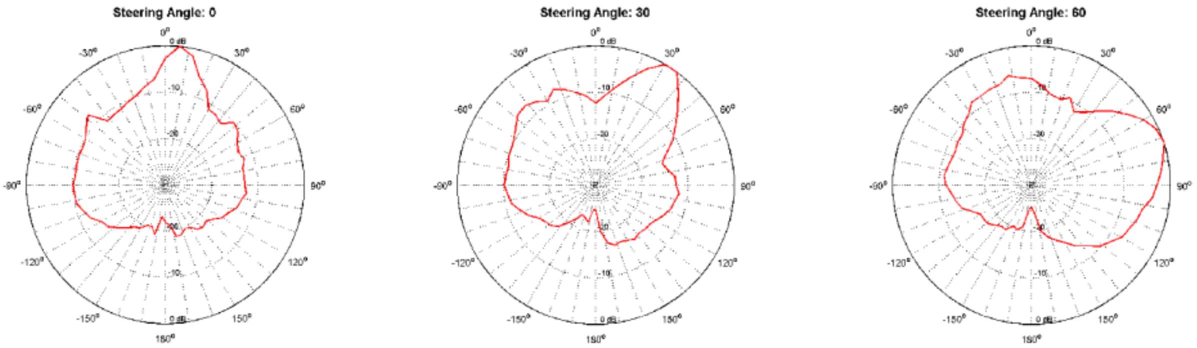


Figure 32: Resulting directivity patterns from the eVADER system, for the beamformer focused on the forward direction and at 30◦ and 60◦ steering angles. Figure as presented in (Quinn et al., 2014).

Overall, eVADER offered a highly refined solution to the warning sound problem by focusing a sound only towards the locations where it is necessary to be conveyed, ensuring that the qualities of the warning sound render it detectable without causing annoyance, and even foreseeing for the adjustment of its level depending on the sonic environment. However, such a solution still has not seen a wide adoption by the industry, possibly due to the high production costs it encompasses, particularly when it comes to the installation of a full-size loudspeaker array in a somewhat vulnerable position at the front bumper of the vehicle.

2.10 Summary of Literature Review

Through the literature review we can conclude that AVAS should be adopted in each EV by the EV manufacturing OEMs in India. Further a deep study needs to be carried out for India to carve out suitable specifications for AVAS as the city traffic noise for India is not similar to that of other countries. As per (Mishra et al., 2019), the current urban city noise at various locations in Delhi ranges from 72.4 to 81.6 dB(A) which is much higher as compared to the rest of the world. Also, the population demography is another factor which needs to be considered. The co-existence of other ICE vehicles also impacts the overall noise and makes it difficult to identify a silent EV. Therefore, a deep study on the city ambient noise in Indian traffic conditions becomes very important to actually understand the level of sound dBA that can have the masking affect. The circumvent the same and develop suitable AIS system with the right sound level and frequency modulation is important. The intensity of sound versus the audibility distance is another aspect on which many researchers has already performed various trials in the European countries. This is a must exercise to be conducted in India with the prevailing city ambient noise so a s the carve out the results on the approach audible distance. The lab test for the acoustic sound type and frequencies is also important to identify the suitable one in the India context. Similar tests are being conducted across the world to identify the same. In the research to be conducted for India, similar surveys and road tests are to be conducted as seen in the literature review. Further, suitable adaptive sound levels are also to be derived to understand the most effective ones which can make the vehicle easily identifiable from the required minimum safe distance. Beyond this the surveys amongst the EV owners and the general pedestrians are also another factor which will give a constructive direction to the prevailing problem. Through the literature review we have seen that earlier researchers have conducted test related to comparison of sound produced by a traditional ICE versus that of an EV. This input is also another importance evidence to collate the as-is sound frequencies and levels. The passer-by-noise is another important study that has helped to understand the minimum audible sound of an EV from a defined distance. While taking this forward many researchers have conducted advanced study on the sound frequency ($_{Hz}$) modulation, directional of sound, positioning of the speaker in array, etc. to understand the most effective conditions to implementation of AVAS in an EV. Another interesting aspect that came out was on concerns that have been raised regarding the potential increase in noise pollution the measures might cause. While we continue on the next chapters, we will further expand through this research the various other factors that could be more relevant to Indian conditions and can impact the effective adoption of AVAS system in Indian EVs.

Chapter 3

Research Methodology

3.1 Overview of the research problem

Through the literature review it has been observed that many countries have understood the essence of implementation of AVAS as a mandatory requirement for all BEV, PHEV and HEV and therefore regulations have been brought by them. However, in case of India, the similar regulation cannot be adopted considering various socio-economic and demographic factors those are quite different than compared to countries like US, European Union, Japan, Korea, etc. These factors are mainly the population demography of India, city urban noise, traffic density, type of vehicles and road infrastructure. The main objective of this research is to study and arrive upon a suitable regulation specific to India with detailed specifications of AVAS sound (dBA) level to be adopted for various types of vehicles depending upon their type (scooters, motorcycles, 3-wheelers, Passenger Cars, LCVs or MCVs), laden weight, maximum vehicle speed, etc. It aims to study the city ambient traffic noise at various location of India to arrive upon the optimum sound dBA levels. Further, it intends to survey among pedestrians, general commuters and EV vehicle riders to understand their perspectives on the various conditions that they face while in traffic. The research also aims to conduct various acoustic tests in laboratory and simulate on road conditions to derive AVAS sound levels necessary to recognize the presence of an EV plying on road or approaching a crowded locality with pedestrians around. The study results may facilitate the necessary framework for regulations to be brought in for deployment of AVAS in electric vehicles in India.

3.2 Outlaying research approach

The objective of the research is to study and arrive upon a suitable regulation specific to India with detailed specifications of AVAS sound (dBA) level to be adopted for various types of electric vehicles. For this a detailed study on the city ambient traffic noise at various location of India is necessary to arrive upon the optimum sound dBA levels. Further, a survey among pedestrians, general commuters and EV vehicle riders is important to understand their perspectives on various conditions that they face in traffic. Detailed acoustic tests are to be conducted in laboratory to simulate on road conditions and derive AVAS sound levels necessary to recognize the presence of an EV plying on road or approaching a crowded locality with pedestrians around. Therefore, following broad activities were planned to achieve the desired outcome from this research:

1. Survey among the EV owners to identify their first-hand experience and views on the silence of their vehicle and the inconvenience related.
2. Survey among the pedestrians with age group varying from 18 to 60+ years divided in four groups namely 18-30 years, 31-50 years, 51-60 years, and 61 years and above. The age group can be moderated to relate on the various other conditions that could be relevant to the specific age.
3. Laboratory tests to create basic understanding on the following:
    a. The sound produced by an ICE vehicle based on their categories, e.g., 2-wheeler scooters, motorcycles, 3-wheelers auto rickshaw, small car - hatchback – sedan - SUV (on Diesel and Gasoline). These data are collated to understand the as-is conditions and further it is also classified in six different stages as follows:
        i. Sound produced by the ICE at speed level between 0-20 KMPH
        ii. Sound produced by the ICE at speed level between 20-30 KMPH
        iii. Sound produced by the ICE at speed level between 30-40 KMPH

    iv. Sound produced by the ICE at speed level between 40-50 KMPH

b. Intensity of the sound (IS) Vs the audibility distance (AD) is another important factor that influences the pedestrian to recognize an approaching vehicle on road. Therefore, tests are conducted to analyse the as-is condition in case of an ICE vehicle so that the same can simulated in case of an EV.

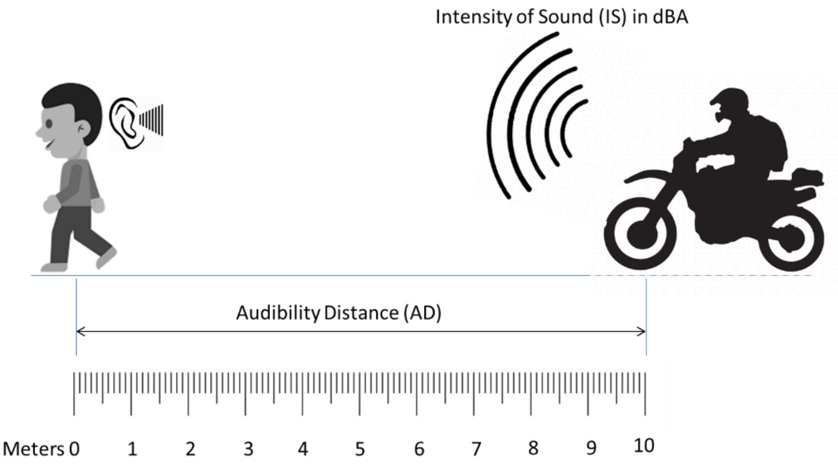


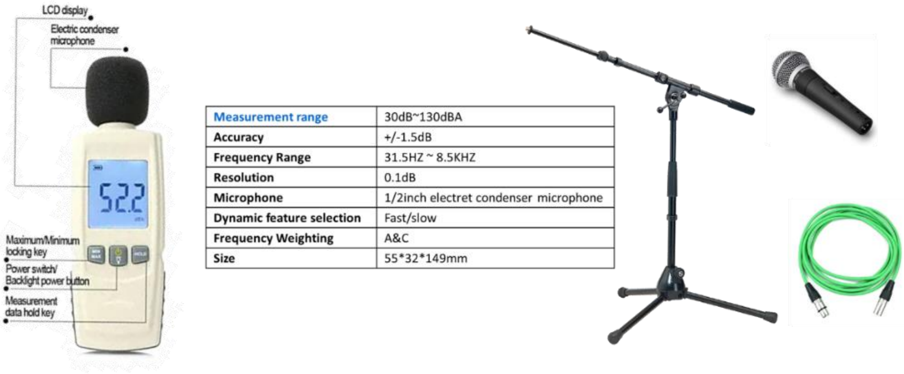
Figure 33: Intensity of Sound (IS) (dBA) Versus Audibility Distance (Meters)

c. Based on the literature review, the frequency of the sound produced by the vehicle is also an important factor for audibility. Therefore, frequency of the sound produced by an ICE vehicle is studied and data is captured to analyse the same. Instruments like Oscilloscope and spectrum analysers are used to measure the readings.

Figure 34: Oscilloscope and Spectrum Analyzer used for measuring frequency

d. Tests are conducted with an EV without having an AVAS system to understand the audibility distance (AD) due to the peripheral sounds created by tyre and motor noise both in a relatively low ambient noise area and under populated city ambient noise. The audibility distance (AD) is measured and the same is further analysed to infer conclusions on the absence of AVAS in the EV.

e. Traffic noise is considered as one of the important sources of noise pollution and its contribution is approximately 75% of the total noise pollution in urban areas. Delhi is considered as second noisiest city in the world. Before narrowing down to most suitable sound levels that an AVAS need to generate in urban India, it is very important to make an in-depth study of traffic noise in Indian urban cities. Therefore, data is collected from various parts of populated traffic to analyse the city ambient noise (dBA) level. Same is also compared with earlier literature review data to understand the co-relation of the increasing trend, if any. To conduct this test various apparatus are used, e.g., digital sound level meter, cable, microphone, microphone stand, etc.



Measurement range	30dB~130dBA
Accuracy	+/-1.5dB
Frequency Range	31.5HZ ~ 8.5KHZ
Resolution	0.1dB
Microphone	1/2inch electret condenser microphone
Dynamic feature selection	Fast/slow
Frequency Weighting	A&C
Size	55*32*149mm

Figure 35: Digital Sound Level (dBA) Meter, Microphone, Cable and Microphone Stand, etc.

3.3 Survey Among EV Owners

A survey among the EV / HEV owners was conducted to understand their perspective on the various conditions that they face once they migrate to EV from traditional ICE vehicles. The survey was drafted in google forms [1] and were distributed. The responses then collated for further study. The google form in the initial heading gives a perspective of the survey and clearly defines the purpose of such survey to enable the EV owners understand the subject. It specifies the importance of artificial sound for silent electric vehicles for safety of pedestrians and averting accidents. The form included a para mentioning that at present the electric vehicles in India are silent. Due to this, it becomes hard for pedestrians to recognize an approaching EV under masking urban noise and can be a potential cause of accident. The purpose of this survey is to understand the inconvenience of the EV owners while driving these silent EVs on busy Indian roads with many pedestrians around that may also include children, senior citizens and physically impaired persons. Following are some of the questions that were asked to the EV owners for their comments and perspective:

1. The first question was regarding their level of inconvenience that they face while their vehicle's presence is not felt or identified by pedestrians or other people around them in the streets. Options for answers in a scale of 1 to 10 were given as:
   a. slight inconvenient - (1-3),
   b. moderate inconvenience - (4-6) and
   c. high inconvenience - (7-10).
2. The second question asked was regarding their age group. The question asks to select their age group which was divided in four groups 18-30 years, 31-50 years , 51-60 years and above 60 years.

3. The third question asks about times that they may have faced a near miss on a possible accident due to the same? The options for answer were to choose between once, twice or more. This gives a reflection on the intensity of severity of the problem.
4. The fourth question was about the increase in frequency of blowing horn ever since they have shifted to EV from conventional ICE vehicle? The options for their answers were given with yes, no and maybe. Indirectly, this could also bring upon a synthesis of being unheard by the pedestrian or other vehicles plying on the road alongside their EVs.
5. The fifth question tries to acquire their recommendation on whether their EV should also produce some level of natural sound to make its presence felt by others in the traffic? And the given options on answers were only in yes and no. The inference of their answers can directly influence the survey.
6. The sixth question is about whether they believe that an acoustic artificial sound in their vehicle can make it easy for the pedestrians, children or senior citizens to identify their vehicle while they are driving in a crowded street or in blind turns or corners? The options for the answers were yes, no and maybe.

3.4 Survey Among Pedestrians

Similarly, it was important to collect the perspective of pedestrians toward the adoption of EVs in India and their feedback on inconvenience that they may have faced due to the same. Another google form [2] concerning the relative questions was used to collect the necessary inputs. The form heading says importance of artificial sound for silent electric vehicles to feel the presence of an approaching EV for safety of pedestrians and averting accidents (Pedestrians Form). A para was included to set the context mentioning that at present the electric vehicles in India are silent. Due to this, it becomes hard for pedestrians to recognize an approaching EV under masking urban noise and can be a potential cause of accident. The purpose of this survey is to understand your perspective on busy Indian roads with many pedestrians around that may also include children, senior citizens and physically impaired persons. Some of the questions that were considered are as follows:

1. The first question asks that how important do they feel the sound of a vehicle helps them to identify a vehicle approaching towards them while they walk down a street? The options that were given to answer this question in a scale on 1 to 10 were
    a. very important - (7-10),
    b. moderate - (4-6) and
    c. negligible - (1-3).
2. The second question asked was regarding their age group. The question asks to select their age group which was divided in four groups:
    a. 18-30 years,
    b. 31-50 years,
    c. 51-60 years and
    d. above 60 years
3. The third question was regarding their opinion on whether it will be inconvenient for them and other pedestrians or children or senior citizens to recognize a silent vehicle on road? The options given for their answer were either yes or no or maybe.
4. The fourth question asks about the probability in terms of percentage (%) of a possible accident on road due to absence of any sound in a vehicle in India? And the options for their answer were:
    a. 10-30%
    b. 40-60% and
    c. 70-100%.

5. The fifth question asks about times that they may have faced a near miss on a possible accident due to the same? This gives a reflection on the severity of the problem. The options for answer were:
    a. Once
    b. twice
    c. more
    d. Not till date

3.5 Laboratory tests

The first lab test conducted as explained in the section 3.2 was to identify the sound produced by an ICE vehicle in as-is condition. This would be helpful to understand the sound dBA level in current scenario. To do this experiment a vehicle dyno was used wherein the front wheel of the vehicle is fixed with the dyno fixture and the rear wheel is placed on the rollers to be able to move freely while accelerating at various speeds. Figure 36 and 37 below shows a lab setup where an ICE Scooter and Motorcycle is being tested for the sound levels (dBA). Once the setup is ready the sound has been recorded with the help of a sound meter shown in the figure 36. To have more inference of sound acoustics two numbers of sound meters are placed at a distance of 1 meter and 3 meters respectively. Same has been shown in the below figure 38. Thereafter, readings have been taken at various speeds (KMPH) of vehicle starting from 10 kmph to 50 kmph in an interval of 10 kmph. The reading will help to understand that whether in case of an ICE the sound level fades out while the speed is increase beyond a certain speed or the trend of increase in sound is unidirectional.

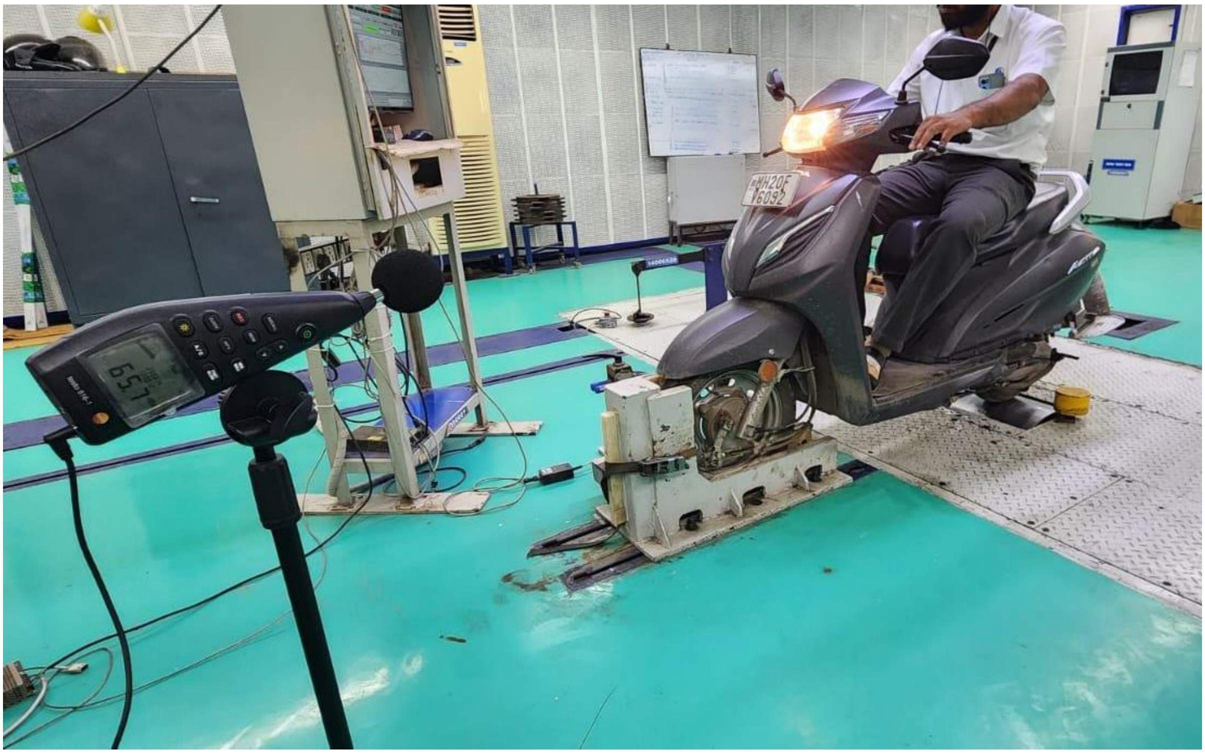


Figure 36: Sound level testing in Lab of ICE scooter at variable speeds with the help of sound meter placed at a distance of one meter from the vehicles.

Figure 37: Sound level testing in Lab of ICE Motorcycle at variable speeds with the help of sound meter placed at a distance of one meter from the vehicles.

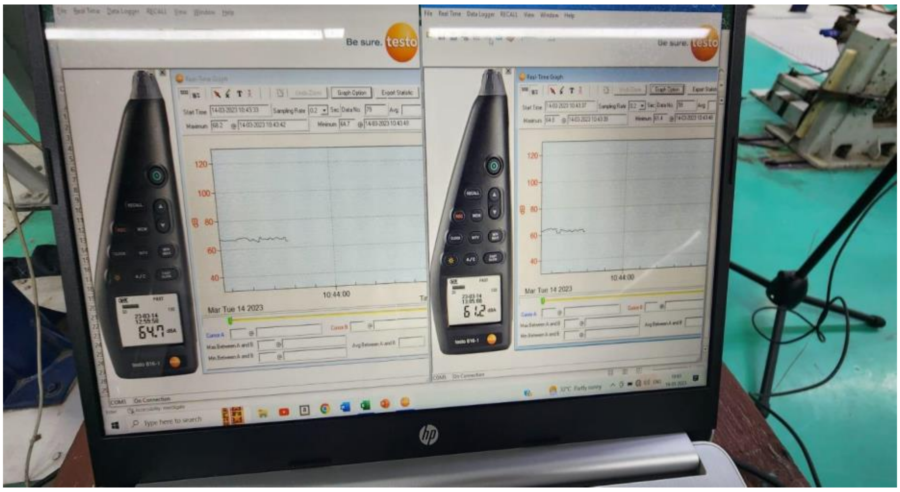


Figure 38: Two meters are placed at a distance of one meter and three meters from the vehicle to record the sound levels at variable speeds from 10kmph to 50 kmph in the test lab on the vehicle dyno.

Similarly, after the ICE trials an EV scooter from Hero Electric was chosen to record sound level data in the lab. The set up was done on the vehicle dyno similar to the ICE vehicle with two numbers sound meters placed at a distance of one and three meters from the vehicle. Figure 39 below shows the setup. Also, while performing this test the ambient noise of the lab was also collected. It was also kept identical to that of the ICE vehicle.

Figure 39: Sound level testing in Lab of EV Hero Electric Scooter at variable speeds with the help of sound meter placed at a distance of one meter from the vehicles.

3.6 Intensity of the sound (IS) Vs the audibility distance (AD)

Intensity of the sound (IS) Vs the audibility distance (AD) is another important factor that influences the pedestrian to recognize an approaching vehicle on road. Therefore, tests were conducted to analyze the as-is condition in case of an ICE vehicle so that the same can simulated in case of an EV. To conduct these tests, we selected ten participants who volunteered for the same. A setup was built on the road with fixing masking tapes at one meter gap to understand the total distance and count the same while a vehicle passes away. The below figure 40 shows the same.

Figure 40: Experiment setup for Intensity of sound (IS) Versus Audibility Distance (AD) with masking tapes at one meter distance to calculate the vehicle distance.

Five types of vehicles were selected to conduct the tests. ICE Scooter (Honda Activa), ICE Motorcycle (Bajaj Avenger), ICE SUV (Mahindra Xylo), ICE Hatchback (Suzuki Baleno), EV Scooter (Hero Electric) and EV Hatchback (Tata Nexon). The participants stood 2 m from the center line A-A as shown in Fig. 40, forming a line with 1-m intervals. The experimental scene is shown below in Fig. 41 and 42. So that the participants paid attention to the sound emitted from vehicles, the participants stood with their backs to the vehicle and closed their eyes during the experiment. The vehicles passed behind the participants at variable speeds starting from 10kmph to 50kmph and the results were recorded. The participants were instructed to raise their hands only when they hear and recognize the sound of an approaching vehicle. The participants were 7 male and 3 female embedded electronics professionals having an average age of 23.4 years. The experiment was recorded using a video camera.

Figure 41: Experimental scene of Intensity of Sound (IS) Versus Audibility Distance (AD) wherein participants are standing in a row at a gap of 1 meter from each one.

Figure 42: Experimental scene of Intensity of Sound (IS) Versus Audibility Distance (AD) wherein participants are raising their hands once they recognize an approaching vehicle.

While recording the sound level (dBA) and the audibility distance it was also important to record the frequency (KHz) of the sound which influence the participants hearing senses. Therefore, a matrix was made between the frequency (KHz) and amplitude (dBA) of the sound recorded. The same was then normalized with the help of Oscilloscope and spectrum analyzer. Few of the experiment scenes are shown below in figure 43, 44 and 45.

Figure 43: Experimental scene of IS Vs AD on Hero Electric EV Scooter

Figure 44: Experimental scene of IS Vs AD on ICE SUV Mahindra Xylo

Figure 45: Experimental scene of IS Vs AD on ICE Hatchback Suzuki Baleno

3.7 Sound Frequency Comparison of ICE Vs EV

Through the IS Vs AD tests significant data was collected to analyze the decibel (dBA) levels that would be necessary for an EV to emit while on road. However, the nature of sound and its effect of the audibility strength is directly proportionate to its frequency and the amplitude of the frequency that the sound produces. Therefore, the collected sound data was then subjected to spectrum analysis to understand the graph on frequency Vs amplitude compared with the traditional ICE. The spectrum was then normalized to form a pattern that could represent the band in case of various types of vehicles as taken for the experiments above. The below figures from 46 to 50 shows audio spectrum band collected with the help of sound recording meter and analyzed in the spectrum analyzer.

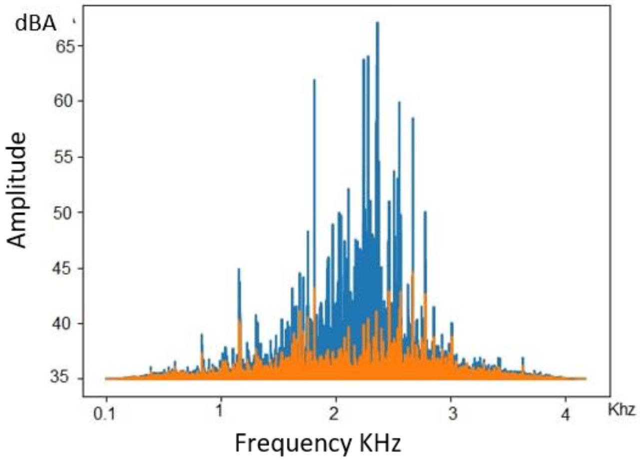


Figure 46: Sound spectrum of Hero Electric EV Scooter

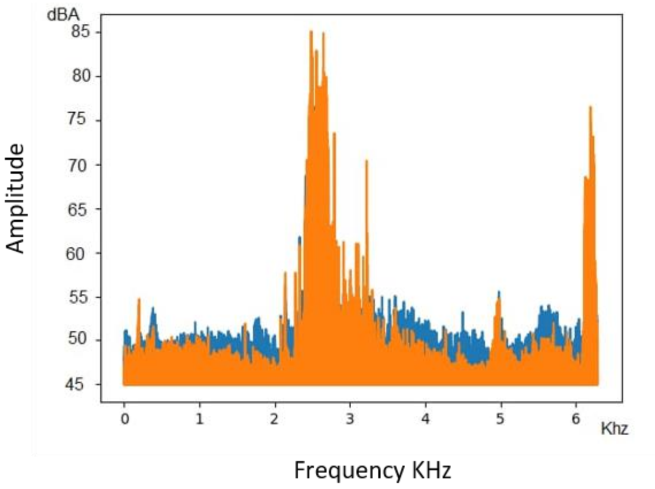


Figure 47: Sound spectrum of ICE SUV Mahindra Xylo

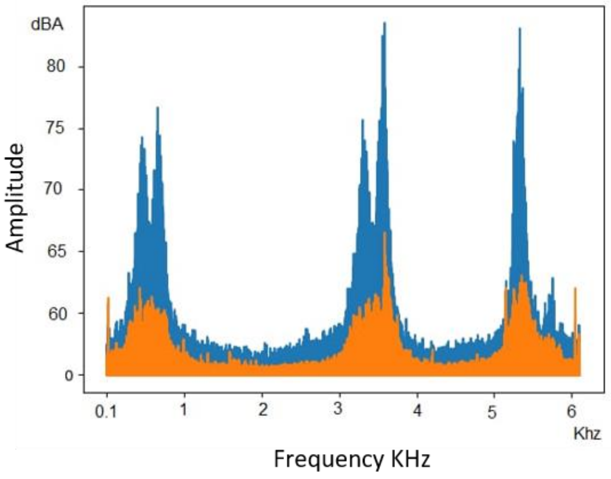


Figure 48: Sound spectrum of ICE Hatchback Suzuki Baleno

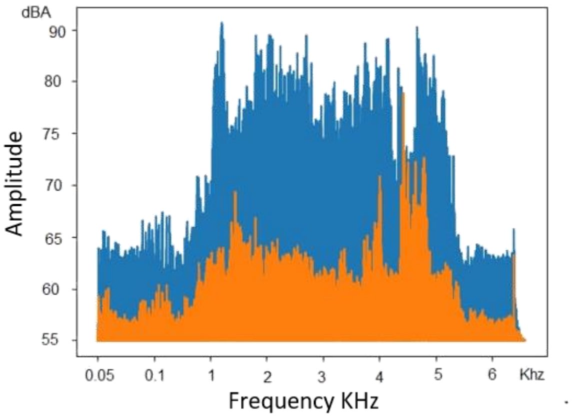


Figure 49: Sound spectrum of ICE Scooter Honda Activa

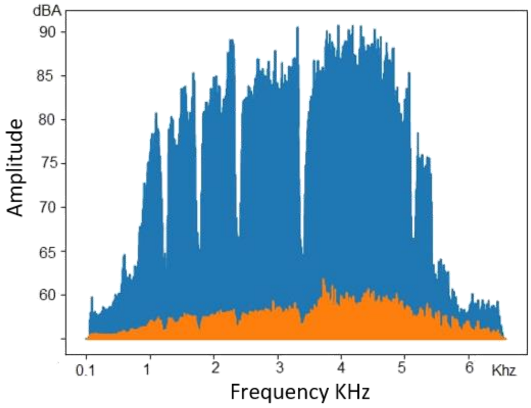


Figure 50: Sound spectrum of ICE Motorcycle Bajaj CD100

3.8 City Ambient Noise

Before narrowing down to most suitable sound levels that an AVAS need to generate in urban India, it is very important to make an in-depth study of traffic noise in Indian urban cities. Therefore, we started collecting the data at selected areas with the help of sound recording meters to understand the city ambient noise alongside the traffic on roads. These experiments were conducted in the city of Aurangabad, Pune and Bengaluru of India. The collected data provides us the overall peak sound levels of road traffic and thereby the masking effect that it may have on an EV. The below figures 51, 52 and 53 are showing the setup which was used to record the city ambient noise.

Figure 51: City Ambient Noise data collection in the city of Pune – India

Figure 52: City Ambient Noise Data Collection in the city of Bengaluru – India

Figure 53: City Ambient Noise Data Collection in the city of Aurangabad – India

3.9 Conclusion

This chapter presented the various methods that were adopted to study the factors necessary to be considered while constructing a regulatory mandate in India towards adoption of AVAS for EVs. The overall research has been broadly divided in two segments. The first one focuses on understanding the people’s sentiment through survey among the EV owners and the pedestrians and the second one is to conduct various tests to understand the audibility distance compared to the ICEs. While conducting the experiments it was noticed that mimicking the ICE sound for EVs can be more effective for the pedestrians around. This has been experienced by the participants volunteered in the experiments. Other artificial sounds were difficult to be related as for an approaching vehicle than the sound as emitted by the current ICE vehicles. Probably this could be relevant to human psychology that is trained to accept the typical ICE sound as the sound of a vehicle. The outcome of these experiments precisely helped us to narrow down on few important artifacts as given below:

1. The level of inconvenience that the EV owners and the pedestrians face in the absence of an AVAS system in EVs thereby signifying the importance of adoption of such system in India through mandatory regulations.
2. The suitable sound dBA level and frequency that should be considered while drafting a mandatory regulation specific to India.
3. The behaviour of AVAS fitted in an EV while accelerating from low-speed levels to a higher speed.
4. The type of sound that an EV should produce to make it easily identifiable compared to an ICE.

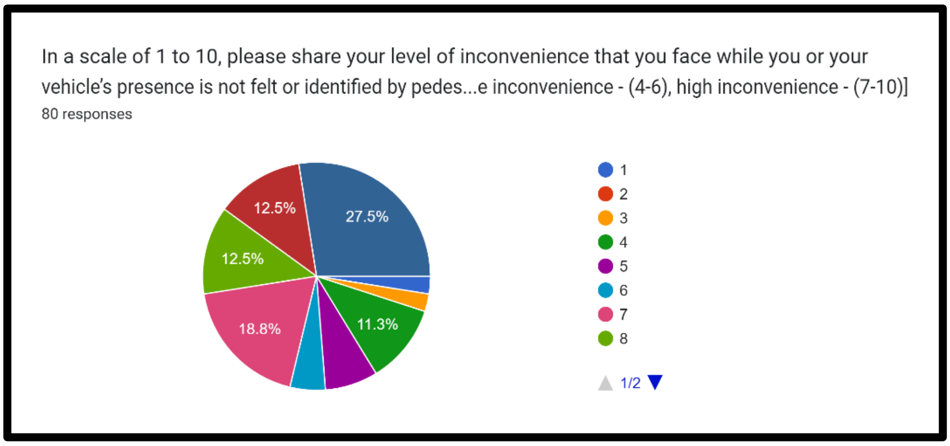
In the next chapter, the results of our investigations and experiments have been collated and analyzed to conclude on aspects that would provide logical reasoning to why AVAS should be a mandatory regulation in India to curb road safety issues.

Chapter 4

Results

4.1 Survey Results – EV Owners

A survey among the EV owners was conducted to understand their perspective on the various conditions that they face once they migrate to EV from traditional ICE vehicles. The survey was drafted in google forms and were distributed. Total 82 participants responded to the survey. The age was grouped in four categories namely 18-30 years, 31-50 years, 51-60 years and above 61 years. This was done to understand their perspectives also by relating them to their age group. Total 6 questions were asked in the survey. The *first question* in the form asks that in a scale of 1 to 10, please share your level of inconvenience that you face while you or your vehicle's presence is not felt or identified by pedestrians or other people around you in the streets. [slight inconvenient - (1-3), moderate inconvenience - (4-6), high inconvenience - (7-10)]. The answers are ungrouped in a scale of 1 to 10. The overall response when presented without grouping shows that 27.5% replied 10 in scale, i.e., high inconvenience, whereas 12.5% replied 9, another 12.5% replied 8 and 18.8% replied 7. Since we grouped 7-10 as high inconvenience, if we total these responses, we see that *71.3% participants responded as high level of inconvenience while their vehicle presence is not felt by pedestrians around them*. The other category of severity on scale for 6 is 5%, for 5 is 7.5% and for 4 is 11.3% which totals to 23.8% for the moderate inconvenience category. For the slight inconvenience category, the responses were balance 4.9%. The below figure 54 shows a pie chart copied from Survey Form [1] describing how the responses to the above question are distributed.



In a scale of 1 to 10, please share your level of inconvenience that you face while you or your vehicle's presence is not felt or identified by pedes...e inconvenience - (4-6), high inconvenience - (7-10)]

80 responses

Figure 54: Responses of question 1 for survey made with EV owners through google forms

The results of the question 1 clearly indicates that majority of the EV owners has expressed high level of inconvenience and considering the severity of the question, if we club the moderate inconvenience category to the same then the broad and clear reply to the question is that the EV owners do feel that in the absence of an AVAS system it is hard for the pedestrians to recognize silent EVs on the road.

The question 2 was about the age group of the participants. The results show that out of 82 participants *77.5% fall in the age group of 18-30 years*, while 31-50 years are 17.5% and balance 51-60 years were 5%. The inference we get from this grouping is that majority of the respondents are in the age group of 18-30 years and that means the EV is more popular in the young age group compared to middle age.

Question 3 was related to the near miss on a possible accident that the EV owners may have faced due to the absence of an AVAS system. The replies were categorized in Once, Twice and More. As per the survey results, *41.6% owners claimed to have a near miss once*, while 19.5% claim to have faced similar incidence for twice. Balance, 39% owners claimed to have faced similar incidence more than twice. The results show high severity of possible accidents. This has clearly indicated that AVAS can add critical value to avert such safety concerns. The below figure 55 shows a pie chart copied from google form [1] describing how the responses to the above question are distributed.

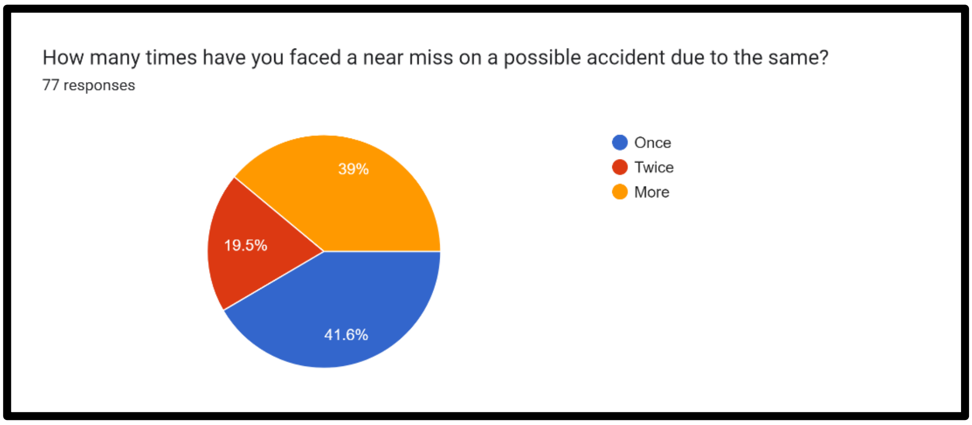


Figure 55: Responses of question 3 for survey made with EV owners through google forms

Question 4 was related to the frequency of blowing horn since they have shifted to EV from conventional ICE vehicle. The answers were categorized in Yes, No and Maybe. As per the respond received through the survey, *61.3% participants replied in Yes*, whereas, 16.2% said No and balance 22.5% participants said Maybe. In case we consider only the Yes responses, we can consider that the majority of participants believe that their frequency of blowing horn has significantly increased ever since they have migrated to EV from conventional ICE. This adds to the earlier questions on inconvenience faced in absence of AVAS system in the EVs. Figure 56 below, shows a pie chart copied from google form [1] describing how the responses to the above question are distributed.

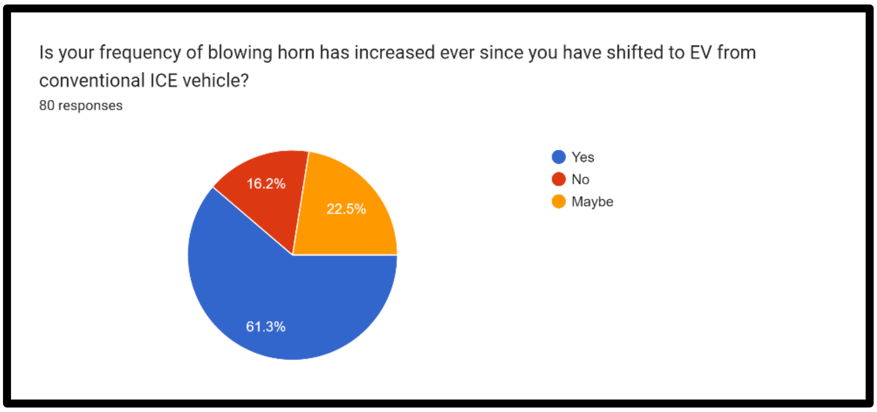
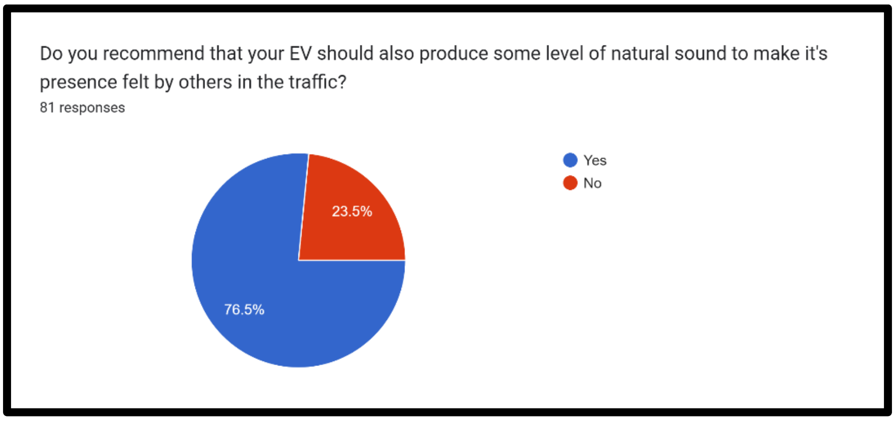


Figure 56: Responses of question 4 for survey made with EV owners through google forms

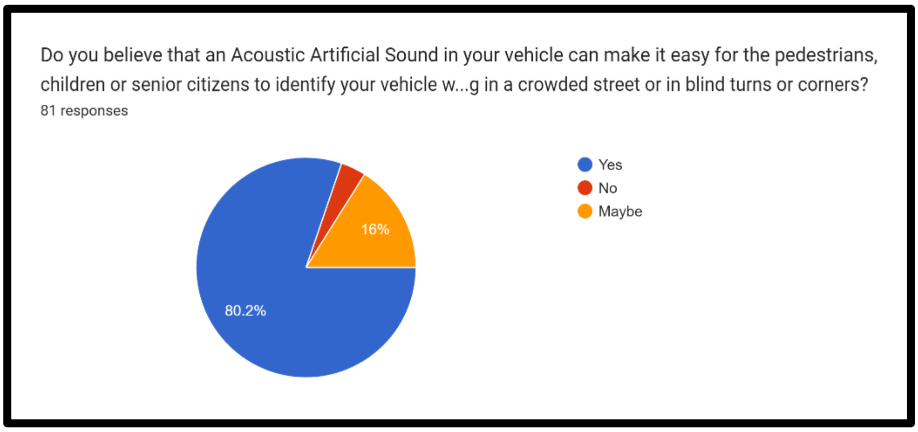
Question 5 in the survey form was about their recommendation on whether their EV should produce some level of natural sound to make its presence felt by others in the traffic? To make the response more concise, the option given on answers was only in Yes or No. The survey results show that *76.5% participants responded in Yes* and they believe that such system will help making their EV's presence felt in traffic. However, there were 23.5% participants who believe that the same shall not be helpful. Figure 57 below, shows a pie chart copied from google form [1] describing how the responses to the above question are distributed.



Do you recommend that your EV should also produce some level of natural sound to make it's presence felt by others in the traffic?
81 responses

Figure 57: Responses of question 5 for survey made with EV owners through google forms

Question 6 in the survey form was whether they believe that an Acoustic Artificial Sound in their vehicle can make it easy for the pedestrians, children or senior citizens to identify their vehicle while they are driving in a crowded street or in blind turns or corners. The answers were categorized in Yes, No and Maybe. The survey results show that *80.2% participants responded in Yes* and they believe that such system will make it easy for the pedestrians, children or senior citizens to identify their vehicle while they are driving in a crowded street or in blind turns or corners. Further, 16.1% participants partially believe in same and responded as Maybe. However, 3.7% participants believe that it may not be helpful. The responses indicate that majority of the EV owners do believe that an AVAS system in their vehicle can be helpful to make it easy for the pedestrians, senior citizens and children to identify their vehicle while driving in a crowded street. Figure 58 below, shows a pie chart copied from google form [1] describing how the responses to the above question are distributed.



Do you believe that an Acoustic Artificial Sound in your vehicle can make it easy for the pedestrians, children or senior citizens to identify your vehicle w...g in a crowded street or in blind turns or corners?
81 responses

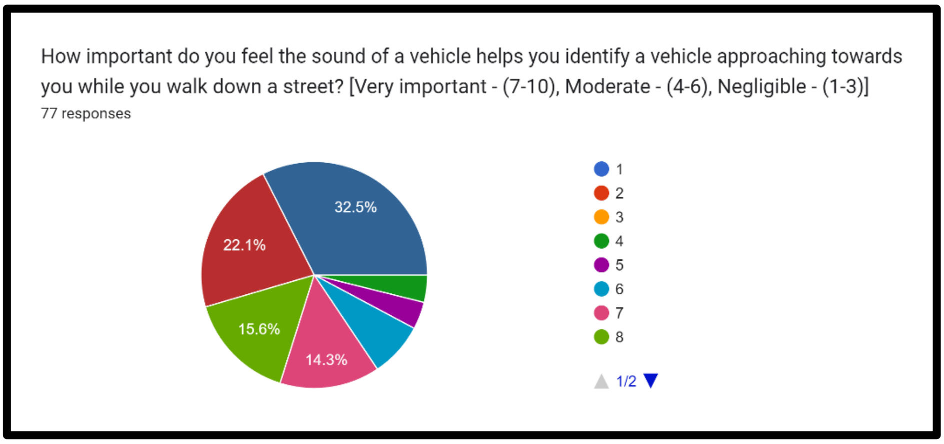
Figure 58: Responses of question 6 for survey made with EV owners through google forms

Summary

In the section 4.1, the survey conducted through google forms [1] for EV owners has been explained. The investigation clearly indicates that majority of the EV owners believe that an acoustic sound system in their EV can be quite helpful for make their vehicle's presence felt by nearing pedestrians and other vehicles on the road. On the inconvenience index total 71.3% participants responded as high level of inconvenience due to absence of AVAS system. Further, 41.6% owners reported at least once a near miss on possible accident. 61.3% owners claimed that their frequency of blowing horn has increased ever since they have shifted to EV from conventional ICE vehicle. While on their recommendation to have a AVAS system in their vehicle, 76.5% owners agreed that such acoustic system can be helpful to avert accidents. Also 80.2% owners believe that such system will make it easy for the pedestrians, senior citizens and children to identify their vehicles in crowded streets. *Overall, the survey results clearly* *indicates that EV owners do acclaim that silent EVs are inconvenient and can be a cause of potential accidents*.

4.2 Survey Results – Pedestrians

A survey among the pedestrians was conducted to understand their perspective on the various conditions that they face while encountering silent EVs plying on road. The survey was drafted in google forms [2] and were distributed. The form heading says importance of artificial sound for silent electric vehicles to feel the presence of an approaching EV for safety of pedestrians and averting accidents (Pedestrians Form). A para was included to set the context mentioning that at present the electric vehicles in India are silent. Due to this, it becomes hard for pedestrians to recognize an approaching EV under masking urban noise and can be a potential cause of accident. The purpose of this survey is to understand your perspective on busy Indian roads with many pedestrians around that may also include children, senior citizens and physically impaired persons. Total 77 participants responded to the survey. The age was grouped in four categories namely 18-30 years, 31-50 years, 51-60 years and above 61 years. This was done to understand their perspectives also by relating them to their age group. Total 5 questions were asked in the survey. The *first question* asks that in a scale of 1 to 10, how important do you feel the sound of a vehicle helps you identify a vehicle approaching towards you while you walk down a street? [Very important - (7-10), Moderate - (4-6), Negligible - (1-3)]. The answers are ungrouped in a scale of 1 to 10. The overall response when presented without grouping shows that 32.5% replied 10 in scale, whereas 22.1% replied 9, another 15.6% replied 8 and 14.3% replied 7. Since we grouped 7-10 as very important, if we total these responses, we see that *84.5% participants responded as very important while they walk down a street*. The other category of severity on scale for 6 is 7.8%, for 5 is 3.9% and for 4 is 3.8% which totals to 15.5% for the moderate category. Out of total 77 participants no one responded for *Negligible* category. The below figure 59 shows a pie chart copied from Survey Form [2] describing how the responses to the above question are distributed.

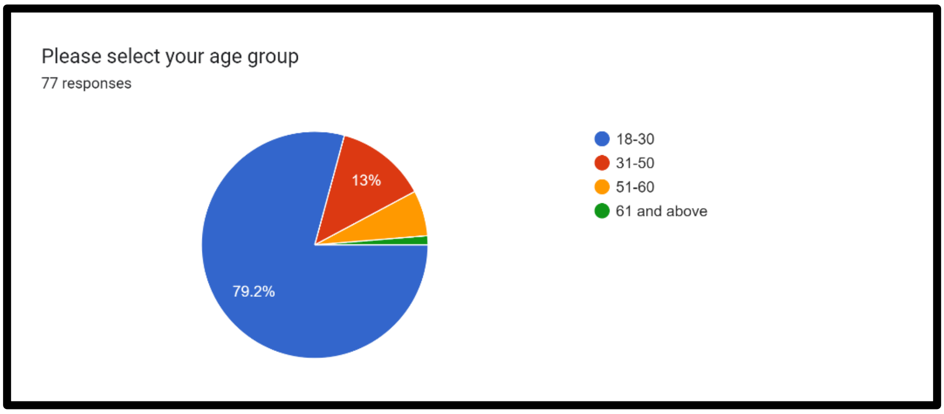


How important do you feel the sound of a vehicle helps you identify a vehicle approaching towards you while you walk down a street? [Very important - (7-10), Moderate - (4-6), Negligible - (1-3)]

77 responses

Figure 59: Responses of question 1 for survey made with Pedestrians through google forms

The question 2 was about the age group of the participants. The results show that out of 77 participants *79.2% fall in the age group of 18-30 years*, 31-50 years are 13% while 51-60 years were 6.5% and balance 61 years and above were 1.3%. The inference we get from this grouping is that majority of the respondents are in the age group of 18-30 years and that means the EV is more popular in the young age group compared to middle age. The below figure 60 shows a pie chart copied from Survey Form [2] describing how the responses to the above question are distributed.

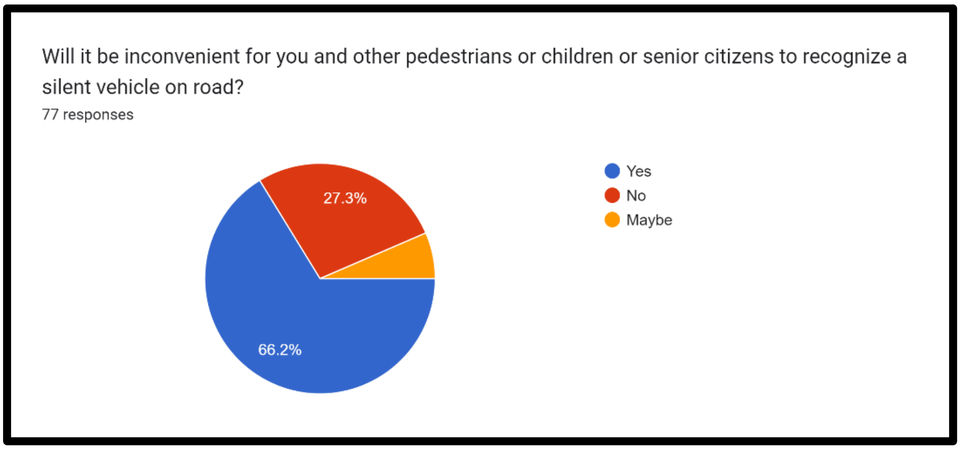


Please select your age group

77 responses

Figure 60: Responses of question 2 for survey made with Pedestrians through google forms

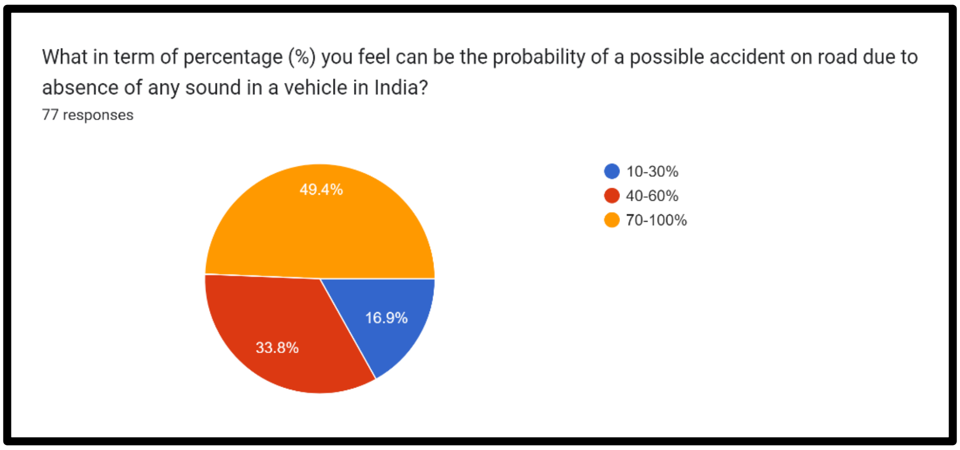
Question 3 was whether it will be inconvenient for the pedestrians or children or senior citizens to recognize an approaching silent vehicle. The answers were categorized in Yes, No and Maybe. The survey results show that *66.2% participants responded in Yes* and they believe that it will be inconvenient for them to recognize a silent vehicle on road. Followed by another 6.5% participants those who replied as Maybe. Therefore, if we group the Yes and Maybe responds together that we can see that total *56 participants out of 77* participants believe that it will be inconvenient for them. However, balance *27.3% participants* have replied in No which indicated that they do not believe that it can create any inconvenience for them. The below figure 61 shows a pie chart copied from Survey Form [2] describing how the responses to the above question are distributed.



Will it be inconvenient for you and other pedestrians or children or senior citizens to recognize a silent vehicle on road?
77 responses

Figure 61: Responses of question 3 for survey made with Pedestrians through google forms

Question 4 of the survey was in terms of percentage (%), what do they feel can be the probability of a possible accident on road due to the absence of AVAS in an EV in India? The options given to answer were divided in three categories. Those were 70-100% for High, 40-60% for Moderate and 10-30% for Low. As per the response received through the survey, *49.4% participants replied in 70-100% category, i.e., High,* whereas, 33.7% participants replied in 40-60% category, i.e., Moderate and balance 16.9% participants replied in 10-30%, i.e., Low probability. If we group the High and Moderate probability responses of the participants, the total comes to 83.1%, which makes it quite evident to consider that majority of the participants believe that in absence of an AVAS system in EVs, there probability of increase in road accidents will be high. The below figure 62 shows a pie chart copied from Survey Form [2] describing how the responses to the above question are distributed.

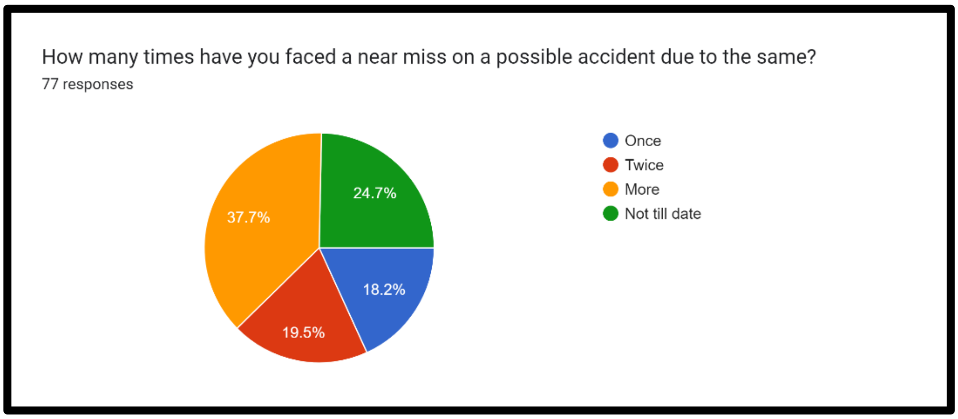


What in term of percentage (%) you feel can be the probability of a possible accident on road due to absence of any sound in a vehicle in India?

77 responses

Figure 62: Responses of question 4 for survey made with Pedestrians through google forms

Question 5 was regarding the number of times that they had a near miss to an accident due to not being able to identify a silent EV approaching towards them. The options for their answers in the survey form [2] were given as Once, Twice, More and Not till Date. As seen through the survey report, out *of total 77 participants, 18.2% said Once, 19.5% said Twice, 37.7% said More than twice and balance 24.6% said that they have not encountered such near miss till date.* Now. If we group all the near misses from once to more than twice, we see that total *75.4% participants have encountered a near miss on a possible accident* due to not being able to identify a silent EV approaching towards them. The overall answers from this question is unambiguously narrowing down to the fact that pedestrians have serious concerns on the silent electric vehicles that pose high probability for potential accidents on road. The below figure 63 shows a pie chart copied from Survey Form [2] describing how the responses to the above question are distributed.



How many times have you faced a near miss on a possible accident due to the same?

77 responses

Figure 63: Responses of question 5 for survey made with Pedestrians through google forms

Summary

In the section 4.2, the survey conducted through google forms [2] for EV owners has been explained. The investigation clearly indicates that majority of the pedestrians do believe that an AVAS system in silent electric vehicles can be quite helpful for them to identify an approaching electric vehicle to avert a potential accident on the road. Of the total pedestrian participants 84.5% agreed that it is important to have a sound in an approaching or plying vehicle on the road so as to make it easy for identifying the presence. Similar answers were received for the question 3 on convenience of senior citizens and children to identify the silent vehicles wherein 72.7% pedestrians agreed that it will be helpful. Further on the probability of possible accidents, total 83.1% participants agreed that the absence of AVAS system in EVs can be a potential cause of accident on road. And through the question 5 when we tried to gauge the severity of happened cases, we found that total 75.4% participants already encountered such near miss on a probable accident due to the absence of AVAS. *Overall, the survey results clearly indicates that participant pedestrians do acclaim that silent EVs are inconvenient and can be a cause of potential accidents*.

4.3 Laboratory Test Results

As described in the section 3.5 above, tests were conducted in lab using a vehicle test rig to acquire the data of the sound produced by a traditional ICE vehicle and EV. The purpose of this data acquisition is to compare the data of both types of vehicles in a similar environment and understand the difference in the overall sound dBA levels. This will also be helpful while deriving the most suitable dBA levels that an AIS system should be able to produce in an EV. Further, the sound dBA level clubbed with the frequency pattern as described in the section 3.7 above wherein the frequency has been plotted against the amplitude for ICE vs EV can be helpful in deriving the suitable sound profile that can be easily identified by any pedestrian.

The first test that was conducted in the lab was on a traditional ICE scooter from *Honda Activa*. To do this experiment a vehicle dyno was used wherein the front wheel of the vehicle is fixed with the dyno fixture and the rear wheel is placed on the rollers to be able to move freely while accelerating at various speeds. Once the setup is ready the sound has been recorded with the help of a sound meter as shown in the figure 36 above. To have more inference of sound acoustics two numbers of sound meters are placed at a distance of 1 meter and 3 meters respectively. Thereafter, readings have been taken at various speeds (KMPH) of vehicle starting from 10 kmph to 50 kmph in an interval of 10 kmph. The reading will help to understand that whether in case of an ICE the sound level fades out while the speed is increased beyond a certain speed or the trend of increase in sound is unidirectional. The readings that we recorded as shown the table 18 below, shows that the ambient noise from the lab environment in sound meter-1 was 62.5 dBA at 1 meter distance from the vehicle dyno and sound meter-2 was 56.1 dBA at 3 meters distance from the vehicle dyno.

Vehicle	**Honda Activa (ICE Scooter)**	
Ambient - Dyno	62.5 dBA	56.1 dBA
Speed Kmph	**Sound dBA @ Meter-1 at 1 meter Distance**	**Sound dBA @ Meter-2 at 3 meter Distance**
10	64.6	57.5
20	66.5	61.1
30	68.2	66.2
40	74.3	71.1
50	81.4	76.6

Table 18: Results of sound dBA test conducted in lab for Honda Activa ICE Scooter

The above results show that incase of both the sound meters the dBA recorded for variable speeds starting from 10kmph to 50kmph travel unidirectionally in increasing order. The ambient noise was also recorded while conducting the tests which shows around 1.4 to 2 decimals less before the ICE vehicle was started. Below figure 64 and 65 is a graphical representation of the sound dBA levels versus the vehicle speeds.

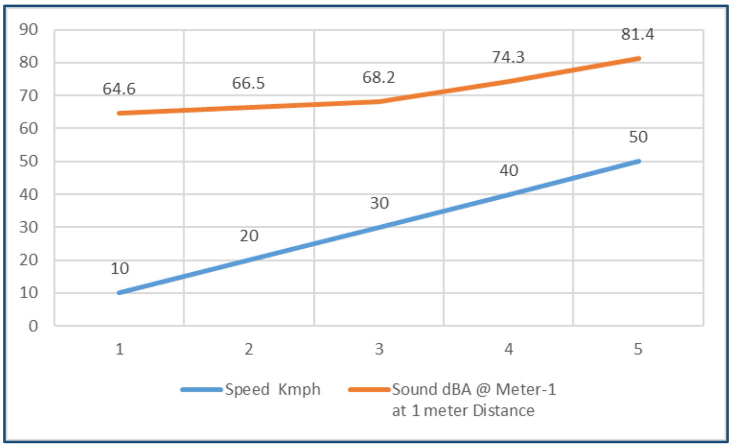


Figure 64: Speed Versus Sound dBA levels for Honda Activa ICE Scooter Sound Meter-1 at 1m distance

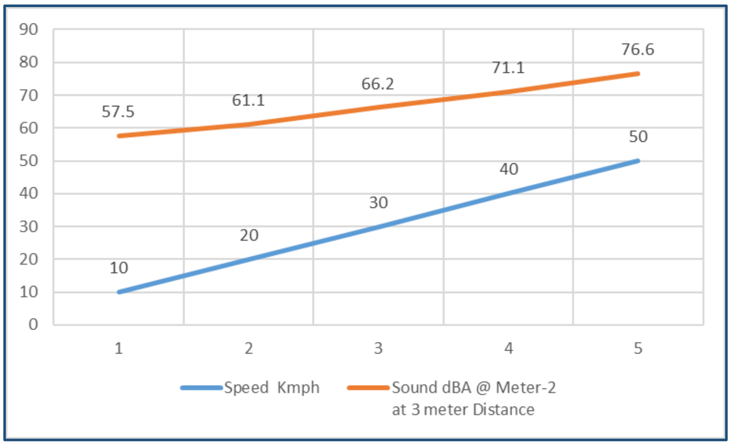
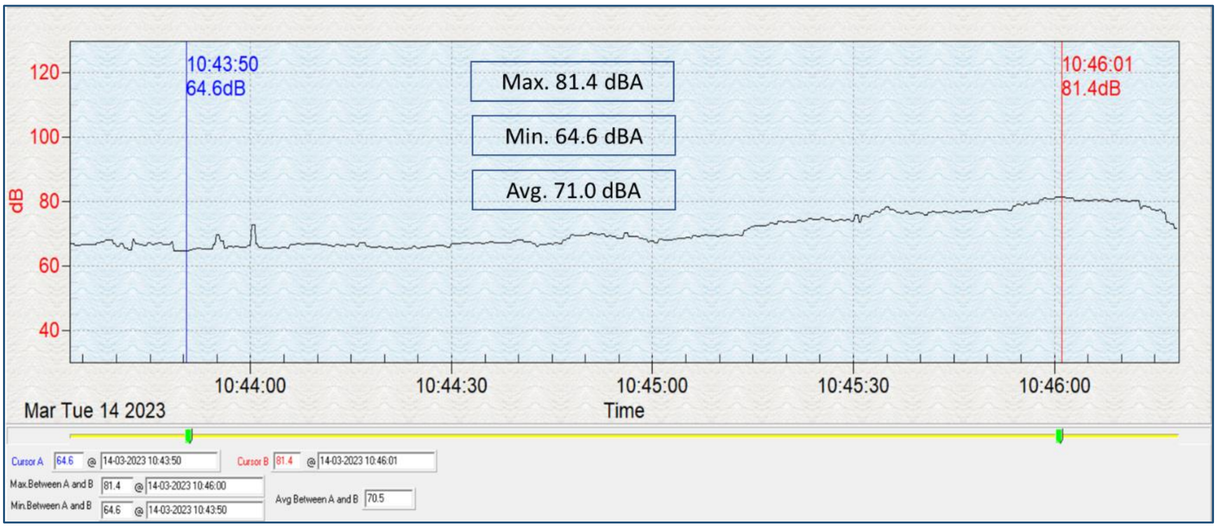


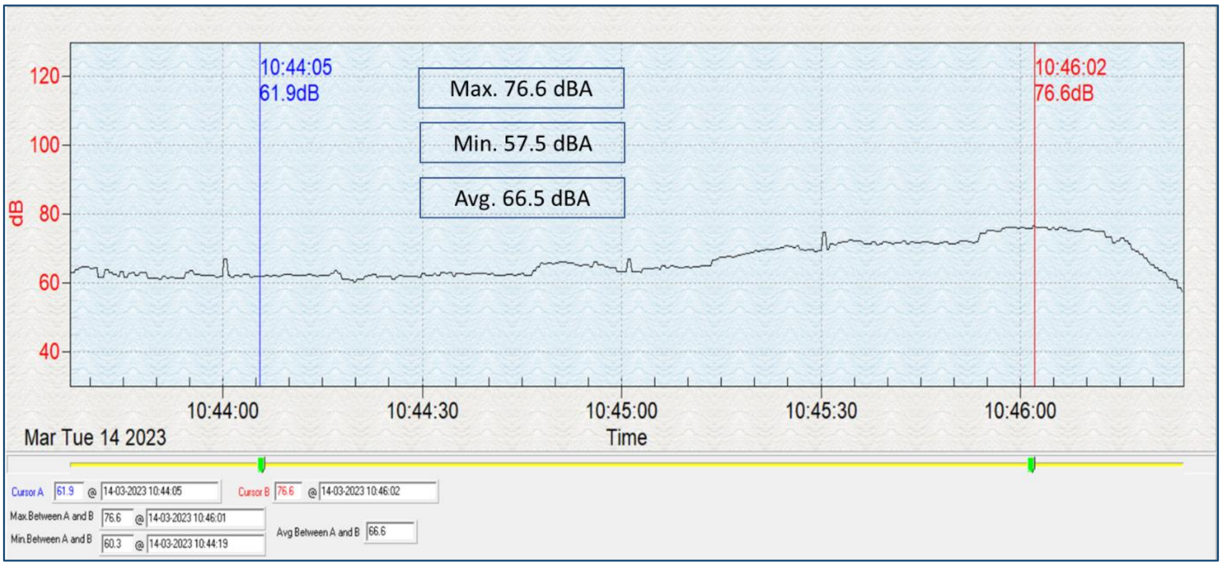
Figure 65: Speed Versus Sound dBA levels for Honda Activa ICE Scooter Sound Meter-2 at 3m distance

Figure 66 and 67 below shows the sound graph derived from the sound meter-1 at 1 meter distance and sound meter-2 at 3-meter distance respectively.



Cursor A 64.6 @ 14-03-2023 10:43:50
Cursor B 81.4 @ 14-03-2023 10:46:01
Max.Between A and B 81.4 @ 14-03-2023 10:46:00
Min.Between A and B 64.6 @ 14-03-2023 10:43:50
Avg Between A and B 70.5

Figure 66: Sound dBA graph for test-1 for Honda Activa ICE Scooter by sound meter-1 at 1m distance



Cursor A 61.9 @ 14-03-2023 10:44:05
Cursor B 76.6 @ 14-03-2023 10:46:02
Max.Between A and B 76.6 @ 14-03-2023 10:46:01
Min.Between A and B 60.3 @ 14-03-2023 10:44:19
Avg Between A and B 66.6

Figure 67: Sound dBA graph for test-1 for Honda Activa ICE Scooter by sound meter-2 at 3m distance

The second test was conducted on Bajaj CD 100 ICE traditional motorcycle. These tests on scooters and motorcycles are very relevant as Indian being the biggest producer and user of 2-wheelers in the world, majority of the people are using these 2-wheelers for daily commuting. Hence in this research we have focused more on 2-wheelers as it needs more attention based on the current scenario of the country. Below table 19 shows the results that we derived in the lab test for Bajaj CD 100 motorcycle.

Vehicle	**Bajaj CD100 (ICE Motorcycle)**	
Ambient - Dyno	62.5 dBA	56.1 dBA
Speed Kmph	**Sound dBA @ Meter-1 at 1 meter Distance**	**Sound dBA @ Meter-2 at 3 meter Distance**
10	67.2	57.9
20	72.7	64.2
30	76.1	71.1
40	80.1	75.7
50	86.2	81.1

Table 19: Results of sound dBA test conducted in lab for Bajaj CD 100 ICE Motorcycle

The above results show that incase of both the sound meters the dBA recorded for variable speeds starting from 10kmph to 50kmph travel unidirectionally in increasing order. The ambient noise shows same results as it was for Honda Activa Scooter. Below figure 68 and 69 is a graphical representation of the sound dBA levels versus the vehicle speeds.

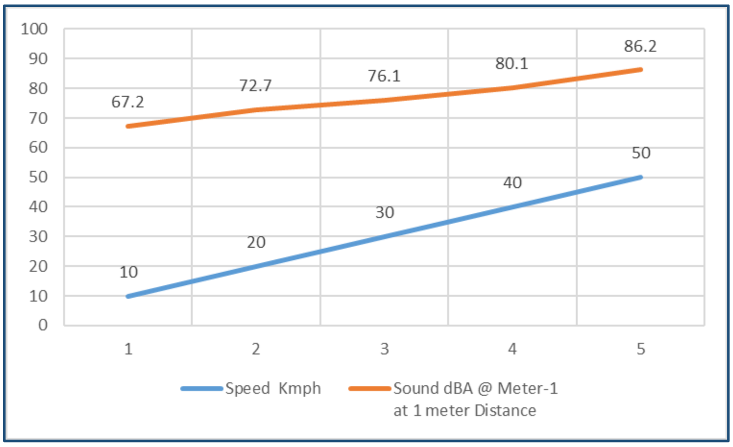


Figure 68: Speed Versus Sound dBA levels for Bajaj CD100 ICE Motorcycle Sound Meter-1 at 1m distance

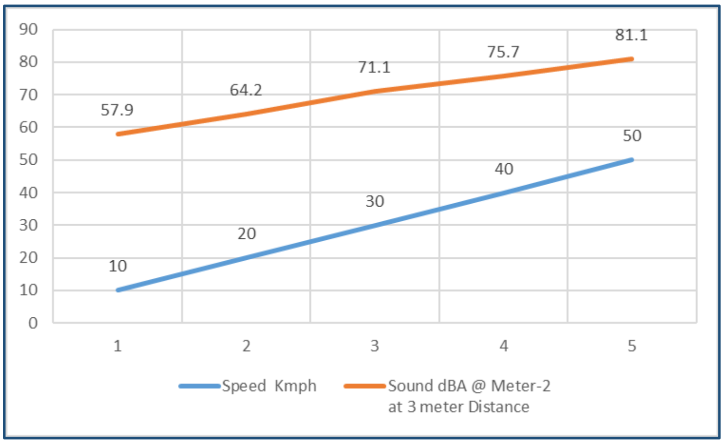
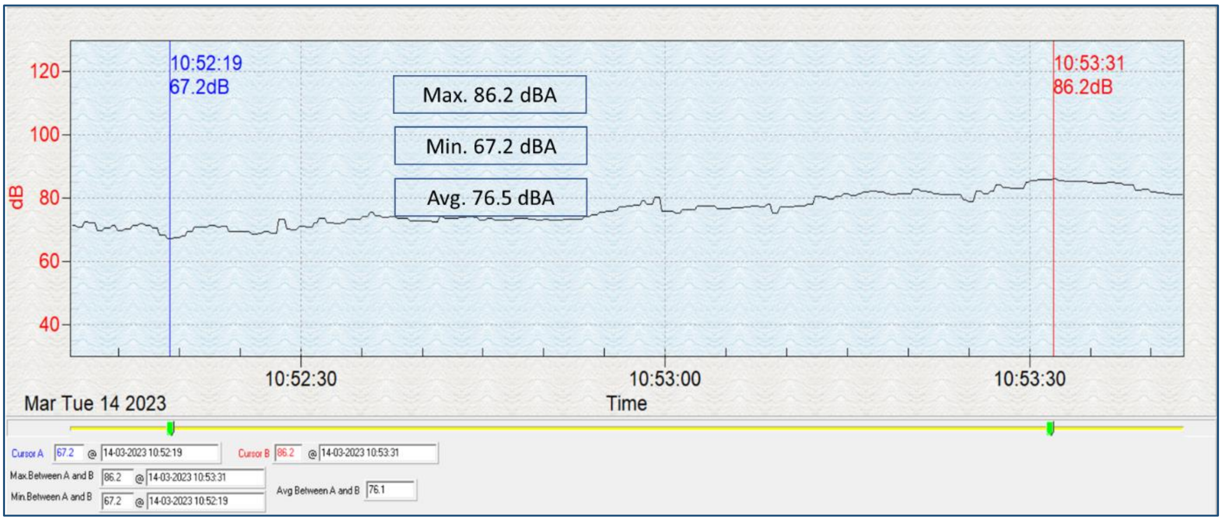


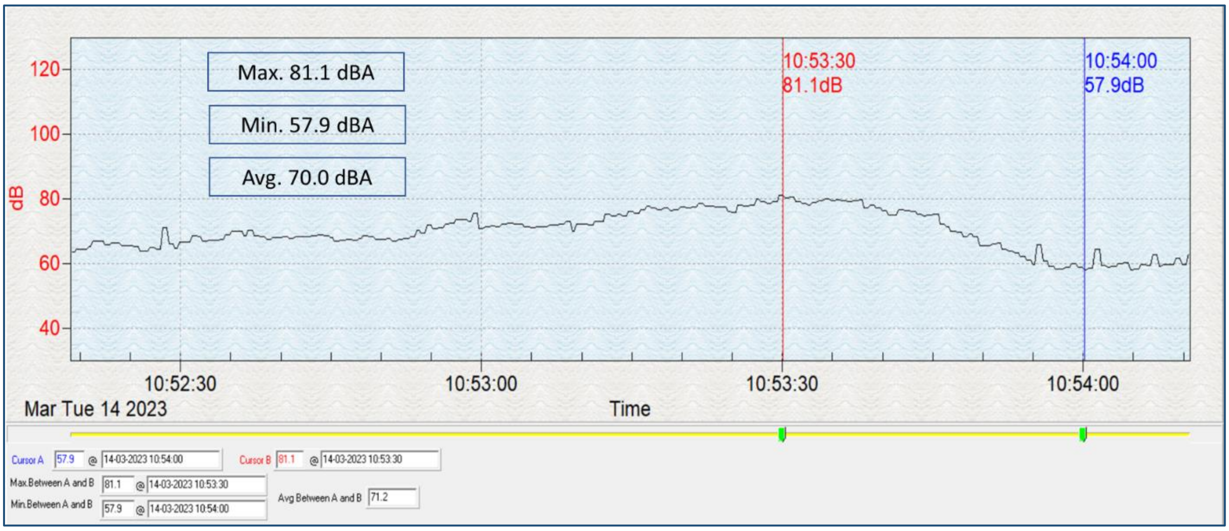
Figure 69: Speed Versus Sound dBA levels for Bajaj CD100 ICE Motorcycle Sound Meter-2 at 3m distance

Figure 70 and 71 below shows the sound graph derived from the sound meter-1 at 1 meter distance and sound meter-2 at 3-meter distance respectively.



Cursor A 67.2 @ 14-03-2023 10:52:19
Cursor B 86.2 @ 14-03-2023 10:53:31
Max.Between A and B 86.2 @ 14-03-2023 10:53:31
Min.Between A and B 67.2 @ 14-03-2023 10:52:19
Avg Between A and B 76.1

Figure 70: Sound dBA graph for test-2 for Bajaj CD100 ICE Motorcycle by sound meter-1 at 1m distance



Cursor A 57.9 @ 14-03-2023 10:54:00
Cursor B 81.1 @ 14-03-2023 10:53:30
Max.Between A and B 81.1 @ 14-03-2023 10:53:30
Min.Between A and B 57.9 @ 14-03-2023 10:54:00
Avg Between A and B 71.2

Figure 71: Sound dBA graph for test-2 for Bajaj CD100 ICE Motorcycle by sound meter-2 at 3m distance

The *third test* was conducted on Hero Electric EV Scooter to compare the data of both types of vehicles in a similar environment and understand the difference in the overall sound dBA levels. The fact that needs to considered here is that an electric vehicle doesn’t have an engine and therefore the noise generated by the vehicle is mostly contributed by Tyres, Suspension, Aerodynamic noise produced by the vehicle at high speeds, Electric Motors and other peripheral components of the vehicles like brake and axle components. Noise produced by the operation of electric motors are characterized by tonal components mainly at frequencies above 2 kHz. These components are speed dependent, resulting from the dominating electromagnetic harmonics and covering a wide rpm range. The below table 20 shows the results of the test-3 conducted in the lab with Hero Electric EV Scooter.

Vehicle	**Hero Electric (EV Scooter)**	
Ambient - Dyno	62.5 dBA	56.1 dBA
Speed Kmph	**Sound dBA @ Meter-1 at 1 meter Distance**	**Sound dBA @ Meter-2 at 3 meter Distance**
10	63.5	57.7
20	64.7	60.2
30	66.7	62.3
40	68.1	63.9

Table 20: Results of sound dBA test conducted in lab for Hero Electric EV Scooter

The above results show that incase of both the sound meters the dBA recorded for variable speeds starting from 10kmph to 40kmph travel unidirectionally in increasing order. The ambient noise shows same results as it was for Honda Activa ICE Scooter. Below figure 72 and 73 is a graphical representation of the sound dBA levels versus the vehicle speeds.

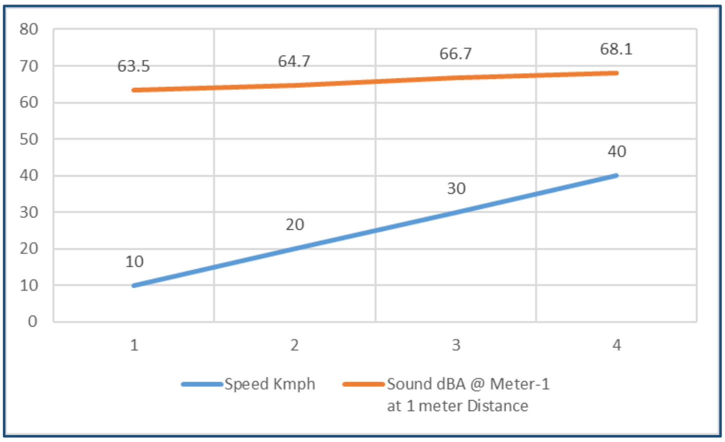


Figure 72: Speed Versus Sound dBA levels for Hero Electric EV Scooter Sound Meter-1 at 1m distance

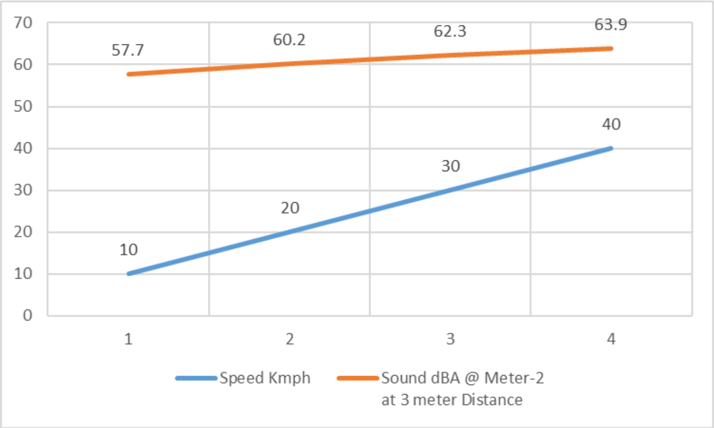
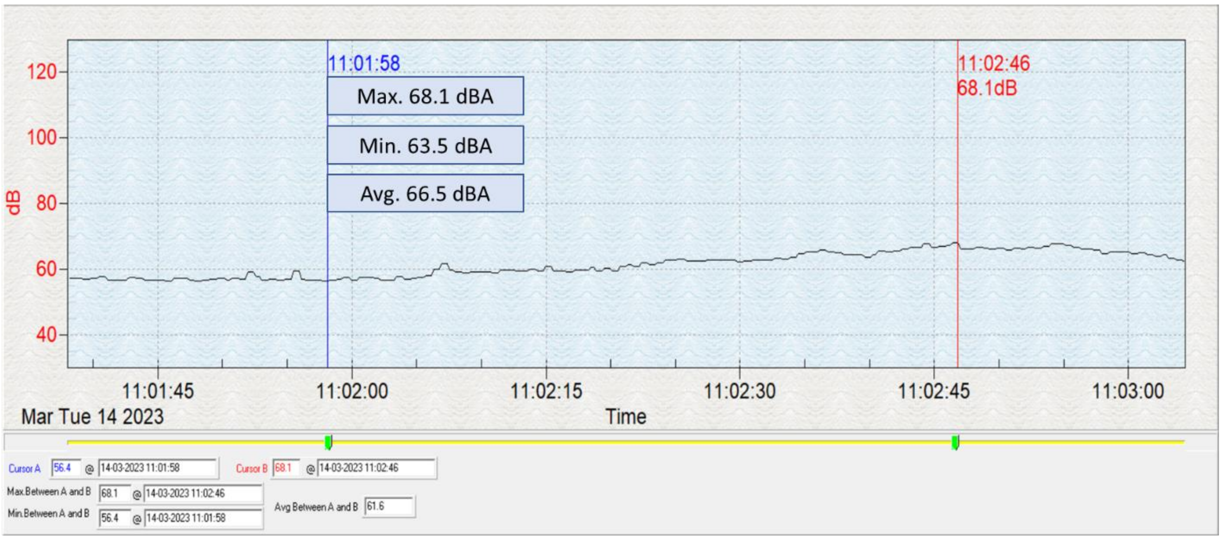


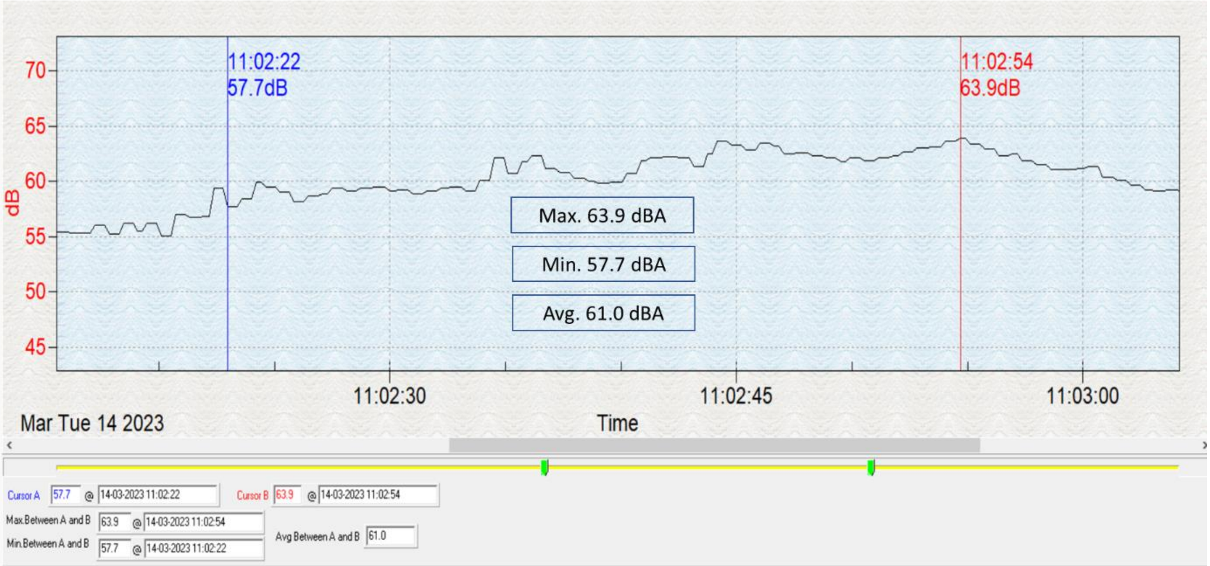
Figure 73: Speed Versus Sound dBA levels for Hero Electric EV Scooter Sound Meter-2 at 3m distance

Figure 74 and 75 below shows the sound graph derived from the sound meter-1 at 1 meter distance and sound meter-2 at 3-meter distance respectively.



Cursor A 56.4 @ 14-03-2023 11:01:58
Cursor B 68.1 @ 14-03-2023 11:02:46
Max.Between A and B 68.1 @ 14-03-2023 11:02:46
Min.Between A and B 56.4 @ 14-03-2023 11:01:58
Avg Between A and B 61.6

Figure 74: Sound dBA graph for test-3 for Hero Electric EV Scooter by sound meter-1 at 1m distance

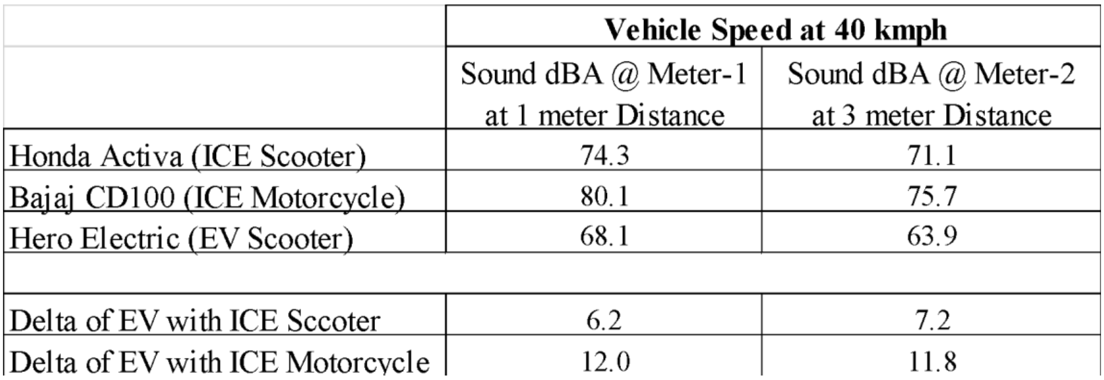


Cursor A 57.7 @ 14-03-2023 11:02:22
Cursor B 63.9 @ 14-03-2023 11:02:54
Max.Between A and B 63.9 @ 14-03-2023 11:02:54
Min.Between A and B 57.7 @ 14-03-2023 11:02:22
Avg Between A and B 61.0

Figure 75: Sound dBA graph for test-3 for Hero Electric EV Scooter by sound meter-2 at 3m distance

Summary

In this section, three types of vehicles were subjected to sound tests in a controlled lab environment. The purpose of the tests conducted was to understand the sound dBA level of the traditional ICE vehicles versus the EV vehicles in lab setup at various speeds limits. Another important purpose was to understand the direction of increase or decrease of sound level based on the variable speeds. From the tests we observed that the sound of both ICE and EV vehicles increase or decrease in a unidirectional path directly proportional to the speed of the vehicles. That means the emitted sound increases with the increase of speed and it also decreased with the decrease of vehicle speed. This was an important understanding that we could conclude form the lab tests. The first purpose of data collection shows us the deltas of comparative sound between ICE and EV shown in the table 21 below.



	Vehicle Speed at 40 kmph	
	Sound dBA @ Meter-1 at 1 meter Distance	Sound dBA @ Meter-2 at 3 meter Distance
Honda Activa (ICE Scooter)	74.3	71.1
Bajaj CD100 (ICE Motorcycle)	80.1	75.7
Hero Electric (EV Scooter)	68.1	63.9
Delta of EV with ICE Sccoter	6.2	7.2
Delta of EV with ICE Motorcycle	12.0	11.8

Table 21: Delta of sound dBA of EV vehicle with ICE vehicles as per test results 1, 2 & 3

As we observe in the table 21, there is a significant difference in the sound dBA levels of ICE vehicles compared to the EV vehicles. The test result shows that Honda Activa ICE scooter emits a sound of 74.3 dBA at 40 kmph speed compared to 68.1 dBA of a Hero Electric EV scooter which is 6.2 dBA less and at the same time when compared with an ICE motorcycle like Bajaj CD100 it is 12 dBA less sound emitted by Hero Electric EV scooter. This delta of emitted sound coupled with the city ambient noise can be a potential reason to make the EV vehicles non-recognizable on road. Another important factor that needs to be considered is the sound profile, meaning the frequency of the sound that typically is generated by an engine also adds up to make the ICE vehicles more audible. Also, we found during the test that the sound dBA level of Bajaj CD100 motorcycle was as high as 80.1 dBA at 40kmph which further increase to 86.2 dBA at 50kmph. Keeping this aspect as a consideration while deriving the most suitable dBA levels that an AIS system should be able to produce in an EV becomes important.

4.4 IS Vs AD Test Results

Intensity of the sound (IS) Vs the audibility distance (AD) is another important factor that influences the pedestrian to recognize an approaching vehicle on road. As explained in the section 3.6 above, the experiment was carried out with the help of ten participants who volunteered for the same. A setup was built on the road with fixing masking tapes at one meter gap to understand the total distance and count the same while a vehicle passes away. Five types of vehicles were used to conduct these tests. ICE Scooter (Honda Activa), ICE Motorcycle (Bajaj Avenger), ICE SUV (Mahindra Xylo), ICE Hatchback (Suzuki Baleno), EV Scooter (Hero Electric) and EV Hatchback (Tata Nexon). The participants stood 2 m from the center line A-A, forming a line with 1-m intervals. The experimental scene has been shown above in Fig. 41 and 42. So that the participants paid attention to the sound emitted from vehicles, the participants stood with their backs to the vehicle and closed their eyes during the experiment. The vehicles passed behind the participants at variable speeds starting from 10kmph to 50kmph and the results were recorded. The participants were instructed to raise their hands only when they hear and recognize the sound of an approaching vehicle. The participants were 7 male and 3 female embedded electronics professionals having an average age of 23.4 years. The test results were recorded and analyzed to understand the audibility distance in case of various vehicles as described above.

The *first vehicle* was Mahindra Xylo – ICE SUV. The vehicle was driven from the center line A-A, at variable speeds in each turn starting from 10 kmph to 40 kmph. The participants were told to close the eyes and raise their hands only when they identify the vehicle approaching towards them. The results are shown in table 22 below. Through the experiment we observed that the audibility distance (AD) unidirectionally increased with higher speeds. So, we can say that the vehicle emits higher dBA sound at higher speeds and can be recognizable by pedestrians from long distance compared to lower speeds. Therefore, the severity of potential accidents can be more while vehicle is plying at a lower speed. The ambient noise being recorded 62.8 dBA the vehicle passer-by noise went up to 82.5 dBA at 40 kmph.

Vehicle	ICE - SUV Xylo											
Ambient Noise	62.8 dBA											
	Distance in Meters										Sound Meter-1	Sound Meter-2
Vehicle Speed	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	1 Mtr from Vehicle Lane	3 Mtrs from Vehicle Lane
10 kmph	7	7	7	7	8	8	8	8	8	8	68.4	63.9
20 kmph	10	10	10	10	10	10	9	9	9	9	71.7	69.1
30 kmph	13	13	13	13	13	12	12	12	12	12	79.5	77.8
40 kmph	17	17	17	17	17	16	16	16	16	16	82.5	80.4

Table 22: Results of IS Vs AD experiment conducted with Mahindra Xylo ICE-SUV vehicle

Below figure 76 is a graphical representation of the experiment results wherein P1 to P10 are representing the number of participants and y-axis shows audibility distance (AD) in meters for variable vehicle speeds from 10kmph to 40kmph.

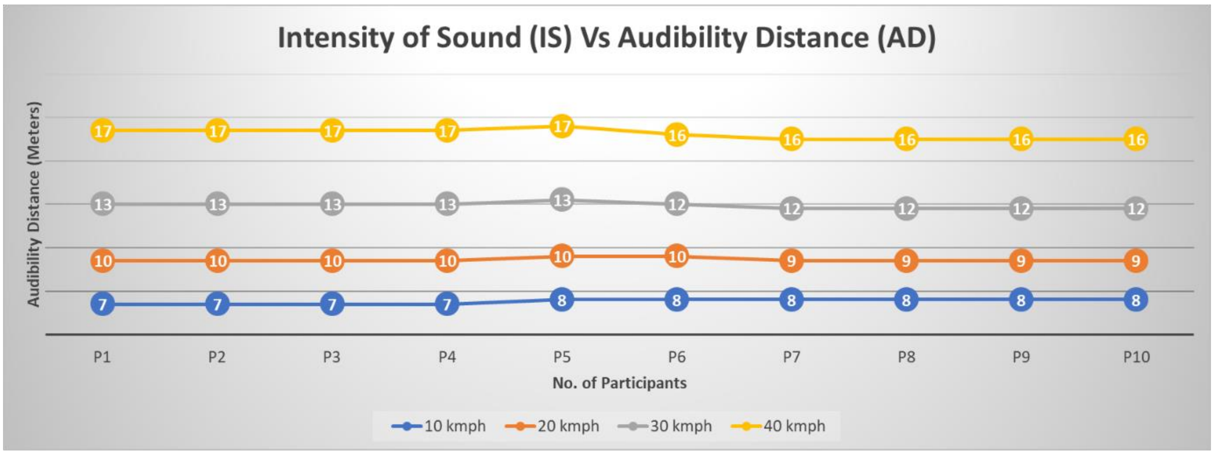


Figure 76: IS Vs AD results with Mahindra Xylo ICE-SUV vehicle

The *second experiment* was conducted with Suzuki Baleno Hatchback – ICE Sedan vehicle. The experiment results show similar observations as for the Mahindra Xylo SUV, except that the audibility distance reduced significantly being a more silent vehicle compared to Mahindra

Xylo and also being a hatchback vehicle series. The below table 23 shows the experiment results.

Vehicle	ICE - Hatchback Baleno											
Ambient Noise	62.8 dBA											
	Distance in Meters										Sound Meter-1	Sound Meter-2
Vehicle Speed	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	1 Mtr from Vehicle Lane	3 Mtrs from Vehicle Lane
10 kmph	4	4	4	4	3	3	3	3	3	3	63.1	62.1
20 kmph	7	7	7	7	7	6	6	6	6	6	65.3	63.9
30 kmph	10	10	10	10	8	8	8	8	8	8	71.2	69.8
40 kmph	12	12	12	12	12	12	12	10	10	10	75.4	73.9

Table 23: Results of IS Vs AD experiment conducted with Suzuki Baleno ICE-Hatchback vehicle

Below figure 77 is a graphical representation of the experiment results wherein P1 to P10 are representing the number of participants and y-axis shows audibility distance (AD) in meters for variable vehicle speeds from 10kmph to 40kmph.

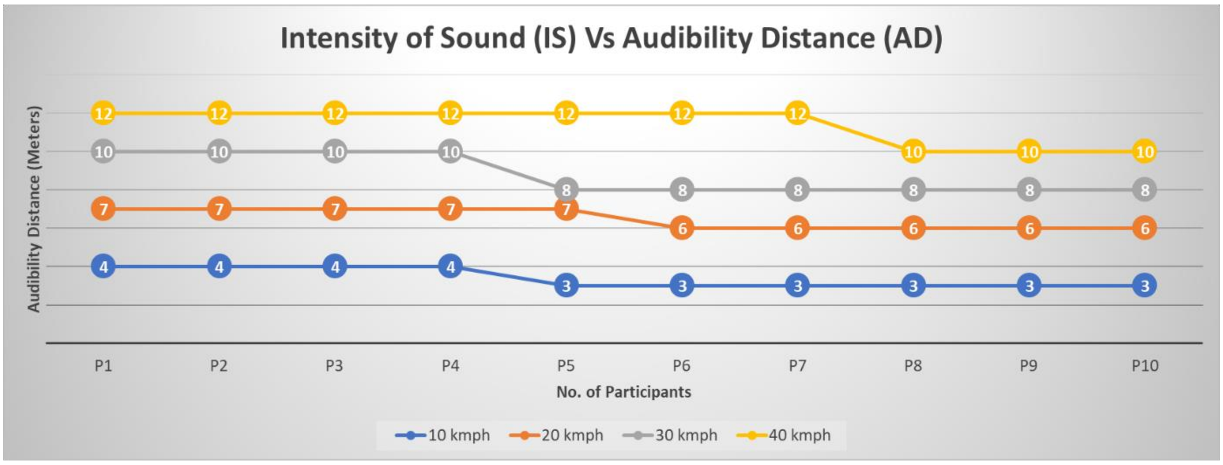


Figure 77: IS Vs AD results with Suzuki Baleno ICE-Hatchback vehicle

The *third experiment* was conducted with Honda Activa ICE-Scooter. The below table 24 shows the results of the experiment conducted. We observed that the Intensity of sound (IS) and the audibility distance (AD) both were higher compared to Suzuki Baleno ICE-Hatchback. This is a unique observation. We could infer from this data that how the frequency of the sound plays an important role in the audibility distance. Though the sound dBA emitted by Honda Activa is bit higher than Suzuki Baleno, but there is a significant increase in the audibility distance. This is because of the frequency difference. Therefore, for a better audibility it is important to select the right frequency while developing an AIS system. This may also be tailored based on the type of vehicle. Further we also observed that the sound emitted by Honda Activa at 40kmph is 80.1 dBA which is higher compared to Suzuki Baleno 75.4 at 40 kmph. This is probably due to a better exhaust muffler design and refined engine tuning.

Vehicle	ICE - Scooter Honda Activa											
Ambient Noise	62.8 dBA											
	Distance in Meters										Sound Meter-1	Sound Meter-2
Vehicle Speed	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	1 Mtr from Vehicle Lane	3 Mtrs from Vehicle Lane
10 kmph	9	9	8	8	8	8	8	8	8	8	73.4	70.1
20 kmph	12	12	11	11	11	11	11	11	11	11	75.2	71.3
30 kmph	12	12	12	12	12	11	11	11	11	11	77.9	76.3
40 kmph	18	18	17	17	17	17	17	17	17	17	80.1	77.1
50 kmph	19	19	19	18	18	18	18	18	18	18	82.7	78.3

Table 24: Results of IS Vs AD experiment conducted with Honda Activa ICE-Scooter

Below figure 78 is a graphical representation of the experiment results wherein P1 to P10 are representing the number of participants and y-axis shows audibility distance (AD) in meters for variable vehicle speeds from 10kmph to 50kmph.

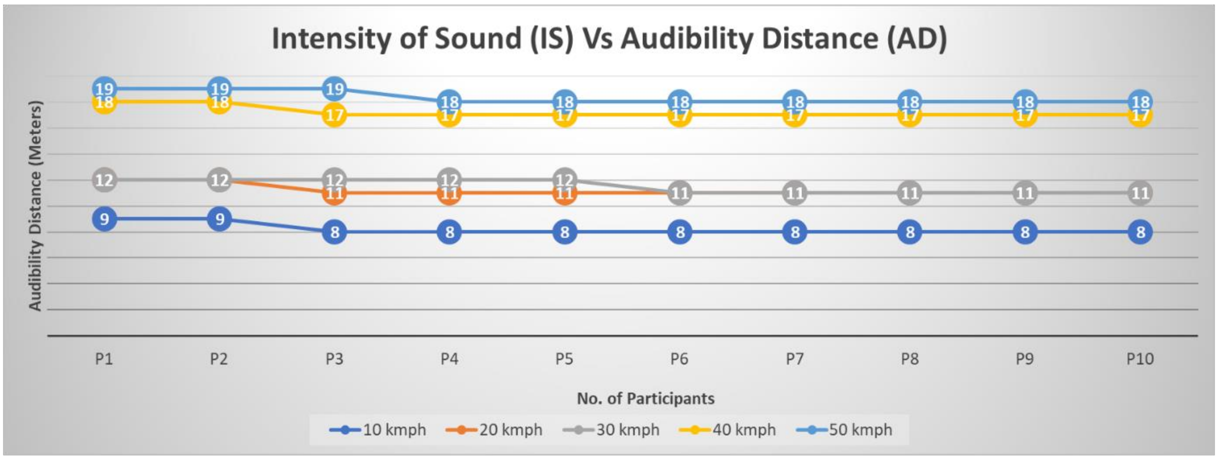


Figure 78: IS Vs AD results with Honda Activa ICE-Scooter

The *fourth experiment* was conducted with Bajaj Dominar ICE-Motorcycle. The below table 25 shows the results of the experiment conducted. The results show that the overall sound dBA levels of the vehicle are high. This Bajaj Dominar is a 200cc motorcycle. At 10 kmph speed, the vehicle emits a sound of 84.6 dBA which is quite high. And therefore, the audibility distance is also high. We observed that at 40 kmph the sound emitted is as high as 94.9 dBA. This indicated that these kind of higher cc motorcycles are well identified by the pedestrians from long distance.

Vehicle	ICE - Motorcycle											
Ambient Noise	72 dBA											
	Distance in Meters										Sound Meter-1	Sound Meter-2
Vehicle Speed	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	1 Mtr from Vehicle Lane	3 Mtrs from Vehicle Lane
10 kmph	17	17	17	17	16	16	16	16	15	15	84.6	81.2
20 kmph	19	19	19	19	19	18	18	18	18	17	85.3	84.2
30 kmph	25	25	25	25	25	25	25	24	24	24	91.3	90.5
40 kmph	35	35	35	35	34	34	33	33	33	33	94.9	92.1

Table 25: Results of IS Vs AD experiment conducted with Bajaj Dominar ICE-Motorcycle

The experiment was conducted in an ambient noise of 72 dBA and in such an environment, the vehicle presence was felt from as far of 33 to 34 meters distance. This can reduce a bit while the vehicle audibility distance is measured with higher city ambient noise. However, the inference that we could draw from this experiment is in case high voltage and KWH EV designed to have higher peak torques and top speed, the AIS system should be so designed that it emits higher dBA sound to make its presence felt form a far distance. Below figure 79 is a graphical representation of the experiment results wherein P1 to P10 are representing the number of participants and y-axis shows audibility distance (AD) in meters for variable vehicle speeds from 10kmph to 40kmph.

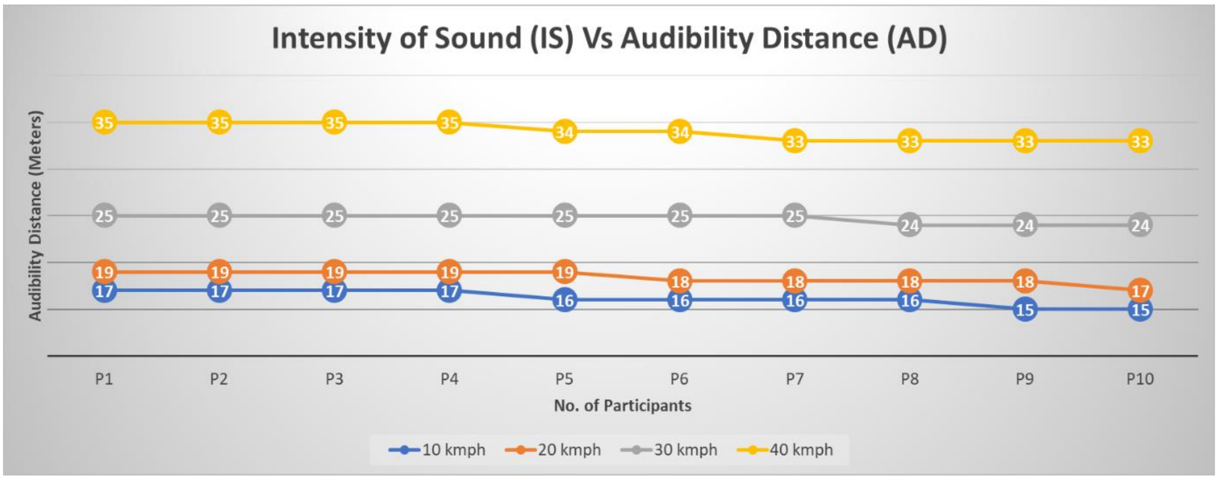


Figure 79: IS Vs AD results with Bajaj Dominar ICE-Motorcycle

The *fifth experiment* was conducted with Hero Electric EV – Scooter. The below table 26 shows the results of the experiment conducted. The results show that the overall sound dBA is significantly low up to the extent that the sound meter -2 didn't record any change of dBA at 10 kmph speed from a distance of 3 meters from the vehicle center line. This is a clear inference that why an AIS system needs to be mandatory for EVs and how can it help gaining the attentions of pedestrians to avert possible accidents. At 10 kmph and 20 kmph, as shown in the table 26, the audibility distance is as low as only 1 to 3 meters which indicated that in a given scenario of accident, the pedestrian or even the EV driver will merely have an opportunity to save meeting an accident.

Vehicle	Hero Electric EV - Scooter											
Ambient Noise	60.1 dBA											
	Distance in Meters										Sound Meter-1	Sound Meter-2
Vehicle Speed	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	1 Mtr from Vehicle Lane	3 Mtrs from Vehicle Lane
10 kmph	1	1	1	1	2	2	2	2	2	2	60.4	60.1
20 kmph	2	2	2	2	2	3	3	3	3	3	60.9	60.5
30 kmph	4	4	4	4	3	3	3	3	3	3	65.3	63.1
40 kmph	6	6	6	6	6	6	5	5	5	5	66.3	64.9

Table 26: Results of IS Vs AD experiment conducted with Hero Electric EV Scooter

As explained earlier in section 4.3, an electric vehicle doesn’t have an engine and therefore the noise generated by the vehicle is mostly contributed by Tyres, Suspension, Aerodynamic noise produced by the vehicle at high speeds, electric motors and other peripheral components of the vehicles like brake and axle components. Another aspect that we observed through the experiment is that the difference between the ambient noise and sound emitted by the EV vehicle at 10 kmph, 20 kmph and 30 kmph is negligible. As we see that the ambient noise was only 60.1 dBA while the experiment was conducted, still the sound of the vehicle got masked. Therefore, in a relatively crowded street with more traffic, the city ambient noise will completely mask the EV vehicle sound and will be close to silent.

Summary

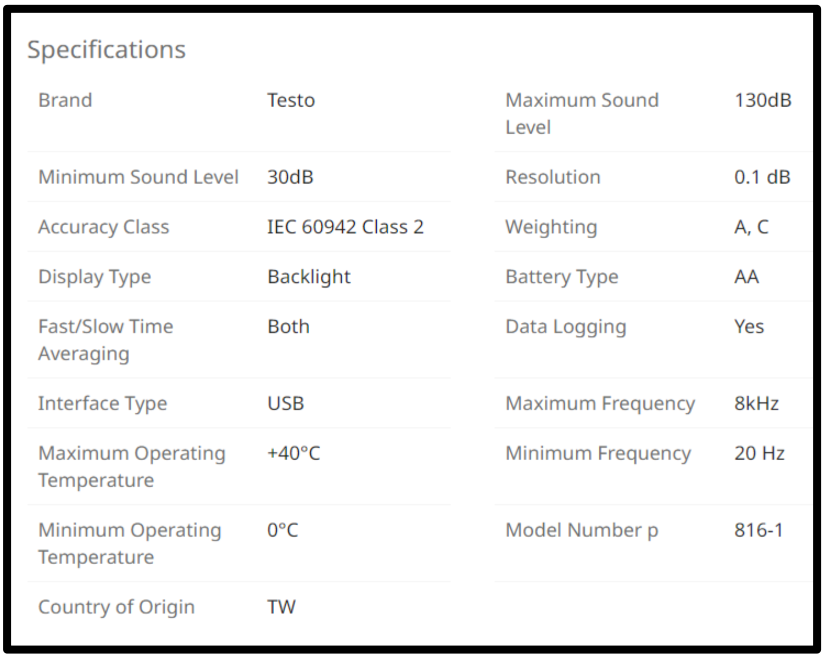
Now if we summarize the above test results, we can infer facts that are quite very interesting to understand. While in the *first experiment* with the Mahindra Xylo SUV car, the sound meter -1 recorded 68.4 dBA against an ambient city noise of 62.8 dBA and the vehicle approach was felt from a distance of 7-8 meters at 10kmph. This is relatively a safe stopping distance for a vehicle running at 10kmph speed for any unpredictable situation on the road. However, the same vehicle while at 20kmph was felt well before 9-10 meters distance and going up to 16-17 meters distance at 40kmph with 82.5 dBA sound emission. This clearly shows that ICE SUV vehicles can be quite safe even when driven at a low speed. In the *second experiment* with Suzuki Baleno hatchback car, we found that the vehicle approach was felt at a distance of 3-4 meters at 10kmph and the emitted sound dBA was slightly higher than the city ambient noise. The emitted sound recorded in sound meter-1 was 63.1 dBA against the city ambient noise of 62.8 dBA. This situation seems to be risky while such petrol ICE hatchback cars are driven at low speeds in a crowded street. It may attract a near miss situation sometimes. However, going higher on speed the approach distance felt went up to 6-7 meters and 10-12 meters at 20kmph and 40 kmph. This shows that mainly when the car is driven at a very low speed or may in times when it is reversed the vehicle becomes silent and could be risky for pedestrians around it. In the *third experiment* conducted with the Honda Active ICE scooter, we found that the audible distance (AD) was 8-9 meters at a low speed of 10kmph. The sound meter-1 recorded 73.4 dBA under a city ambient noise of 62.8 dBA. This AD can be considered to be quite safe to recognize any approaching ICE scooter. In fact, going at a running speed to 40kmph the AD further increases to 17-18 meters and the sound emitted is 80.1 dBA which indicates that the scooter can easily identified from a far distance and there is no potential threat for nearby pedestrians. The *fourth experiment* was conducted on an ICE Motorcycle Bajaj Dominar 200CC wherein the AD was as high as 15-17 meters at a low speed of 10kmph and the sound emitted as recorded by the sound meter-1 was 84.6 dBA under an ambient noise of 72 dBA. This then further increases to 33-35 meters AD while the vehicle is run at a speed of 40kmph emitting a sound of 94.9 dBA. This experiment clearly signifies that ICE motorcycles are clearly identified by their emitted sound from far distances and there are no potential threats even while these vehicles ply at a low speed. Going forward the *fifth experiment* was conducted with a Hero Electric EV scooter. The results were completely eye opening. The vehicle audibility distance (AD) was as low as 1-2 meters at 10kmph emitting only 60.4 dBA sound under a city ambient noise of 60.1 dBA. It indicates that the vehicle is almost silent while being driven at 10kmph. This is a clear potential threat to nearly pedestrians. Further, even when the speed is increased to 20kmph the sound emitted marginally increases to 60.9 dBA with AD of 2-3 meters. This indicates that an EV approaching at a speed of 20kmph is also almost silent and can meet a potential accident being its presence not felt or recognized by the fellow riders or nearby pedestrians. The experiment conducted at 40kmph shows that yet the sound emitted marginally increases to 66.3 dBA by taking the AD to 5-6 meters which is also an unsafe stopping distance in case of an emergency braking at 40 kmph.

Therefore, through the experiments conducted for IS Vs AD, we can conclude that the EVs are much silent at various speed levels compared to any kind of ICE vehicles. And this silent character of the EV vehicles makes it quite unsafe for the pedestrians and fellow riders to identify their presence from a safe audibility distance.

4.5 City Ambient Noise Data

As discussed in the section 3.2 (3) e, traffic noise is considered as an important sources of noise pollution and its contribution is approximately 75% of the total noise pollution in urban areas. Delhi is considered as second noisiest city in the world. Before narrowing down to most suitable sound levels that an AVAS need to generate in urban India, it is very important to make an in-depth study of traffic noise in Indian urban cities. Therefore, data is collected from three major cities of India to analyze the city ambient noise (dBA) level. These cities were Pune, Bengaluru and Aurangabad.

The first study conducted in Pune city of Maharashtra state was on the "Paud Road". The selection of this road was considering based on its higher traffic density that is generally witnessed. To acquire the city ambient noise data, an acoustic system was setup using *"Testo 816-1 Datalogging Sound Level Meter"*. This sound level meter can record sounds between 30 dBA to 130 dBA and max frequency of 8KHz. The detailed specification of the system is shown in the table 27 below.



Specifications

Brand	Testo	Maximum Sound Level	130dB
Minimum Sound Level	30dB	Resolution	0.1 dB
Accuracy Class	IEC 60942 Class 2	Weighting	A, C
Display Type	Backlight	Battery Type	AA
Fast/Slow Time Averaging	Both	Data Logging	Yes
Interface Type	USB	Maximum Frequency	8kHz
Maximum Operating Temperature	+40°C	Minimum Frequency	20 Hz
Minimum Operating Temperature	0°C	Model Number p	816-1
Country of Origin	TW		

Table 27: Specifications of Testo 816-1 Datalogging Sound Level Meter

Two numbers Testo 816-1 Datalogging Sound Level Meter were setup at a distance of one meter from the road connected to the real time data logging T816-1 software in a laptop. The data was collected in the evening time when generally heavy traffic is witness due to peak hours. The data shows the maximum dBA recorded was 92.9 dBA and the minimum was 68.2 dBA, while the average sound level was found to be 75.8 dBA. Based on our experiment, we can say that the minimum dBA recorded can be the representation of the sound level of that area, considering no vehicle plying at a particular moment. That means this data is basically the city ambient noise minus traffic noise. At the same time the highest data recoded is also representing the peak sound that may be due to a horn blown by a vehicle in a particular moment. Therefore, to normalize the readings we have derived a mean value between the average and peak values which comes to

$$\frac{92.9 + 75.8}{2} = 84.3\ dBA$$

The graphical representation of the collected data is shown in figure 80 below:

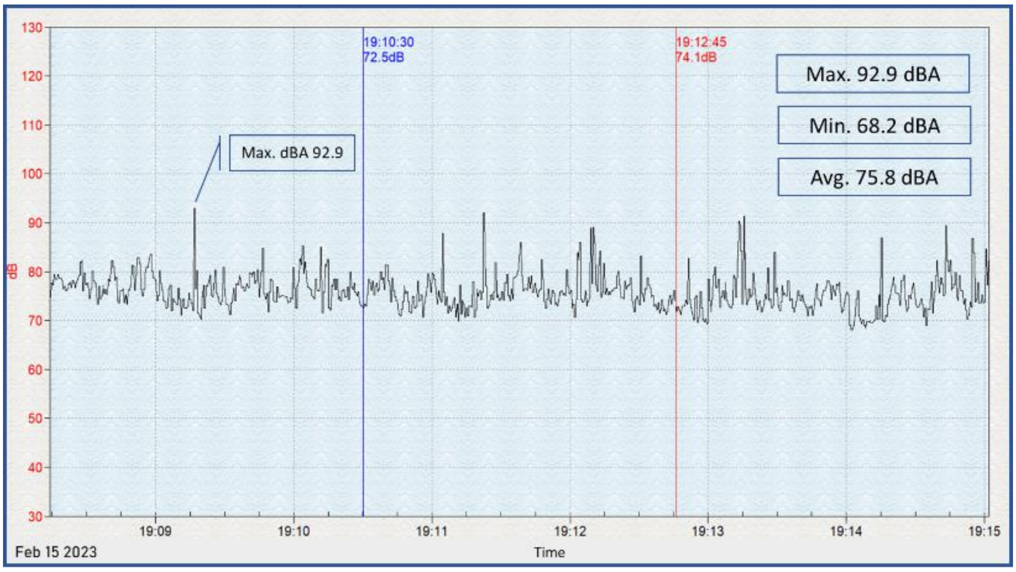


Figure 80: Sound level data collection on Paud Road, Pune, Maharashtra

The second study was conducted in Bengaluru city of Karnataka state on the "*Electronic City Road*". The selection of this road was considering based on its higher traffic density that is generally witnessed. The same acoustic system using *"Testo 816-1 Datalogging Sound Level Meter"* was setup to acquire the city ambient noise data. Again, two numbers Testo 816-1 Datalogging Sound Level Meter were placed at a distance of one meter from the road connected to the real time data logging T816-1 software in a laptop. The data was collected in the evening time when generally heavy traffic is witness due to peak hours. The data shows the maximum dBA recorded was 90.7 dBA and the minimum was 62.5 dBA, while the average sound level was found to be 70.9 dBA. As explained earlier, the minimum dBA recorded can be the representation of the sound level of that area, considering no vehicle plying at a particular moment. At the same time the highest data recoded is also representing the peak sound that may be due to a horn blown by a vehicle in a particular moment. Therefore, to normalize the readings we have derived a mean value between the average and peak values which comes to

$$\frac{90.7 + 70.9}{2} = 80.8\, dBA$$

The graphical representation of the collected data is shown in figure 81 below:

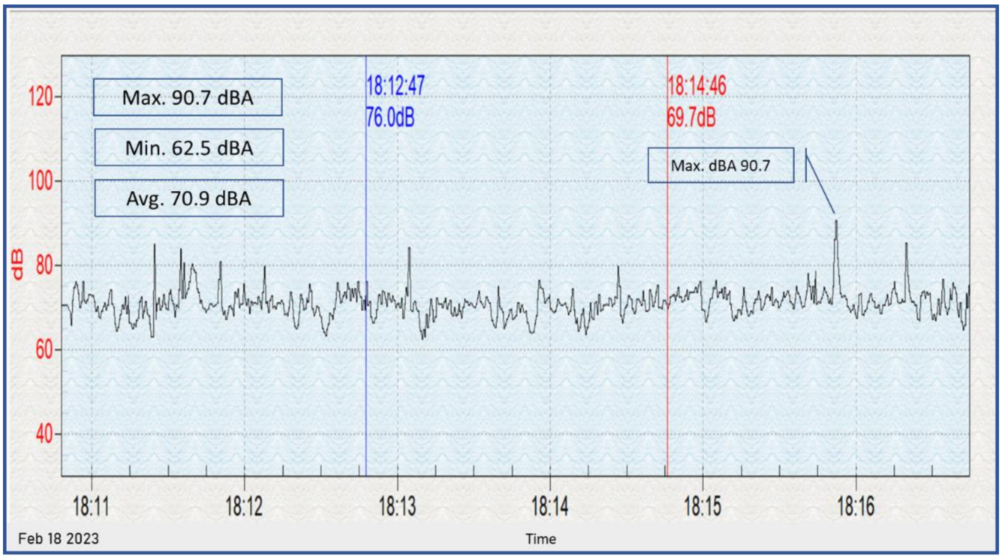


Figure 81: Sound level data collection on Electronic City Road, Bengaluru, Karnataka

The third study was conducted in Aurangabad City of Maharashtra State on the "*Railway Station Road*". A similar system was setup to collect the city ambient noise and traffic noise data. The datalogging sound meters were placed one meter away from the road connected to the real time data logging T816-1 software in a laptop. The data was collected in the evening time when generally heavy traffic is witness due to peak hours. The data shows the maximum dBA recorded was 79.0 dBA and the minimum was 62.7 dBA, while the average sound level was found to be 70.8 dBA. The results of the normalized mean value between the average and peak values come to

$$\frac{79.0 + 70.8}{2} = 74.9\ dBA$$

The graphical representation of the collected data is shown in figure 82 below:

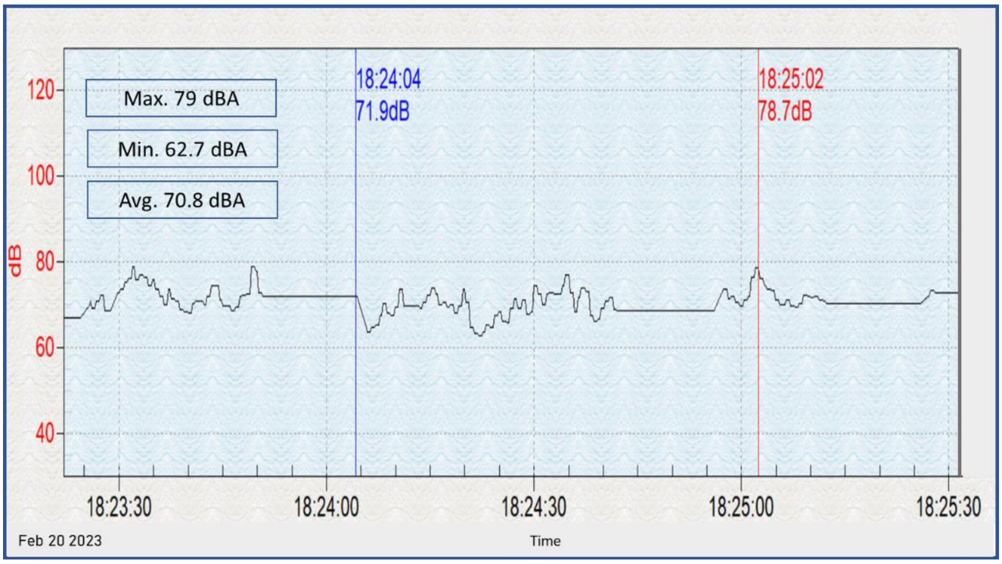


Figure 82: Sound level data collection on Railway Station Road, Aurangabad, Maharashtra

The fourth study was conducted in the Aurangabad City of Maharashtra State on "*Pune-Aurangabad Highway*". The study setup was similar as to the earlier cases. The intention of this data collection was to understand and differentiate between a city road and a highway where the vehicles ply at a relatively higher speed than the city road. The study was conducted in the evening hours considering the traffic peak hours. The data shows the maximum dBA recorded was 93.8 dBA and the minimum was 68.8 dBA, while the average sound level was found to be 75.4 dBA. Apparently, as we were anticipating the data at its first glance shows higher dBA than compared to the city traffic noise data. This can be related to the higher speed of vehicles. As we have already witnessed in our earlier IS Vs AD experiment as well, that the ICE vehicles emit higher sound while they are running at higher speeds. As we normalized the data to reach a mean value between the average and peak values, the result come to

$$\frac{93.8 + 75.4}{2} = 84.6\ dBA$$

The graphical representation of the collected data is shown in figure 83 below:

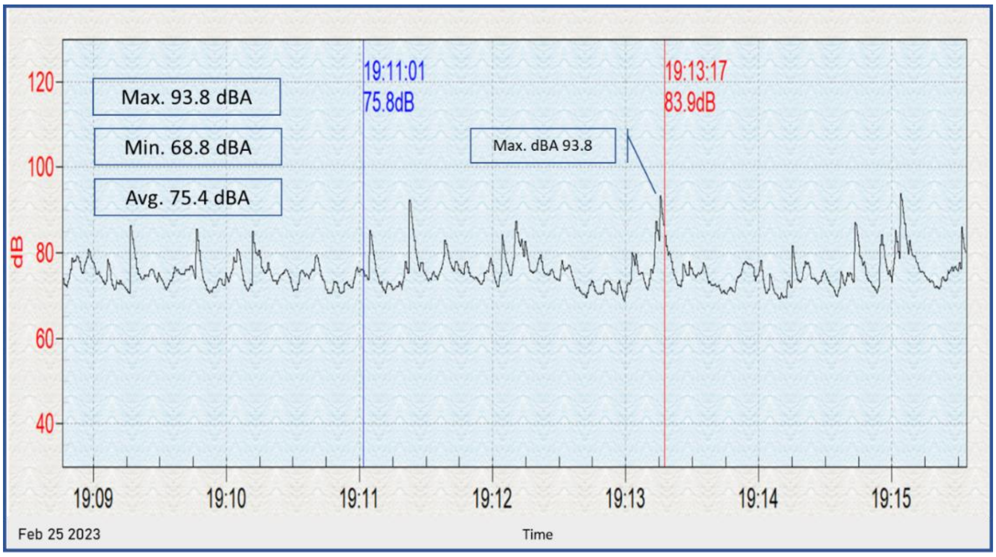
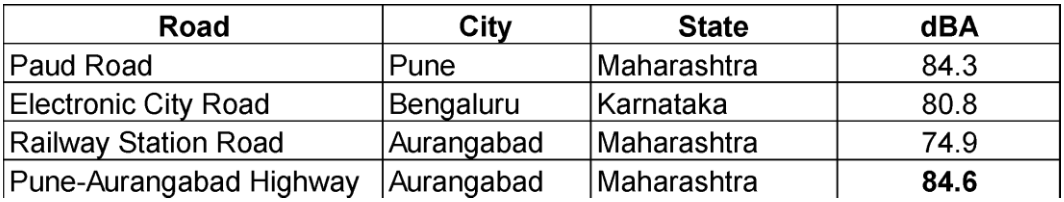


Figure 83: Sound level data collection on Pune-Aurangabad Highway, Aurangabad, Maharashtra

Summary

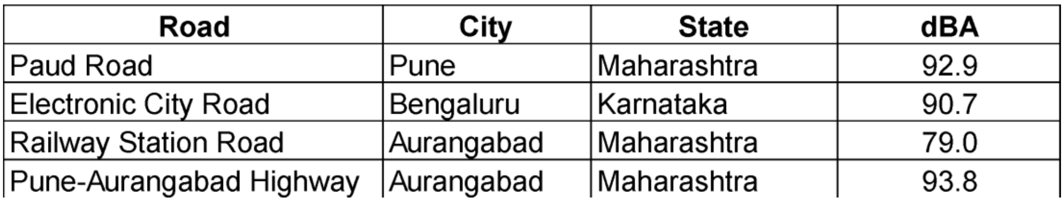
Through the above study, we could get a fair idea about the city ambient noise and the traffic noise that could have a masking effect on the silent EVs. If we collate the mean values following are our observation shown in table 28 below.



Road	City	State	dBA
Paud Road	Pune	Maharashtra	84.3
Electronic City Road	Bengaluru	Karnataka	80.8
Railway Station Road	Aurangabad	Maharashtra	74.9
Pune-Aurangabad Highway	Aurangabad	Maharashtra	**84.6**

Table 28: Normalized mean values of City traffic noise collected at four different locations in India

If we take an average of the normalized mean values of all the above cities, it comes to 81.15 dBA. This is significant value which may be capable of masking the natural sound emitted by an EV. For example, EVs are expected to generate low natural noise while being driven in a medium speed say between 20-30kmph speed. These noises are mainly generated due to the tyres, suspension, aerodynamic noise produced by the vehicle at high speeds, electric motors and other peripheral components of the vehicles like brake and axle components. However, in our earlier studies we have observed that the EV generated max 68.1 dBA in the lab test at 40kmph whereas in the IS Vs AD experiment we observed that the maximum noise that got generated was 66.3 dBA at 40kmph. This dBA sound level is much lower than the city ambient mean value which is 81.15 dBA. Hence, the EV shall not be recognizable while plying on the road. Another aspect that is alarming and needs to be considered is the peak values that we have witnessed in our data collection. Though we have normalized the same by deriving a mean value between the average and the peak value, but the peak sound dBA recorded will also have an impact at times. The peak values that we observed are mentioned in below table 29.



Road	City	State	dBA
Paud Road	Pune	Maharashtra	92.9
Electronic City Road	Bengaluru	Karnataka	90.7
Railway Station Road	Aurangabad	Maharashtra	79.0
Pune-Aurangabad Highway	Aurangabad	Maharashtra	93.8

Table 29: Peak values of sound data recorded in road traffic at various cities of India

As we see in the above table, the peak value goes up to 93.8 dBA which is significantly high compared to the peak sound dBA emitted by an EV (68.1 dBA in controller lab environment). This is a clear indication that in absence of an AVAS system there is no scope for pedestrians or co-drivers or people nearby the road to identify an approaching EV. All these aspects will influence the factors necessary to derive a suitable sound dBA level of the proposed AVAS system for India.

In the next section, we will collate all the above tests and experiments and try to derive necessary inferences to arrive upon a suitable minimum sound dBA level that should be considered while drafting a regulatory mandate for India for the implementation of AVAS in each EV.

4.6 Conclusion

In this chapter 4, the study and experiment results were shown and discussed. As we defined in the methodology, the various ways by which we attempted to narrow down to a logical reasoning of why an AVAS system should be mandatory through regulations were conducted successfully. As we observed through the survey conducted among the EV owners and the survey results clearly indicates that EV owners do acclaim that silent EVs are inconvenient and can be a cause of potential accidents. Similarly, the results of the survey conducted among the pedestrians clearly indicates that majority of the pedestrians do believe that an AVAS system in silent electric vehicles can be quite helpful for them to identify an approaching electric vehicle to avert a potential accident on the road. While we collected the lab data on sound dBA for various vehicles, it clearly came out that the sound emitted by an EV including the sounds produced by ancillary parts like tyres, suspension, electric motor, aerodynamic noise and peripheral parts is significantly low than compared to and ICE. The recorded sound dBA level while the EV vehicle was running was marginally higher than the ambient noise of the lab. This clearly indicates that the city ambient noise which range above the EV emitted noise will easily mask it and make it completely silent. In the intensity of sound versus audibility distance test, we could clearly observe that in case of EV vehicle the AD was significantly less at lower vehicle speeds. Such low AD of approximate 1-2 meters can be an obvious reason for potential accidents on road. At the same time the peak values of the data collected for city ambient noise and traffic noise shows up to 93.8 dBA in highway and 92.9 dBA in city. Even if we consider the normalized mean values, it shows 84.6 dBA for highway and 84.3 dBA for city. These values are much higher compared 60.4 dBA to 66.3 dBA at 10kmph to 40kmph speed of EV as we observed in our IS Vs AD experiment. Therefore, the EV noise will merely be noticeable to any pedestrian and will be fully masked under the city ambient noise.

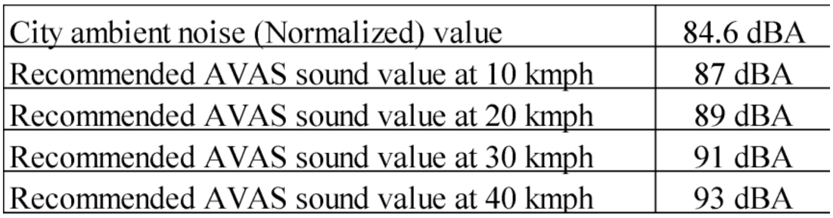
Chapter 5

Summary & Future Work

This is chapter we will summarize the results of the studies conducted within the project and lists the conclusions of this research. In addition, ideas for future work and the further development of the concepts that may influence faster adoption of AVAS system for all EVs and facilitate drafting a mandatory regulation specific to India. Through the introduction we have seen that in order to promote adoption of electric vehicles in India, the Government launched the Faster Adoption and Manufacturing of Hybrid & Electric Vehicles in India (FAME India) Scheme since 2015 on pan India basis. Presently, Phase-II of FAME India Scheme is being implemented for a period of 5 years w.e.f. 01st April, 2019 with a total budgetary support of INR 10,000 crores.

Govt. of India targets to achieve 30% penetration of EVs in passenger cars and more than 50% in all other segments by 2030. India is well equipped to make the shift to EVs due to availability of skilled workforce and abundance of renewable energy. Other macro-economic factors such as disposable income, environmental consciousness and Internet of Things (IoT) are expected to accelerate on-going disruptions in the automobile industry, especially for Electric Vehicles. These factors have pushed the Indian government to issue aggressive targets to leapfrog from conventional ICE Vehicles to Electric Vehicles in the next 10 years. On the other hand, vehicles powered by electric machines offer the advantage to be more silent than vehicles equipped with an internal combustion engine. Though, the reduced noise levels enable an improvement of the inner-city noise pollution, at the same time, quiet vehicles entail risks not to be acoustically detected by surrounding pedestrians and cyclists in the lower speed range. To mitigate this risk various countries came up with mandatory regulations to equip all EVs with AVAS system. Japan was the first country in the world to have considered and addressed how to improve the detectability of silent vehicles. Japan issued guidelines for such warning devices in January 2010. The vehicle must make a continuous noise level of at least 56 dBA (within 2 meters) if the car is going 20 km/h (12 mph) or slower, and a maximum of 75 dBA. The United States was also a pioneer in the field, taking the issue to national level with the publication of the Pedestrian Safety Enhancement Act of 2010, for which FMVSS regulation 141 [Minimum Sound Requirements for Hybrid and Electric Vehicles] was published in 2017. Pursuant to the Pedestrian Safety Enhancement Act of 2010 (PSEA), NHTSA issued a new FMVSS regulation setting minimum sound level requirements for low-speed operation of hybrid and electric light vehicles. Based on the NHTSA guidelines, the European Union introduced a similar voluntary guide [UNECE Consolidated Resolution on the Construction of Vehicles (R.E.3)], which was then taken up by the European Union in a regulation (540/2014/EC) [Regulation (EU) No.540/2014 of the European Parliament and the Council of 16 April 2014 on the sound level of motor vehicles and of replacement silencing system. In sync with USA & Europe, China also drafted regulation No. GB/T 37153 to standardize AVAS. The Chinese regulation is fully aligned with UNECE regulation 138 except that all minimum noise levels are 2 dB higher and implemented in September’2019. In Canada, The Motor Vehicle Safety Regulations (MVSR) are amended to introduce Canada Motor Vehicle Safety Standard (CMVSS) 141 — Minimum Sound Requirements for Hybrid and Electric Vehicles (CMVSS 141). On the other hand, India’s population of 1.31 billion, the second largest globally, comprises 17% of the world’s total (United Nations 2015), and the United Nations Population Division estimates that India’s population will in fact overtake China’s by 2028. The average population density of Urban India is around 10,359 persons/Sq. km. This is an important parameter to be considered while understanding the specific need of a country like India. Through the literature review we have seen that the statutory towns and census towns are densely populated having an average population ranging up to 3977 numbers and 2069 numbers respectively per square kilometer. The onward effect of such population density in absence of adequate road infrastructure is further magnified with increased average traffic density on roads. The co-existence of other ICE vehicles also impacts the overall noise and makes it difficult to identify a silent EV. Several researchers and government bodies made studies on the sound dBA levels at various cities of the country to identify the peak traffic noise. Researchers from various countries conducted several field tests and experiments to derive a suitable sound level for AVAS system. Surveys among the EV owners and the pedestrians were conducted. We also found that advanced studies were made to understand the frequency spectrum and also an adaptive AIS system. Directional sound system for an AIS was also another topic on which researchers have conducted extensive study to make an AIS system more effective. The audibility tests were conducted to understand the safe stopping distance for a vehicle.

Therefore, we conducted several tests and experiments that has helped us to understand why the AVAS system is more necessary for India and what should be the minimum dBA levels for an AVAS system. Through the survey among the EV owners and the pedestrians it was clearly evident that both the groups do acclaim that an AVAS system will be quite helpful for them to avert potential accidents on road. To derive dBA numbers that should be helpful in Indian city and highway conditions, the first inference that is important is the city ambient noise that we collected in our experiments. Considering the normalized mean values, it shows 84.6 dBA for highway and 84.3 dBA for city. Therefore, the EV must produce and emit minimum 2 to 3 dBA more than 84.6 dBA to be audible in a traffic. And this minimum value should be emitted at low speed of 10kmph. The dBA should further increase with increase in the speed level of the vehicle. So, if we try to make comparative study between the existing ICE and EV the below table shows the possible recommendations for the suitable dBA level for an EV vehicle.



City ambient noise (Normalized) value	84.6 dBA
Recommended AVAS sound value at 10 kmph	87 dBA
Recommended AVAS sound value at 20 kmph	89 dBA
Recommended AVAS sound value at 30 kmph	91 dBA
Recommended AVAS sound value at 40 kmph	93 dBA

Table 30: Recommendation for minimum sound dBA level for an AVAS system in India

It is not only the maximum sound level of AVAS which influence the potential detection by pedestrians. As part of the development of different AVAS sound design, the frequency content has been very important. In general, traffic noise has a peak around 800 - 1200 Hz, when tyre /road noise is dominating. In the regulations for AVAS and minimum noise levels, it is recommended that the frequency content is not masked by the tyre /road noise. The regulations should have specific recommendations for minimum sound levels in the frequency spectra from 160 to 5000 Hz. The other important factor that should be taken in consideration is the frequency of the sound should resemble an ICE vehicle sound profile to make it more effective in audibility. In our experiment we have collected the frequency spectrum of ICE vehicle that shows the frequency is spread until 6.5 KHz at an amplitude between 80 to 90 dBA. The AVAS sound for EV should also be designed in a similar fashion so as to improve its audibility distance.

5.1 Review of Objectives and Contributions

Through the research presented in this doctoral thesis, the following contributions were made:

1. A thorough study was conducted on the topic of AVAS to understand the various work that is being carried out across the globe regarding the same. Through the literature review, we could see how various researchers across the world has tried to narrow down on the risk mitigation for silent electric vehicle. This literature review study enabled to find the right direction of research that needs to be undertaken by us to understand the factors specific to India.
2. A detailed survey among the EV owners was conducted to understand their perspective on the silence of their EV and how it creates inconvenience for them while driving the vehicle on crowded roads.
3. Similarly, a survey among the pedestrians was conducted to understand their perspective on the inconvenience that they face due to the silent EV vehicles plying on the road.
4. Lab tests were conducted to record the sound emitted by various types of vehicles both in ICE and EVs. This test was significant to understand the pattern of the direction in which the volume of the sound flows while the vehicle increases the speed.
5. Through the lab test we have also gathered the sound frequency spectrum of each type of vehicle. The frequency spectrum plays an important role in the audibility distance for the pedestrians to recognize an approaching vehicle.
6. Tests were conducted for intensity of sound versus the audibility distance with 10 participants. The audibility distance was measured for various vehicles which include conventional ICE and EV vehicles.

7. City ambient noise was collected from four locations in three cities of India to understand the city ambient noise and also the traffic noise. The highway was also considered in this experiment to acquire the data for vehicles plying at a higher speed.

From the above contributions, the objectives set out at the beginning of this research have been addressed as follows:

1. Through the survey among EV owners their holistic perspective was understood. The survey results clearly indicate that majority of the EV owners believe that an acoustic sound system in their EV can be quite helpful to make their vehicle’s presence felt by nearing pedestrians and other vehicles on the road. On the inconvenience index total 71.3% participants responded as high level of inconvenience due to absence of AVAS system.
2. Through the survey among the pedestrians, we could realize that majority of the pedestrians do believe that an AVAS system in silent electric vehicles can be quite helpful for them to identify an approaching electric vehicle to avert a potential accident on the road. Of the total pedestrian participants 84.5% agreed that it is important to have a sound in an approaching or plying vehicle on the road so as to make it easy for identifying the presence.
3. Various types of vehicles were subjected to sound tests in a controlled lab environment. From the tests we observed that the sound of both ICE and EV vehicles increase or decrease in a unidirectional path directly proportional to the speed of the vehicles. That means the emitted sound increases with the increase of speed and it also decreased with the decrease of vehicle speed. This was an important understanding that we could conclude form the lab tests. Through the test we could also derive deltas of comparative sound between ICE and EV.

4. Since the nature of sound and its effect of the audibility strength is directly proportionate to its frequency and the amplitude of the frequency that the sound produces. Therefore, spectrum analysis was conducted to understand the graph on frequency Vs amplitude compared with the traditional ICE. The spectrum was then normalized to form a pattern that could represent the band in case of various types of vehicles as taken for the experiments above. Audio spectrum band collected with the help of sound recording meter and analyzed in the spectrum analyzer.
5. Experiments were conducted for intensity of sound versus audibility distance which clearly indicated that compared to the ICE vehicles the EVs are extremely silent. In case of EV the vehicle audibility distance (AD) was as low as 1-2 meters at 10kmph emitting only 60.4 dBA sound under a city ambient noise of 60.1 dBA. It indicates that the vehicle is almost silent while being driven at 10kmph. This is a clear potential threat to nearly pedestrians.
6. Data was collected for city ambient noise and traffic noise. To normalize the values, we considered the mean value between the average sound dBA and the peak dBA. The normalized values ranged between 74.9 dBA to 84.6 dBA. This is a clear indication that in absence of an AVAS system there is no scope for pedestrians or co-drivers or people nearby the road to identify an approaching EV.

5.2 Suggestions for Future Work

In this study our main ambition was to exhibit the importance of an AVAS system for the silent EV vehicle plying on the Indian road that possess potential risk of accidents. However, further studies should be made on aspects related to the architectural design of AVAS as a product. The electronic and acoustic design, speaker placement, frequency spectra tuning are areas where more research is needed specially for Indian automotive sector. Another aspect that needs to be further worked upon is the adaptive AVAS system, wherein, with use of algorithms and sensors, the vehicle sound can be modulated based on the city ambient noise or vehicle speed levels. With the use of sensitive microphones fitted in the vehicle the ambient or traffic noise can be measured to modulate the AVAS sound emission levels. For example, in a relatively less crowded or silent zone the AVAS sound dBA levels can be lesser compared to a highly crowded traffic. This kind of flexibility will further improve the overall performance and will provide higher degree of safety for the pedestrians and the vehicle driver. Going forward more studies on these aspects should be conducted.

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Abbreviation

1.	AVAS	Acoustic Vehicle Alerting System
2.	AIS	Approach Information Sound
3.	dBA	Decibels
4.	EV	Electric Vehicle
5.	HEV	Hybrid Electric Vehicle
6.	BHEV	Battery Hybrid Electric Vehicle
7.	BEV	Battery Electric Vehicle
8.	PHEV	Plug-in Hybrid Electric Vehicle
9.	ICE	Internal Combustion Engine
10.	NHSTA	National Highway Traffic Safety Administration
11.	UNECE	United Nations Economic Commission for Europe
12.	CMVSS	Canada Motor Vehicle Safety Standard
13.	KMVSS	Korea Motor Vehicle Safety Standards
14.	FMVSS	Federal Motor Vehicle Safety Standards
15.	IS	Intensity of Sound
16.	AD	Audibility Distance
17.	QRTV	Quiet Road Transport Vehicle
18.	CPCB	Central Pollution Control Board
19.	NANMN	National Ambient Noise Monitoring Network
20.	VESS	Virtual Engine Sound System
21.	EPS	Environmental Perception System
22.	LBS	Location Based System
23.	GPS	Global Positioning System
24.	SUV	Sports Utility Vehicle
25.	GHSL	Global Human Settlement Layer
26.	GDP	Gross Domestic Product
27.	CAGR	Compound Annual Growth Rate
28.	GHG	Green House Gas
29.	FAME	Faster Adoption & Manufacturing of Hybrid and Electric Vehicles
30.	NITI	National Institution for Transforming India
31.	MLIT	Ministry of Land, Infrastructure, Transport and Tourism
32.	PC	Passenger Car

33. HEV	Heavy Commercial Vehicle
34. OEM	Original Equipment Manufacturer
35. LCV	Light Commercial Vehicle
36. MCV	Medium Commercial Vehicle
37. EC	Environmental Concerns
38. PSEA	Pedestrian Safety Enhancement Act
39. MVSR	Motor Vehicle Safety Regulations
40. GVWR	Gross Vehicle Weight Rating
41. FHWA	Federal Highway Administration
42. CORTN	Calculation of Road Traffic Noise
43. RLS 90	Richtlinien für den Lärmschutz an Straben (estimation of noise levels)
44. NVH	Noise Vibration and Harshness
45. PWM	Pulse Width Modulation
46. TRL	Transport Research Laboratory (UK Department)
47. JASIC	Japan Automobile Standards Internationalization Centre
48. VSP	Vehicle Sound for Pedestrians
49. DTU	Technical University of Denmark
50. eVADER	Electric Vehicle Alert for Detection and Emergency Response
51. Hz	Hertz
52. KHz	Kilo Hertz
53. SPL	Sound Pressure Level

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