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The concept of adaptive AVAS – results from a small test program

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ABSTRACT

The current regulations on AVAS, as in UN ECE Reg.138 and FMVSS 141 (US) specify the minimum noise level at low speeds (below 30 km/h). There are also requirements for the tonal components, both regarding the frequency content and the frequency shift (speed depending). In this paper, the results from a small test program on adaptive AVAS is presented. The idea was to test if the sound level of AVAS could be reduced when the background level is very low (less than 40 dB) and then again be increased if the background level is high, as in a busy city street. The test program was conducted using an electric vehicle (EV) with a front mounted loudspeaker with an adjustable AVAS sound level. In addition, a loudspeaker with an artificial designed noise spectrum was used to simulate different background noise levels. 8 test persons (3 blind and 5 normal seeing, but with sleep shades) participated in the test, pressing a button when they could hear the vehicle approaching. The detection time (or distance) has a direct connection to the safety for pedestrians when an EV is approaching. The main results from the experiment are presented in the paper.

Keywords: Noise, Electric vehicles, AVAS
I-INCE Classification of Subject Number: 13

1. INTRODUCTION

Electric vehicles and hybrid vehicles in electric mode are in most cases significantly quieter at speeds lower than 20 km/h, compared to cars with internal combustion engines (ICE)[1]. With increasing number of such "silent" vehicles in the traffic, a strong concern has been raised by blind and visually impaired persons. They have found it more un- safe to move around in traffic, where these electric/hybrid vehicles

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have become more frequent. Usually, visually impaired persons rely on their hearing abilities to define if it is for example, safe to cross a street with approaching vehicles.

Even if Norway has the highest density in the world of electric and hybrid vehicles, as a percentage of the total vehicle fleet[2], there have been no reports so far of any fatal or serious accidents between this category of vehicles and pedestrians/bicyclists. However, some near misses have been reported. In 2017, a blind person with a white stick was nearly hit by an electric car, when he was crossing the street at the zebra crossing. His stick was broken, and he claimed that he could not hear that this car was approaching him without stopping.

Under the term of "universal design", the ability to move around safely in a traffic environment is a civil right for every citizen, independent on any physical disability. It is in this context, the national organization of blind people in Norway has complained about the situation and asked for measures to make it safer for them to move around in trafficked areas.

2. INTERNATIONAL REGULATIONS

Partly based on initiatives from the World Blind Union and other organizations for visually impaired people in the U.S, international regulations have been developed describing requirements of the minimum of external sound level of vehicles running at speeds below 20-30 km/h (QRTV). By the UN, the ECE Regulation 138[3] was introduced from October 2016. In the US, the NHTSA rule FMVSS 141[4], which also regulates the minimum sound of vehicles has recently been adopted. The requirements in the US rule is somewhat different from the ECE regulation, especially concerning maximum vehicle speed and tonality requirements for the artificial sound. The basic principles of UN ECE Reg.138 has been implemented by EU in the regulation 540/2014[5] This regulation states that all new vehicles type approved after 1 July 2019, must meet these requirements. By 1 July 2021, all new quiet vehicles must meet the regulation. For electric vehicles and hybrid vehicles running in electric engine mode, it requires an additional artificial warning sound, named AVAS (Acoustic Vehicle Alerting System) to meet these regulations.

Both regulations are based on (identical) international approved sound measurement methods ISO 16254[6] and SAE J2889-1[7].

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 2 m distance from the centre 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.

The regulations define AVAS, with respect to the minimum sound required on 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[8]. 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.

3. OBJECTIVES OF INVESTIGATION

The regulations do not specify any adaption of the sound pressure level of AVAS, depending on the background noise level. This means that the sound level of AVAS at a given vehicle speed is the same, independent if the car is in a quiet residential area during night time or in a busy city street during day time. Most of the present EVs with AVAS engaged have a sound level around 60 dB[9] at 20 km/h. In a quiet residential street during night time, the background noise level can be 40 dB or lower. In these conditions, the audibility of the AVAS signal can be very high. Complaints have been made from people experiencing a neighbor parking his/her electric car near to their bedroom, when the window is open. Then the AVAS signal (especially from the reverse signal) has been reported as annoying, since it can be 10-20 dB higher than the background noise levels.

In the opposite situation, in a busy city traffic, the background noise level can easily be in the range of 65-70 dB. In these situations, it can be very difficult to hear the AVAS signal at all. However, it may be that blind people in general do not rely on hearing the individual vehicle to make decisions to stop or go, unless the vehicle is very close. Any increase in the sound level of AVAS to improve this situation must in any case be balanced against the general need to reduce road traffic noise. However, it may be solved if the AVAS is for example only engaged at special locations (by GPS) as near pedestrian crossings, schools or kindergartens.

It has been calculated that the potential reduction of road traffic noise is around 3-4 dB, if all present ICE vehicles are replaced by electric vehicles[10].

The main objectives of the project presented in this paper have been twofold:

1) To investigate if the sound level of AVAS could be increased if the background noise is high

2) If the sound level of AVAS could be reduced at low background noise levels and still be detectable

The results could then be part of an evaluation of the principles of an adaptive AVAS, as a supplement or amendment of present regulations.

4. LAY-OUT OF FIELD TEST

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 1. 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.
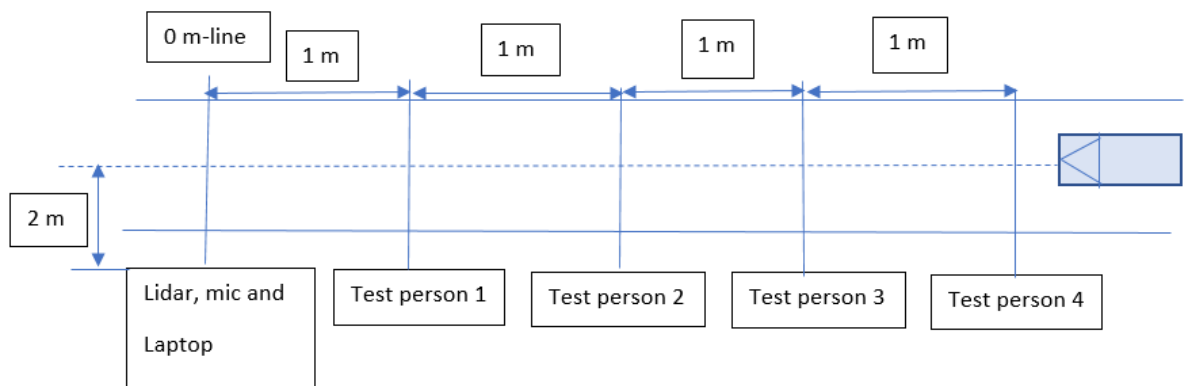
Figure 1. Lay-out of test area

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 1) defines the detection distance of the car from the 0 m-line.

Figure 2 show the positions of the test persons near the road and figure 3, the lidar, microphone and loudspeaker.

Figure 2. Test persons located at the road side

Figure 3. Microphone and loudspeaker (to the left – behind on the grass) and Lidar

A loudspeaker was placed behind the test persons (figure 3). From this loudspeaker the background noise level was played at different levels, calibrated at the microphone position.

The normalized noise spectrum is shown in figure 4. It is a recommended noise spectrum to be used in such listening tests. It is based on recordings of 1-5 minutes of background noise levels at several locations in Copenhagen[10].

The benefit of using such a standard noise signal, compared to a time-variable noise signal (as found in a city), is that it is possible to make repeatable and reproduceable test conditions.
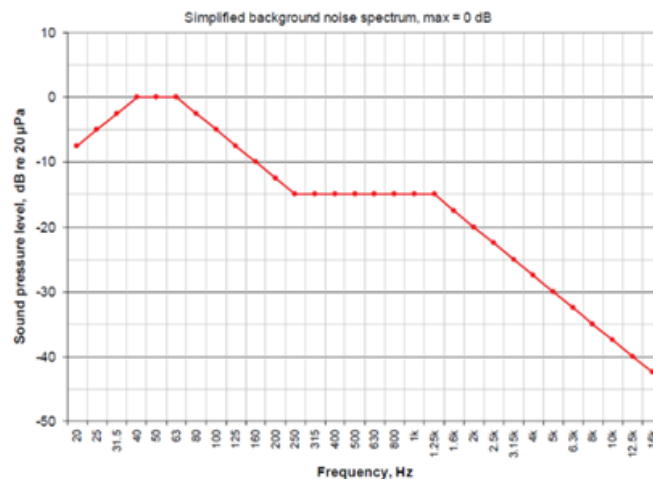

Figure 4. Normalized traffic noise spectrum used as a background noise signal[10]

Table 1 gives an overview of test persons, gender, age and their visual ability. 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, but this was not feasible within the time set for the test.

Table 1. Test persons

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

Two cars were used for the test: As an ICE reference car: VW Caddy (diesel engine and manual transmission), see figure 5. During the test, only 2nd gear was used at the speed of 20 km/h. As an electric vehicle (EV): Nissan e-NV 200, see figure 6. This is a rather large EV with 7 seats. Tyres on the EV: Goodyear EfficientGrip 185/65 R15. The EV was only a few weeks old at the time of the test.

Figure 5. VW Caddy   *Figure 6. Nissan e-NV 200*

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.

In addition to the standard AVAS (emitted from a loudspeaker hidden under the wheel case on the left side of the car), a modified system for AVAS was implemented. A loudspeaker was mounted in the front of the car, with the membrane directed downwards, as shown in figure 7. A recorded AVAS signal (from a Renault Zoe at a speed of 20 km/h) was used as a "modified "AVAS. This modified AVAS was adjusted to different sound levels at the position of the microphone in figure 1. This means that during each test, AVAS was constant both regarding tonality and sound level.

Figure 7. Mounting of loudspeaker with modified AVAS signal

On the location of the test, the existing background noise level was measured to be in the range of 38-40 dB, when there was no audible activity in the area. However, there were occasionally some events, like an aircraft passing, some other vehicles, etc., which then could influence the tests. In case such events occurred during a test, this test was removed from the analysis.

Table 2 gives an overview of all combinations of car, sound level of AVAS and background noise levels used during the tests. All tests were made at 20 km/h. Note that it was not possible to measure the level of the original AVAS signal at this speed, as the dominating noise source was the tyre/road contact (see also table 3).

Table 2. Test conditions: car, level of AVAS and background noise level

Test no.	Car	AVAS	Sound level, AVAS, dB(A)	Background noise dB(A)
1	ICE	-	-	38 - 40[2]
2	EV	Paused	-	38 - 40
3	EV	Org. AVAS	-[1]	38 - 40
4	EV	Mod, AVAS	50	38 - 40
5	EV	Mod, AVAS	50	50
6	EV	Mod, AVAS	55	50
7	EV	Mod, AVAS	60	60
8	EV	Mod, AVAS	60	65

1) Not measured due to tyre/road noise level   2) Natural background noise level at location

A total of 8 persons were used (table 1), with 4 in each test. Each test condition was repeated 5 times, to reduce the statistical uncertainty. This created a total of 80 data files for further analysis. However, some of these files were removed due to unwanted noise events during the test.

5. MEASUREMENT RESULTS

5.1 Analysis of maximum noise levels and detection distance

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 3, as the average of 5 runs.

In test 2, the original AVAS has been paused, while it is engaged in test 3. As table 3 show, there is no significant difference in the maximum sound levels, indicating that the tyre/road noise contribution is the dominating noise source at 20 km/h.

In test 4 to 6, the maximum noise level is unchanged, even if the background noise signal from the loudspeaker has a level of 50-55 dB and the modified AVAS level is 50 or 55 dB. For all these test conditions, the maximum noise level at the position of the microphone is defined by the tyre/road noise on this specific electric vehicle/tyres and on this specific road surface.

When the AVAS signal is increased to 60 dB and the background noise level is either 60 dB (test 7) or 65 dB (test 8), there is, as expected, an increase of the overall maximum sound level of 2 - 5 dB.

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 3. Maximum A-weighted sound level, LAmax, dB(A) with standard deviation. Speed: 20 km/h

The requirements in the regulation[2] for minimum sound level at 10 km/h are 50 dB and 56 dB at 20 km/h. This is 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 (tests 1 and 2), 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 rule[3] 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 our analysis, we 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 8. In this case (test no. 5), the AVAS level is set to 50 dB and the background noise level set to 50 dB. 0 second is at the 0 m-line in figure 1. 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).
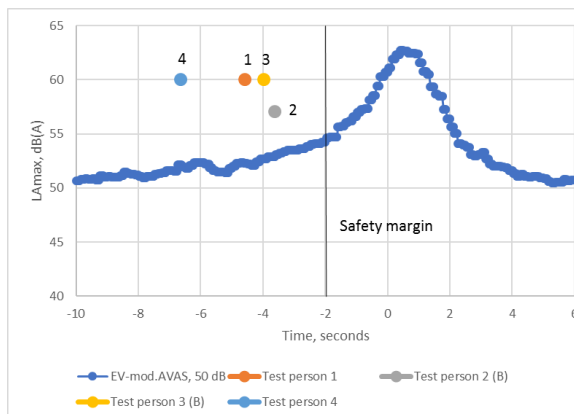

Figure 8. Example of analysis and results of one run (test no.5). Persons 2 and 3 are visually impaired

In this specific example, all test persons could hear the car before reaching the 2 seconds (11 m) safety margin.

In figure 9, 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 shows that the probability is 95 % that the average detection distance is 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.
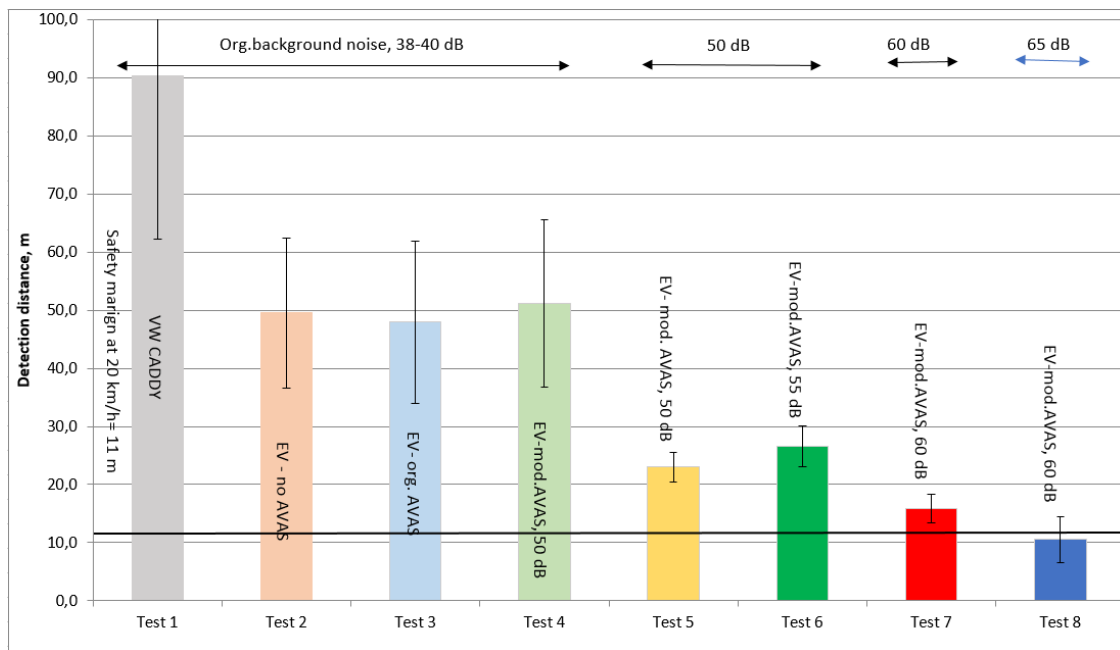

Figure 9. Average detection distance with 95 % confidence interval

As shown in figure 9, 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 these results, we would have liked to repeat the test with the ICE car, also when the background noise was high, like during test 8. 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 3), 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 9 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), we have a situation where several of the test persons could not hear the car within the safety margin. These tests indicated that in very normal 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 (basis for the spectrum in figure 4) 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, or 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 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 others, especially when the background noise level is high. However, the analysis showed that we could not find any significant difference between the groups. However, one should bear in mind that there were only 3 persons in the visually impaired group. Also, the persons in this group was in the same age category (55-60 years). Another important factor is that when the normal seeing test persons were blindfolded, they had to concentrate using their ears to listen for the approaching car. This may mask any such differences between the two groups. In a "normal" situation, where the eyes are also used, the sound of the vehicle may be neglected in many situations.

5.2 Increased safety margin

A similar project, as described in this paper has been conducted by Western Michigan University, US[11]. In this project, a so-called "crossing margin" has been used in their analysis. This margin is defined as the margin which allows a person to cross a street, without any danger of being hit by an approaching vehicle. In their tests, this margin was set to be 6,9 seconds, based on the following assumptions:

- *A person shall cross a two-way street being 7,3 m (24ft) wide and this person walks with a speed of 1,07 m/s (3,5 ft/s).*

If an approaching car has a speed of 20 km/h (~5,6 m/s), the car must be 38 m before the pedestrian crossing area, in order to a safe crossing for the pedestrians. In this analysis, any possible reaction from the driver and breaking of the car is not included, only the time needed for crossing.

We have used this criterion and in figure 10, this increased crossing margin of 38 m is shown together with the detection distances.
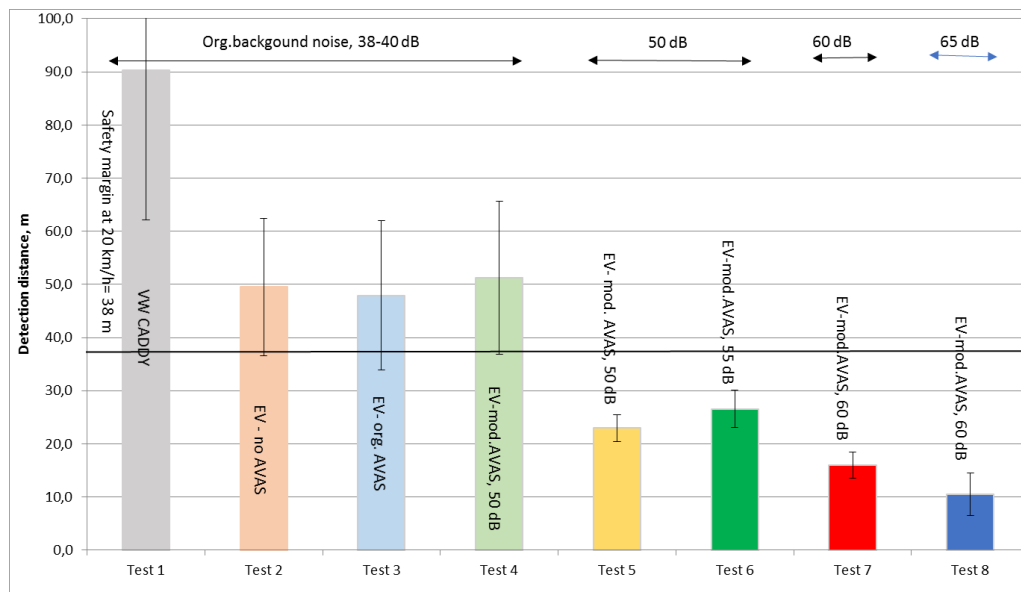

Figure 10. Detection distance with a safety margin of 38 m

Based on this criterion, we can see that when the background noise is 50 dB or higher (tests 5 to 8), it is not feasible for a blind/visually impaired person to cross the street safely, if the driver is **not** aware of this person and do not break/stop the car.

This analysis is based on a fixed walking speed of the pedestrian. In reality, this speed would of course vary, due the age/physical condition etc. of the person. If the assumed walking speed of 1.07 m/s (approximately 3,9 km/h) is varying with ± 25 % (in the range of 3 to 5 km/h), it would vary the crossing margin from about 30 to 50 m. A crossing margin of 30 m will not change the situation shown in figure 10, as tests 2 to 4 still give a safe crossing. However, if the person walks in a speed around 3 km/h, which is not unrealistic, the crossing margin will be around 50 m. Then, conditions for tests 2 to 4 could be unsafe, even with a low background noise level.

Within the scope of this project, it was not possible to investigate the effect on the detection distance if the sound level of AVAS was increased (above 50-60 dB), with a crossing margin of 38 to 50 m, especially when the background noise level is low.

In any case, an increased sound level of AVAS to say, 65-70 dB could be problematic and counterproductive for the need to reduce road traffic noise in general.

6. CONCLUSIONS

The project conducted and presented in this paper 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 safety 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) in the survey, 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, with different background noise levels, at this speed condition.

- 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 table 3) 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.

7. ACKNOWLEDGEMENTS

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