# The influence of location of the privileged vehicle siren on the vehicle traffic safety

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## ABSTRACT

Audible emergency signals generated by sirens of privileged vehicles should be audible and recognisable by all participants of the traffic. Currently in Poland, A-weighted sound pressure levels of audible emergency signals generated by sirens of privileged vehicles range between 104 and 108 dB. In turn, the A-weighted sound pressure levels measured inside the privileged vehicles may exceed the value of 90dB. Such high sound pressure levels may adversely affect the working conditions of the privileged vehicle crew. A commonly applied solution, aimed at limiting the exposure of the privileged vehicle crew to noise, is fitting the siren in the engine compartment rather than in the vehicle roof lightbar. Changing the location of the siren can reduce the measured sound pressure levels inside the vehicles by about 10 dB. Changing the location of the siren has also a significant impact on the audibility of the emergency signal by the other participants of the road, and thus affects the vehicle traffic safety. It is necessary to initiate a discussion on improving the acoustic comfort of the vehicle crew, and at the same time maintain the informational function of the emergency signals.

Keywords: Noise, Privileged vehicles, Exposure to noise, Drivers

## 1. INTRODUCTION

According to the Polish Highway Code, if an ambulance, fire engine or police vehicle is to be treated as an privileged vehicle on duty, it must emit emergency audible and light signals. Other road users have an absolute obligation to give the right of way to any vehicle that "…is emitting blue flashing light in combination with audible signals of variable frequency, and is moving with its headlights (high or low beam) on…" [7]. Usage of complementing emergency audible and light signals allows the privileged vehicle to inform the other road users from a significant distance about the necessity to give the right of way and to allow the unobstructed pass-by of the vehicle. At congested traffic – when light signals may not be very helpful in localizing the position of the privileged vehicle – that function must be taken over by the audible signals [5]. Therefore, the latter signals must be audible and identifiable from a safe distance i.e. a distance giving sufficient time for other road users to enable pass-by of the privileged vehicle. Considering high variability of acoustic conditions in the urban environments and types of the emergency signalling devices currently used, the safest way to ensure the audibility of the audible emergency signals emitted is a high sound pressure level of these signals [1]. The notion of "a high sound pressure level" is not particularly precise, but no detailed regulations concerning audible emergency signals generated by sirens of privileged vehicles can be found in any Polish law in force. The withdrawn PN-S-76006:1975 Polish standard [9] that applied only to two-tone audible emergency signals generated by sirens of privileged vehicles specified the requirement that maximum A-weighted sound pressure level of an audible emergency signal measured at a distance of 2m in front of the forward facing end of the vehicle should be not less than 115dB. No detailed guidelines concerning audible emergency signals have been specified either in Poland or elsewhere in the world. However, SAE (Society of Automobile Engineers) J1849 [11] is one of the most essential international documents specifying the guidelines concerning such signals. According to these guidelines, maximum A-weighted sound pressure level of an audible emergency signal measured at distance of 3m from the privileged vehicle shall not exceed 118dB. The provisions

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concerning minimum A-weighted sound pressure level of audible emergency signals may also be found in Swiss [12] and German [10] legislation. Each of these documents specifies somewhat different values of the allowed sound pressure levels, as well as different measurement methods. Despite the absence of Polish regulations concerning audible emergency signals, three main types of signals are used in practice. These are signals of A-weighted sound pressure levels of 100 to 115dB and frequencies within the 500…2000Hz range [2]. Sound pressure levels above 100dB seem to be quite high, however in practice, particularly due to high traffic congestion, signals of such intensity may be insufficiently audible.

## 2. EXPOSURE OF PRIVILEGED VEHICLES' DRIVERS TO NOISE

For majority of road users the audible emergency signals may be the most important way of notification about an approaching privileged vehicle, but for the crew of the vehicle – in particular for the driver – the same signal may be a source of bothersome noise. Studies conducted in Central Institute for Labour Protection – National Research Institute (CIOP-PIB) showed that privileged vehicle signals are the main source of noise inside cabins of such vehicles [2]. A few noise values measured inside the cabin in the vicinity of driver's head, including the equivalent A-weighted sound pressure level ($L_{Aeq,T}$), the peak C-weighted sound pressure level ($L_{Cpeak}$) and the maximum A-weighted sound pressure level ($L_{Amax}$), are presented in Table 1. The measurements were taken in a vehicle moving in the traffic. The measured noise values were compared to the permissible noise levels defined to protect human hearing.

Table 1 – Exemplary noise levels measured inside cabin of an privileged vehicle moving in the traffic

| The siren | $L_{Aeq,T}$ [dB] | $L_{C,peak}$ [dB] | $L_{A,max}$ [dB] |
|---|---|---|---|
| deactivated | 65 | 102 | 69 |
| activated | 90 | 115 | 94 |

As soon as audible emergency signals were turned on, all noise levels measured in the vicinity of the driver's head increased: equivalent A-weighted sound pressure level ($L_{Aeq,T}$) by about 25dB, peak C-weighted sound pressure level ($L_{Cpeak}$) by about 13dB, and maximum A-weighted sound pressure level ($L_{Amax}$) by about 25dB (Table 1). It is noticeable that neither limit value of peak C-weighted sound pressure level (135dB) nor limit value of A-weighted sound pressure level (115dB) inside the vehicle were exceeded. Daily exposure, calculated on the basis of the $L_{Aeq,T}$, of privileged vehicle crew to noise (noise exposure level, normalized to an 8-h working day – $L_{EX,8h}$) may be exceeded in extreme circumstances (natural disasters, catastrophes, etc.). However, assuming that the mean privileged vehicle crew travel time with the audible emergency signals activated is about 60 minutes, the exposure normalized to 8 hours will amount to about 80dB. There are no dedicated Polish regulations regarding permissible noise levels inside the privileged vehicles. However, due to the specific nature of the work of drivers of such vehicles one can consider applicability of the PN-N-01307:1994 Polish standard [8]. This standard defines limit values of noise in work environment from the point of view of ability of the workers to accomplish their basic tasks i.e. criteria deciding when noisy environment becomes a bothersome. Assuming that the work of an privileged vehicle driver (i.e. driving such vehicles) requires precision and is a highly responsible job, one can accept 65dB as the applicable maximum equivalent A-weighted sound pressure level. The above indicated choice may then be justified by the fact that a high level of noise would increase stress with hazardous consequences for health and life of the exposed driver and other people. Such drivers work in particularly stressful conditions since they are expected to drive their vehicles both fast and safely under the pressure of time [4]. Besides, the study conducted by CIOP-PIB [6] showed that noise emitted by audible emergency signals is one of the main common factors for mental exhaustion of paramedics. The issue has been known for a long time, but no action undertaken so far to decrease the exposure of privileged vehicle crew members to excessive noise turned out to be effective. In some cases acoustic comfort was improved by moving a siren of the emergency signalling device from the lightbar mounted on the roof of the privileged vehicle into vehicle engine compartment or behind the vehicle's front apron.

Table 2 – Exemplary noise levels measured inside cabin of an privileged vehicle for various siren locations

| The siren location | $L_{Aeq,T}$ [dB] | $L_{C,peak}$ [dB] | $L_{A,max}$ [dB] |
|---|---|---|---|
| inside the roof lightbar | 87 | 99 | 88 |
| inside the engine compartment | 76 | 88 | 84 |

This solution could decrease A-weighted sound pressure level inside the vehicle cabin by about 10dB (Table 2), but the question is whether the audibility of emergency signals by other road users will not significantly decrease as a side effect.

## 3. AUDIBILITY OF EMERGENCY SIGNALS

Moving the siren of the emergency signalling device from the lightbar mounted on a vehicle roof to the vehicle engine compartment or behind vehicle's front apron means lowering its position by about 2m. In congested traffic conditions, vehicles of other road users usually effectively noise barrier the audible emergency signals out (reflect and absorb acoustic energy of the signal emitted). The lower the siren position is, the more effective the acoustic shielding effect. The audibility of such acoustic shielded signals may significantly drop.

Numeric simulations were carried out in order to determine the influence of changing the signal position on the audibility of the signal for other traffic participants. The simulations used the CadnaA software package designed to make calculations, evaluations and presentations related to noise levels in the environment. Several hypothetical situations that may occur when an privileged vehicle moves along a single-carriageway local road routed between 6-storey buildings have been simulated. The road consists of two lanes each 2.5m wide and a 2m wide pavement at each road side. Sanitary ambulance built on the basis of the Mercedes-Benz G 280 vehicle was the simulated privileged vehicle. Two variants were simulated: (1) the siren mounted on lightbar placed at height of 2.7m on the vehicle roof, and (2) the siren mounted inside the vehicle engine compartment at height of 0.6m. A signal of 118dB A-weighted sound pressure level measured at a distance of 1m and frequencies range 500…2000Hz was the audible emergency signal used in the simulations. The selected parameters correspond approximately to acoustic parameters of the currently applied real audible emergency signals.

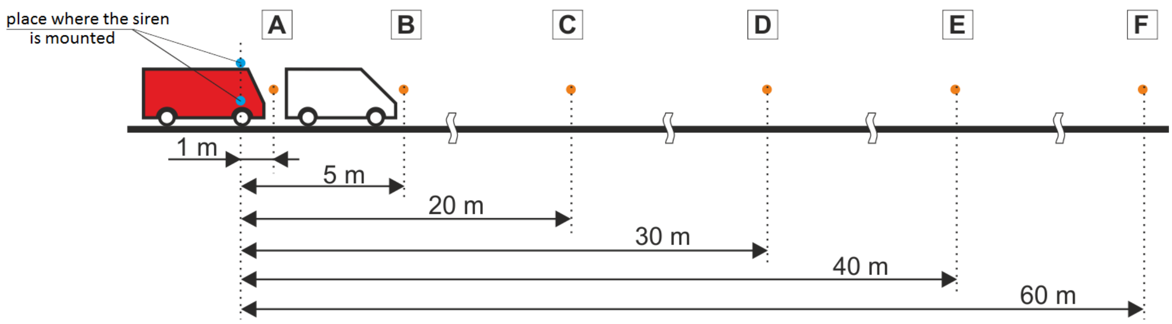


Figure 1 Diagram showing the measurement points (side view)

The first reference simulation point (designated A in Fig. 1) was selected at a distance of 1m from the siren, subsequent points B,C,D,E,F – at distances of 5,20,30,40,60m from the vehicle respectively, all points were located at the symmetry axis of the road and 1m above the road surface. Red colour on the diagram depicts the privileged vehicle, white colour – a "acoustic shielding vehicle" of other road user.

In case there are no other vehicles in front of the privileged vehicle, sound pressure levels obtained for both locations of the siren are similar. The differences do not exceed 1dB except for the reference point A, where the higher difference reflects only a different distance from the simulation point (fixed elevation 1m above the ground) to sound source in both cases (mounting height of siren – 0.6m and 2.7m in variant 1 and 2).

The situation changes radically if any other vehicle appears in close vicinity in front of the sound source. In an example illustrated in Fig. 2, another vehicle (depicted with a yellow rectangle) of a size similar to the size of the privileged vehicle (depicted with a red rectangle) is placed 1m in front of the latter. Simulation results (especially for variant 2) are then quite different. In point B, results obtained in both variants do not differ much (by about 2dB), however the differences grow in subsequent points to exceed 12dB. Sound pressure level decreases much faster with the distance to the privileged vehicle if the siren is located inside vehicle engine compartment (variant 2): in variant 1 it is higher than in variant 2 by 10.4,11.3,11.7,12.4dB in points C,D,E,F, respectively. Simulations performed in CIOP-PIB lead to a general conclusion that the results are similar if the number of interfering vehicles on the road is higher than one.

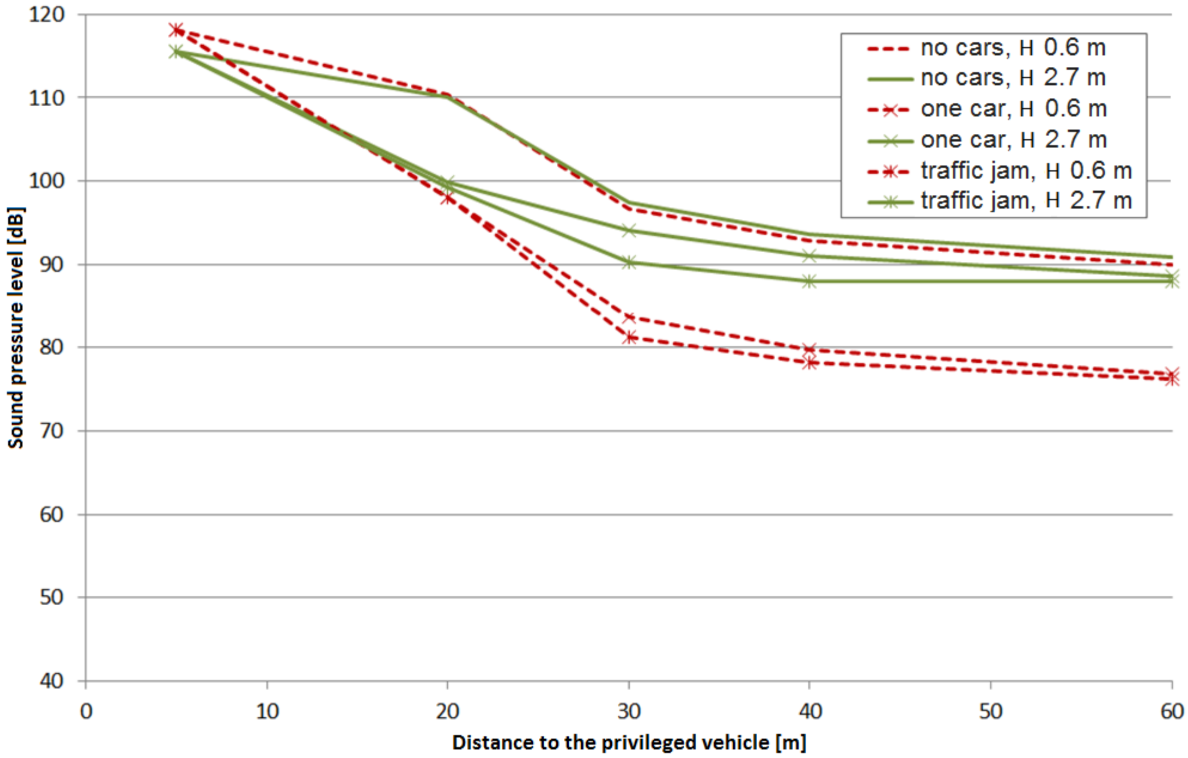


Figure 2 Decrease of audible emergency signal sound pressure level vs distance to the privileged vehicle on the road.

Results of the simulations are presented in Fig. 2. Solid lines depict the results obtained for variant 1 (the siren on the roof), dashed lines depict results obtained for variant 2 (the siren inside the engine compartment). Lines without any markers depict results obtained in the case when there are no other vehicles on the road in front of the privileged vehicle. Lines with crosses depict the results obtained for the case when a single vehicle in front of the privileged vehicle is interfering (acoustic shielding emergency signals). Lines with asterisks depict results obtained for the case when the road in front of the privileged vehicle is fully clogged by other vehicles (the so-called traffic jam, modelled as a collection of vehicles of a size similar to the privileged vehicle size distributed 1m apart from each other on both lanes of the road).

Results obtained in both variants do not differ much (by less than 1dB) only in case when the road in front of the privileged vehicle is empty. Presence of just a single interfering vehicle significantly reduces sound pressure level of audible emergency signals emitted by the siren mounted inside vehicle engine compartment (variant 2) as compared to the same siren mounted on vehicle roof lightbar (variant 1). Influence of additional interfering vehicles in front of the privileged vehicle is not significant (less than 3dB).

As can be seen in Fig. 2, if any other vehicle appears in front of privileged vehicle with the siren located inside engine compartment (variant 2), sound pressure level decreases faster (than in variant 1) at distances above about 5m, the difference reaches about 20dB at 20m. In variant 1 acoustic shielding by other vehicles decreases (less than 3dB at 60m), while in variant 2 the difference stays constant around 10dB at distances within the 5-60m range. The difference between sound pressure level when there are no other vehicles in front of the privileged vehicle and sound pressure level at the same point when there are some other vehicles in front of the privileged vehicle was taken as the parameter numerically describing effect of acoustic shielding by the other vehicles. Assuming by averaging that audible emergency signal must be no weaker than 85dB in order to be to be practically audible on the road, one can conclude that in variant 1 the signal will be heard outside cars at distances up to about 60m, while in variant 2 – only up to about 20m.

## 4. SUMMARY

The above presented results of researches show that exposure of privileged vehicle drivers to noise in the form of their own audible emergency signals is significant and new measures to decrease it should be searched. However, measures that would decrease the audibility of the signals by other road users cannot be accepted. The relocation of the siren from the roof lightbar to the vehicle engine compartment on one hand allows to decrease noise in privileged vehicle cabin by about 10 dB, but on the other hand height of the sound source above the ground is also decreased by about 2m. Such change in location of the siren unfortunately decreases the audibility of the emitted emergency signals in road traffic conditions, that way decreasing safety of the moving privileged vehicle. The decrease is significant especially if any other vehicle close to and in front of the privileged vehicle is acoustic shielding the emitted audible emergency signals. The acoustic shielding effect is much more evident than in case of an privileged vehicle with its siren mounted on its roof lightbar. Simulations done in this work indicate that the difference in audible emergency signal sound pressure levels at the same points may reach 12dB in favour of variant 1 (the siren was mounted in roof lightbar). The difference influences into the distance from which audible emergency signal will be heard outside cars: 20m for siren mounted inside vehicle engine compartment, and 60m for siren mounted on vehicle roof lightbar. Therefore, the siren of the emergency signalling device should be mounted at the highest possible elevation, in practice on the vehicle roof lightbar.

In view of the above, new innovative methods capable to decrease exposure of privileged vehicle crew to noise generated by audible emergency signals should be developed. Such methods might for example include active noise reduction methods, modification of directional characteristics of the emitted signal, or emergency signalling devices capable of adaptive control of sound pressure level of the emitted signal. No ready-to-use solutions are available, however model solutions of certain active methods have already been proposed [3].

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