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# Occupational Exposure to Noise From Authorized Emergency Vehicle Sirens

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*Warning signals generated by sirens of authorized emergency vehicles should be audible and recognizable to all road users. Currently, there is no legislation in Poland defining sound pressure levels (SPLs) of audible warning signals generated by sirens of authorized emergency vehicles. Measured* A*-weighted SPLs of those signals range between 104 and 108 dB. While for road users, an audible warning signal is a source of important information and its* A*-weighted SPL is acceptable, it may be a source of annoying noise to an emergency vehicle crew. That is why, it is necessary to find a method of improving the acoustic comfort of the crew and, at the same time, maintaining the informational function of audible warning signals.*

emergency vehicles occupational exposure to noise drivers



## 1. INTRODUCTION

Ambulances, fire engines and police cars are just a few of the emergency vehicles encountered every day. Even though authorized emergency vehicles are a relatively small group of road users, they are very important, because human life often depends on how fast they can reach their destination. According to highway codes, an on-road authorized emergency vehicle should emit visual and audible signals at the same time. These signals are designed to inform other road users not only about the presence of an authorized emergency vehicle but, most of all, of the need to give way to allow it to pass unrestricted. For this reason, it is important that this information reaches road users from as far as possible to give them time to respond correctly. Drivers usually learn about an oncoming authorized emergency vehicle by hearing it first. Subsequently, they locate it on the basis of visual signals. Due to varying acoustic conditions, e.g., traffic noise, an appropriately high sound pressure level (SPL) of the warning signal ensures correct reception of an audible warning signal.

High SPLs of emitted signals, however, are a major concern for emergency vehicle crews as they may adversely affect the crew's acoustic comfort [1]. In this paper, acoustic comfort is defined as acoustic conditions that enable workers to implement their basic tasks without a decrease in psychomotor performance. Currently, to improve the crew's acoustic comfort, the siren of an audible warning device is often moved from the lightbar on the roof of the vehicle to the engine compartment. Changing the location of the siren is not a good solution, which this paper will show. Even though acoustic comfort improves, this change impacts perception of the audible warning signals in traffic, thus affecting safety.

This paper was based on the results of a research task carried out within the scope of the second stage of the National Programme "Improvement of safety and working conditions" partly supported in 2011–2013—within the scope of research and development—by the Ministry of Science and Higher Education/National Centre for Research and Development. The Central Institute for Labour Protection – National Research Institute was the Programme's main co-ordinator.

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## 2. SPL OF SIGNALS: REQUIREMENTS

Currently, there is no legislation in Poland defining admissible values of SPLs of on-road authorized emergency vehicles. UN/ECE Regulation No. 28 [2], Directive 70/388/EEC [3] and Standard No. PN-S-76004:1992 [4] set out the requirements for audible warning devices in vehicles, but not for audible warning signals of authorized emergency vehicles. Standard No. PN-S-76006:1975, withdrawn in 2005, required that the maximum *A*-weighted SPL of an audible warning signal generated by a siren of an emergency vehicle be at least 115 dB at a distance of 2 m [5]. However, this standard applied to two-tone warning signals only.

Standard No. SAE J1849_201210 is one of the most important international documents setting out the technical requirements for sirens of audible warning devices of an emergency vehicle [6]. It describes the acoustic parameters audible warning signals of authorized emergency vehicles should meet. According to this standard, the maximum *A*-weighted SPL of a signal generated by a siren 3 m from a vehicle and along its main axis cannot exceed 118 dB. Regulation No. RS 741.41 lists similar provisions, with different requirements for two- and three-tone warning signals [7]. Those requirements do not apply to modulated warning signals, which are common in Poland. The *A*-weighted SPLs accepted as minimum and maximum threshold levels are 100 and 115 dB for two-tone, and 93 and 112 dB for three-tone signals, respectively. Those SPLs are measured 7 m from the vehicle with the siren. Standard No. DIN 14610:2009-01 specifies 110 dB as the minimum value of the signal [8]. According to this standard, the minimum *A*-weighted SPL is measured in an anechoic chamber, 3.5 m from the siren.

Because no legislation in Poland defines admissible values of SPLs of on-road authorized emergency vehicles, limit values of SPLs for audible warning signals of authorized emergency vehicles are sometimes listed in the terms and conditions of purchase of emergency vehicles by the police, health or fire services. These provisions on threshold limits may be worded as follows: "a combined public address and warning device sending audible warning signals of an emergency vehicle must produce sounds whose equivalent *A*-weighted SPL measured with an integrating-averaging sound meter located 7 m in front of the vehicle must be 100–115 dB, for any kind of sound". As these provisions are not mandatory, in practice, requirements are often limited to "modulated audible signal with a power of at least 100 W and voice message delivery compliant with applicable regulations".

Despite considerable discretion in determining audible sound signals of an authorized emergency vehicle permitted by Polish legislation, three types of signals are usually used:

- a hi–lo signal, which is composed of 950- and 1150-Hz tones alternating every 0.5 s;
- a yelp signal, which is a linear tonal course of alternately rising and falling frequencies (the lower frequency of the signal is 500 Hz, the higher is 2000 Hz; the rises and falls in frequency are equal at 4 s);
- a wail signal, which is a repetitive descending tonal course of frequencies in the range from 1800 to 600 Hz; the frequency fall time is 2.5 s.

During rescue operations, emergency vehicles often use a mixed signal of 2-s fragments of all signals. Depending on the manufacturer of audible warning devices, these signals may differ slightly.

## 3. SPL OF SIGNALS AROUND VEHICLES

SPL of audible warning signals (generated by sirens around emergency vehicles) were measured in an open space; the emergency vehicles were parked in an empty car park. The car park was part paving stone, part gravel; it was located ~100 m from buildings. A Svan 948 four-channel sound and vibration meter and analyser (Svantek, Poland) was used. Peak *C*-weighted SPL ($L_{\mathrm{C\,peak}}$), maximum *A*-weighted SPL ($L_{\mathrm{A\,max}}$) and equivalent *A*-weighted SPL ($L_{\mathrm{Aeq\,T}}$) were measured. The emergency vehicle warning signal that was measured was mixed. The measurements involved police vans, ambulance vans and police cars.

At first, the measurements were taken 5 m from the front of the vehicle at a height of 1.5 m. The results of these measurements showed that $L_{AeqT}$, $L_{C peak}$ and $L_{A max}$ of a signal generated by sirens fitted in emergency vehicles were similar (Table 1).

**TABLE 1. Noise Emitted by Siren of Audible Warning Device by Vehicle (dB)**

| Vehicle | $L_{AeqT}$ | $L_{Cpeak}$ | $L_{Amax}$ |
|---|---|---|---|
| 1 | 104 | 115 | 108 |
| 2 | 106 | 116 | 108 |
| 3 | 108 | 117 | 112 |
| 4 | 108 | 118 | 112 |

*Notes.* $L_{AeqT}$ = equivalent *A*-weighted sound pressure level over duration *T*, $L_{Cpeak}$ = peak *C*-weighted sound pressure level, $L_{Amax}$ = maximum *A*-weighted sound pressure level; vehicle 1, 2 = van, vehicle 3, 4 = car.

A further analysis involved the values of SPL versus the distance from the emergency vehicle. Measurements were taken along the axis of the vehicle at selected distances from the front of the vehicle (Table 2). Due to the different height of the vehicles, the height at which the siren was located was the basic difference that affected the acoustic parameters of the generated audible warning signal. The siren of vehicle 2 (van) was placed at a height of 2.6 m, the siren of vehicle 3 (car) at a height of 0.6 m.

The analysis included measuring the directivity of audible warning signals emitted by the siren of vehicle 2, in which the siren was located in the roof lightbar. Measurements were taken on a horizontal plane at the height of the lightbar, 2.6 m above the ground (Table 3). Figure 1 shows measuring points (P1–P8) placed 1 m from the vehicle. The measuring points were selected taking into account available area. The analysis of the results showed that the tested emergency vehicle sirens were almost omnidirectional, with a slight (~3 dB) emphasis on the direction of movement of the emergency vehicle.

Analysing noise emitted by a siren of an emergency vehicle also involved measuring its frequency characteristics. Figures 2–3 show the results of measuring SPL in one-third-octave bands for vehicles 1 (van) and 3 (car) with the siren located in the engine compartment. In both cases, the measurements were taken at a standstill, 5 m from the front of the vehicle, at a height of 1.5 m. The spectra of signals emitted by both vehicles had very similar distribution, and most of the energy was concentrated in the frequency range from 630 to 2000 Hz. The measurements showed that SPLs of signals emitted by sirens of audible warning devices from a number of manufacturers were similar.

**TABLE 3. Noise Emitted by Siren of Audible Warning Device by Direction (Vehicle 2) (dB)**

| Point [a] | $L_{AeqT}$ | $L_{Cpeak}$ | $L_{Amax}$ |
|---|---|---|---|
| P1 | 114 | 127 | 119 |
| P2 | 116 | 126 | 119 |
| P3 | 111 | 123 | 116 |
| P4 | 104 | 115 | 108 |
| P5 | 98 | 111 | 101 |
| P6 | 98 | 110 | 102 |
| P7 | 104 | 116 | 110 |
| P8 | 113 | 123 | 117 |

*Notes.* a = for location of measurement points, see Figure 1; $L_{AeqT}$ = equivalent *A*-weighted sound pressure level over duration *T*, $L_{Cpeak}$ = peak *C*-weighted sound pressure level, $L_{Amax}$ = maximum *A*-weighted sound pressure level; vehicle 2 = van.

**TABLE 2. Noise Emitted by Siren of Audible Warning Device by Distance From Vehicle (dB)**

| | Vehicle 2 | | | Vehicle 3 | | |
|---|---|---|---|---|---|---|
| Distance (m) | $L_{AeqT}$ | $L_{Cpeak}$ | $L_{Amax}$ | $L_{AeqT}$ | $L_{Cpeak}$ | $L_{Amax}$ |
| 1 | 114 | 127 | 119 | 111 | 118 | 113 |
| 10 | 110 | 122 | 115 | 101 | 112 | 102 |
| 20 | 105 | 116 | 110 | 97 | 108 | 98 |
| 30 | 101 | 111 | 105 | 93 | 103 | 95 |

*Notes.* $L_{AeqT}$ = equivalent *A*-weighted sound pressure level over duration *T*, $L_{Cpeak}$ = peak *C*-weighted sound pressure level, $L_{Amax}$ = maximum *A*-weighted sound pressure level; vehicle 2 = van, vehicle 3 = car.

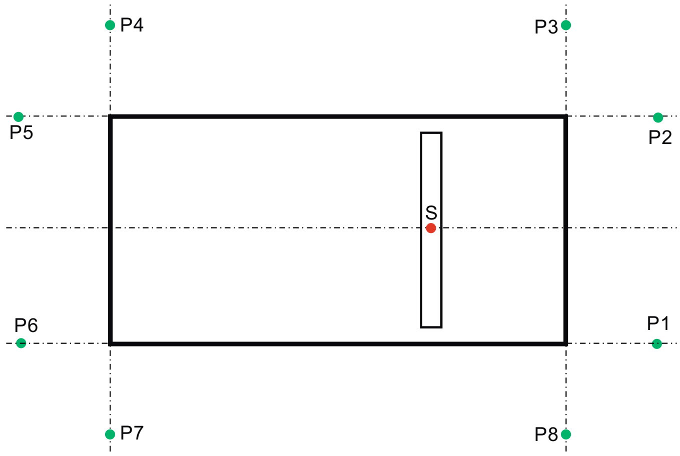


**Figure 1. Location of measuring points around an emergency vehicle.** *Notes.* P1–P8 = measurement points, S = siren.

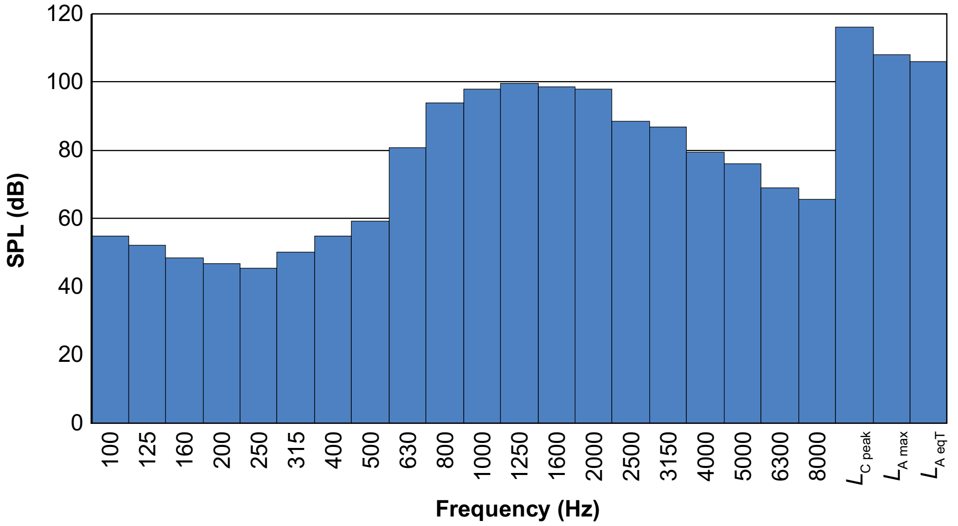


**Figure 2. One-third-octave-band sound pressure level (SPL) of warning signal; vehicle 1 (van).** *Notes.* $L_{C\,peak}$ = peak *C*-weighted sound pressure level, $L_{A\max}$ = maximum *A*-weighted sound pressure level, $L_{AeqT}$ = equivalent *A*-weighted sound pressure level over duration *T*.

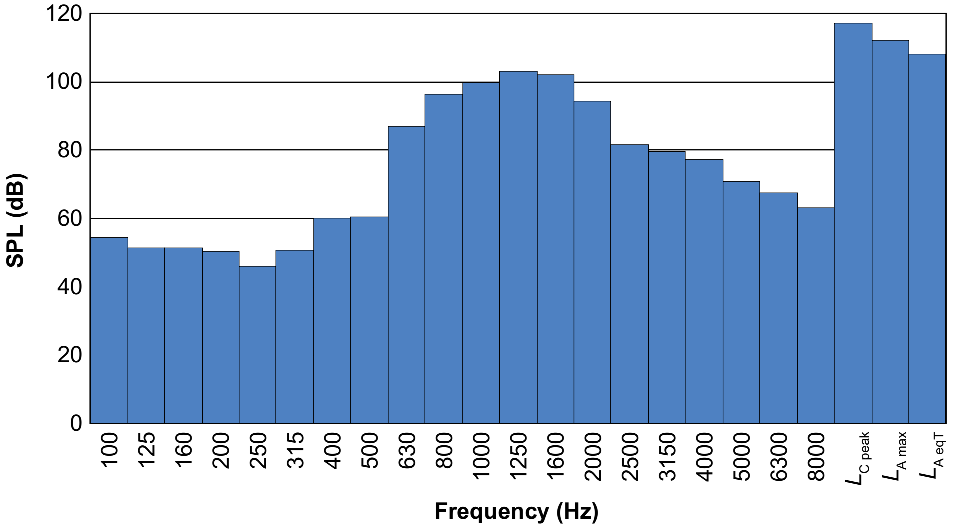


**Figure 3. One-third-octave-band sound pressure level (SPL) of warning signal; vehicle 3 (car).** *Notes.* $L_{C\,peak}$ = peak *C*-weighted sound pressure level, $L_{A\max}$ = maximum *A*-weighted sound pressure level, $L_{AeqT}$ = equivalent *A*-weighted sound pressure level over duration *T*.

Slight differences in the levels of the emitted audible signal and their spectral distribution resulted from the different structure of the electro-acoustic transducers used, different methods of mounting sirens and various methods of generating the signal.

## 4. SPL OF SIGNALS INSIDE VEHICLES

While for road users an audible warning signal is useful and its *A*-weighted SPL is acceptable, the the emergency vehicle crew may find it annoying. According to Morzyński and Górski, *A*-weighted SPLs inside an authorized emergency vehicle with an enabled siren can exceed 90 dB, which has an adverse impact on the working conditions of the driver and the crew; in extreme cases, it can lead to hearing loss [9].

Table 4 shows the results of measurements of $L_{\text{C peak}}$, $L_{\text{A max}}$ and the daily noise exposure level ($L_{\text{ex 8h}}$). The values of $L_{\text{C peak}}$, $L_{\text{A max}}$ and $L_{\text{ex 8h}}$ and measurement methods were selected in accordance with the relevant regulations [10, 11, 13]. $L_{\text{ex 8h}}$ was determined for a 55-min operation of an audible warning device during an 8-h workday, avoiding exposure to noise from other sources. Measurements were taken when vehicle 2 was driving on a 2-km-long flat road of smooth asphalt (a) at 60 km/h, (b) at 120 km/h and (c) accelerating from 60 to 120 km/h ("variable speed" in Table 4), with the audible warning device both disabled and enabled. A Svan 948 four-channel sound and vibration meter and analyser (Svantek, Poland) was used. Table 4 shows that an enabled audible warning device, whose signal is the main component of noise in the vehicle, raised $L_{\text{ex 8h}}$ by ~25 dB. The lower the speed, the higher was the increase. This relationship is critical for emergency vehicles moving in heavy traffic. In none of the cases, were $L_{\text{C peak}}$ and $L_{\text{A max}}$ exceeded. Under Polish law, these values are set at $L_{\text{A max}}$ = 115 dB and $L_{\text{C peak}}$ = 135 dB [10]. However, when driving for over 2.5 h with the audible warning device enabled, it is possible to exceed $L_{\text{ex 8h}}$ of 85 dB [9]. Situations like that are exceptional, though; they will happen if, e.g., there is a natural disaster, which makes them unlikely in the context of the emergency vehicle crew's exposure to noise. However, it is possible that $L_{\text{ex 8h}}$ will exceed the action limit value of 80 dB [11]. If the average travel time of an emergency vehicle crew with an enabled audible warning signal is ~60 min, $L_{\text{ex 8h}}$ exceeds 80 dB. The employer should then implement measures to reduce exposure to noise.

**TABLE 4. Noise Emitted by Siren of Audible Warning Device Inside Vehicle 2, Privileged Passage (dB)**

| Measurement Conditions | | | | |
|---|---|---|---|---|
| speed (km/h) | siren | $L_{\text{C peak}}$ | $L_{\text{A max}}$ | $L_{\text{ex 8h}}$ |
| variable | disabled | 110 | 67 | 56 |
| 60 | disabled | 101 | 64 | 54 |
| 120 | disabled | 110 | 75 | 62 |
| variable | enabled | 112 | 91 | 80 |
| 60 | enabled | 110 | 89 | 79 |
| 120 | enabled | 111 | 92 | 81 |

*Notes.* $L_{\text{C peak}}$ = peak *C*-weighted sound pressure level, $L_{\text{A max}}$ = maximum *A*-weighted sound pressure level, $L_{\text{ex 8h}}$ = daily noise exposure level; vehicle 2 = van.

Currently, there is no specific legislation on an admissible SPL for noise inside emergency vehicles. Standard No. EN 1789:2007+A1:2010, which discusses noise inside an on-road ambulance, does not require noise emitted by an emergency vehicle siren to be measured [12]. It should be noted that during a rescue operation, great concentration is required of the driver as are good verbal communication with the crew and the emergency centre or rescue co-ordination centre. That is why, in determining the driver's and the crew's limits of occupational exposure to noise, Standard No. PN-N-01307:1994 should be considered as it defines noise limits in the context of the ability to work, i.e., values that are used as a criterion for noise annoyance [13]. Following an analysis of these requirements, the equivalent *A*-weighted SPL of 65 dB is proposed as the limit value of noise for drivers of emergency vehicles. As previously mentioned, fitting the siren of the audible warning device in the engine compartment is a common solution aimed at reducing noise exposure of the driver and the crew. In the van, the siren was in the lightbar on the roof of the vehicle; in the car, it was in the engine compartment.

The measurements were taken inside the vehicles, parked in a car park, with a Svan 948 four-channel sound and vibration meter and analyser (Svantek, Poland). The measurements were taken 10 cm from the driver's ear [13]. Table 5 shows that changing the location of the siren can reduce SPLs by ~10 dB.

**TABLE 5. Sound Pressure Level of Siren by Location of Audible Warning Device (dB)**

| Location | $L_{AeqT}$ | $L_{Cpeak}$ | $L_{Amax}$ |
|---|---|---|---|
| Lightbar on roof | 87 | 99 | 88 |
| Engine compartment | 76 | 88 | 84 |

*Notes.* $L_{AeqT}$ = equivalent *A*-weighted sound pressure level over duration *T*, $L_{Cpeak}$ = peak *C*-weighted sound pressure level, $L_{Amax}$ = maximum *A*-weighted sound pressure level.

## 5. SIMULATION TESTS

In addition to great improvement in acoustic comfort, a change in the location of the siren impacts the audibility of emergency vehicle warnings in traffic, thus affecting safety. According to Table 1, SPLs of audible warnings outside the vehicle were similar when the siren was on the roof and in the engine compartment. However, these values were measured in the open, without any obstacles in the propagation of the signal.

In the case of emergency vans, moving the siren from the roof to the engine compartment results in the siren being located ~2 m lower (a change from ~2.6 to ~0.6 m). Such low location of the siren may result in much reduced SPLs of the audible warning signal reaching other road users, especially if surrounding cars acoustically shield the emergency vehicle. This situation was modelled with CadnaA version 3.5.115 (32 bit) software [1] for calculating and assessing the distribution of SPLs in the environment. Figure 4 shows the results of simulation tests of SPLs of audible warning signals. The signal frequency in those figures is the lower one of the wail signal (800 Hz). From the whole frequency bandwidth of the audible warning signal, this frequency has the lowest sensitivity to acoustic shielding.

A hypothetical situation was modelled. An emergency vehicle (dark rectangle in Figure 4) of the size of an ambulance was moving on a two-way road in a high-rise development area (striped). Another vehicle, of the same dimensions (white rectangle in Figure 4) was moving in front of it. The edge of the road is indicated. All measurement points were located at a height of 1.5 m, outside the vehicles. Measurement point A was 1 m from the vehicle; the other points were at the following distances: B 20 m, C 40 m, D 60 m, E 80 m along the axis of the movement of the emergency vehicle. Points F and G were located ~20 m from the intersection, on the street crossing the one on which the emergency vehicle was moving.

In both cases, i.e., when the sirens of emergency vehicles was located in an engine compartment and in the lightbar on the roof, at point A, the SPL was practically the same (~111 dB). However, at points B and C, the difference in SPL was 6 and 8 dB, respectively. At point E, the difference was ~9 dB. The differences between SPLs at points F and G were minute; therefore, they were not considered. The situation was critical at the intersection of the two streets (point D), where SPL differed by 10 dB. As the analysed frequency has the lowest sensitivity to acoustic shielding, the differences for the other frequencies will be greater.

The estimated SPL of the audible warning signal at the intersection was ~76 and ~86 dB for the siren in the engine compartment and in the roof lightbar, respectively. Assuming the background noise level to be ~70 dB, which is not much, the audibility of the warning to other road users at point D was estimated. According to an equation in Standard No. ISO 7731:2003, a warning is audible if its level is 15 dB higher than that of background noise [14]. This dependence is satisfied only if the siren is located on the roof of the emergency vehicle. In the other case, the emergency vehicle is likely to be audible when it is ~20 m away from the intersection. Braking distance at 60 km/h on dry asphalt is ~18.5 m. If the response times of the driver and of the braking

[1] http://www.datakustik.com/en/products/cadnaa

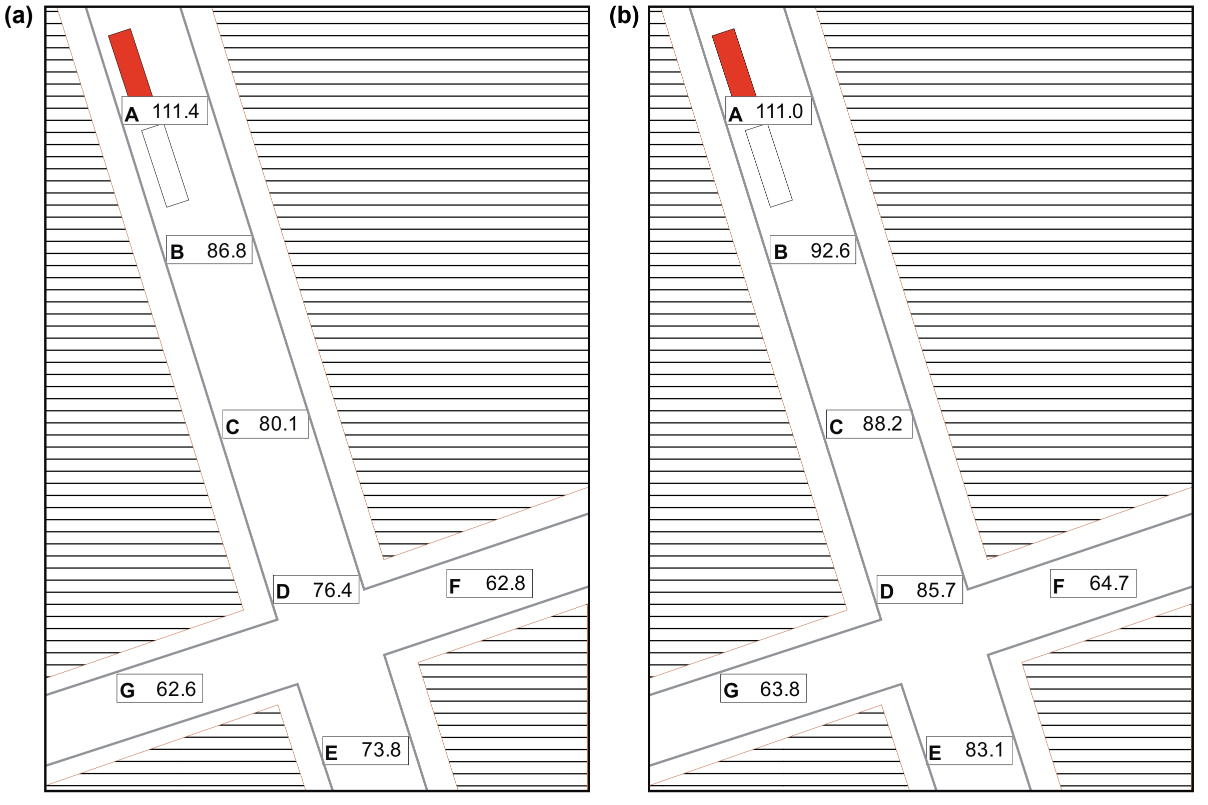


**Figure 4. Results of simulation tests of sound pressure levels (dB) of audible warning signals generated by sirens of emergency vehicles located (a) in an engine compartment at 0.6 m, (b) in the lightbar on the roof at 2.6 m.** *Notes.* A, B, C, D, E = measurement points 1, 20, 40, 60, 80 m from vehicle along the axis of the movement of the vehicle, respectively; F, G = measurement points ~20 m from the intersection, on the street crossing the street on which emergency vehicle is moving; dark rectangle = emergency vehicle, white rectangle = a vehicle the same size as the emergency vehicle; striped area = high-rise development area.

system are considered, this distance is ~40 m, which is much too far for a road user to hear the emergency vehicle. Given current sound insulation of vehicles and the fact that the audibility of an emergency vehicle warning can be further reduced by the radio and air conditioning, SPLs generated by the emergency warning are in both cases too low. Solomon's results confirm this: in a vehicle moving at 60 km/h (with the radio and air conditioning turned off), an emergency vehicle warning is audible at ~100 m [15]. When the radio and air conditioning are turned on in the car, this distance is reduced to under 15 m.

## 6. SUMMARY

This paper demonstrates that *A*-weighted SPLs emitted by sirens of audible warning devices are not the same, with their values within the range of 104–108 dB. The differences in SPLs of the emitted audible signal and their spectral distribution result from the different structure of electroacoustic transducers, and various methods of mounting the siren and of generating audible signals. *A*-weighted SPLs of a signal measured inside emergency vehicles can exceed 90 dB. Such high SPLs adversely affect the working conditions of the emergency crew and of the driver, in particular. That is why, it is necessary to reduce drivers' exposure to noise. Fitting the siren in the engine compartment rather than in the roof lightbar is a common solution to reduce exposure of the crew to noise. However, even though acoustic comfort improves, moving the location of the siren impacts the audibility of warnings in traffic. In light of the simulation tests this paper presents, moving the siren is wrong and, in extreme conditions, it can make the warning inaudible, thus reducing the safety of the vehicle. Therefore, it is necessary to look for innovative methods of reducing exposure to noise of emergency vehicle crews, e.g., active noise reduction methods, modifying the directivity of the emitted audible warning or using adaptive control of SPLs of emitted warnings [9, 16].

## REFERENCES


1. Onusic H, Hage MM. Parameters used for acoustic qualification/quantification of automotive vehicles. International Journal of Vehicle Design. 2005;37(1):81–98.
2. Regulation No. 28 of the Economic Commission for Europe of the United Nations (UN/ECE)—uniform provisions concerning the approval of audible warning devices and of motor vehicles with regard to their audible signals. OJ. 2001;L323: 33–45. Retrieved August 6, 2014, from: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:42011X1206(02)&from=EN.
3. Council Directive of 27 July 1970 on the approximation of the laws of the Members States relating to audible warning devices for motor vehicles (70/388/EEC). OJ. 1970;L176:571–6. Retrieved August 6, 2014, from: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31970L0388&from=EN.
4. Polski Komitet Normalizacji, Miar i Jakości (PKNMiJ). Pojazdy samochodowe i motorowery—własności akustyczne ostrzegawczych sygnałów dźwiękowych—podział, wymagania i badania [Road vehicles and mopeds—acoustic properties of audible warning devices—classification, requirements and tests] (Standard No. PN-S-76004:1992). Warszawa, Poland: Wydawnictwa Normalizacyjne Alfa; 1992.
5. Polski Komitet Normalizacji, Miar i Jakości (PKNMiJ). Pojazdy samochodowe. Właściwości akustyczne sygnałów dwu-dźwiękowych pojazdów uprzywilejowanych w ruchu. Wymagania i badania [Road vehicles. Audible warning devices for privileged motor vehicles. Requirements and tests] (Standard No. PN-S-76006:1975). Warszawa, Poland: Wydawnictwa Normalizacyjne Alfa; 1975.
6. SAE International. Emergency vehicle sirens (Standard No. SAE J1849_201210). Warrendale, PA, USA: SAE International; 2012.
7. Confédération suisse. Ordonnance concernant les exigences techniques requises pour les véhicules routiers (OETV) [Regulation on the technical requirements for road vehicles] (No. RS 741.41). Bern, Switzerland: Les autorités fédérales; 1995. Retrieved August 6, 2014, from: http://www.admin.ch/opc/it/classified-compilation/19950165/index.html.
8. Deutsches Institut für Normung (DIN). Akustische Warneinrichtungen für bevorrechtigte Wegebenutzer [Sound warning devices for authorized emergency vehicles] (Standard No. DIN 14610: 2009-01). Berlin, Germany: Beuth; 2009.
9. Morzyński L, Górski P. Sygnalizator ostrzegawczy w pojazdach uprzywilejowanych zintegrowany z systemem aktywnej redukcji hałasu [Warning device in priviledged vehicles integrated with an active noise reduction system]. Bezpieczeństwo Pracy. 2008;(7–8):24–7. In Polish, with an abstract in English. Retrieved August 6, 2014, from: http://www.ciop.pl/28637.
10. Rozporządzenie Ministra Pracy i Polityki Społecznej z dnia 29 listopada 2002 r. w sprawie najwyższych dopuszczalnych stężeń i natężeń czynników szkodliwych dla zdrowia w środowisku pracy [Ordinance of the Minister of Labour and Social Policy of November 29, 2002, on the maximum admissible concentrations and intensities of harmful to health agents in the working environment]. Dz U. 2002;(217):item 1833.
11. Rozporządzenie Ministra Gospodarki i Pracy z dnia 5 sierpnia 2005 r. w sprawie bezpieczeństwa i higieny pracy przy pracach związanych z narażeniem na hałas lub drgania mechaniczne [Ordinance of the Minister of Economy and Labour of August 5, 2005, on occupational health and safety with regard to works associated with exposure to noise or mechanical vibration]. Dz U. 2005;(157): item 1318.
12. European Committee for Standardization (CEN). Medical vehicles and their equipment—road ambulances (Standard

No. EN 1789:2007+A1:2010). Brussels, Belgium: CEN; 2010.

13. Polski Komitet Normalizacji, Miar i Jakości (PKNMiJ). Hałas—dopuszczalne wartości parametrów hałasu w środowisku pracy—wymagania dotyczące wykonywania pomiarów [Noise—permissible values of noise in the working environment—requirements regarding measurements] (Standard No. PN-N-01307:1994). Warszawa, Poland; Wydawnictwa Normalizacyjne Alfa; 1994.
14. International Organization for Standardization (ISO). Ergonomics—danger signals for public and work areas—auditory danger signals (Standard No. ISO 7731:2003). Geneva, Switzerland: ISO; 2003.
15. Solomon SS. Emergency vehicles accidents: prevention and reconstruction. Tucson, AZ, USA: Lawyers & Judges; 1999.
16. Górski P, Zawieska W. Active noise control in emergency vehicles. In: 2nd Polish-German Structured Conference on Acoustics. 2011. p. 245–54.