Applying spatial continuity and the Doppler effect along with auralisation in urban environment

Sound and Vibrations

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An analysis of the interpolation methods along with the influence of the Doppler effect in urban acoustics

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Abstract

Noise pollution as a result of traffic has a negative health impact.
A-weighted sound pressure levels offer a way to quantify noise, however they do not fully capture how people perceive the acoustic surroundings. Auralisation makes it possible to hear for example the impact of a proposed road or sound attenuating measure such as a noise barrier. Performing auralisations can become computationally costly especially for larger models which are typical for urban acoustics. Using interpolations methods has the potential not only to improve the performance at discontinuities close to barriers and walls but also cut costs related to noise investigations. Furthermore investigation around the Doppler effect and especially the Doppler factors impact on auralisation has been scarce. Therefore these two aspects were also considered when auralising the different pass by situations. Six different interpolation methods were tested with 12 different discretisation steps, evaluated qualitatively as well quantitatively by energy levels and psycho acoustic metrics. The qualitative listening tests indicate along with the quantitative tests that step size is more important than choice of interpolation method. The Doppler effect and Doppler factor had an impact on the auralisations however not larger than the Just noticeable difference for the psycho acoustic metrics.

Keywords: Auralisation, interpolation, Doppler effect, Doppler factor, urban acoustics, psychoacoustics, noise barrier, acoustics, noise mapping, diffraction.

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Aristidis Tsoukalios, Asmundtorp, November 2022

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

EDT	Edge diffraction toolbox
ESIE	Edge source integral equation
rms	root mean square
JND	Just noticeable difference
DFT	Discrete Fourier Transform
FFT	Fast Fourier transform

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Introduction

1.1 Background

Noise pollution from for example traffic and industry is a serious health issue which has to be taken into careful consideration in city development and urban planning. However there are some measures that have been proven effective with respect to attenuation of noise, such as sound barriers and green facades. The effect of these measures can be estimated by using different models with varying complexity. The estimates are then presented as for example either noise maps or auralisations. The latter is a way to make the estimate audible to the listener while the former consists of a map containing expected sound pressure levels for example. These are valuable tools for city planners and urban acoustical engineers when presenting a proposed solution and urban plan. However these sound propagation models are often computationally intense and the accuracy of the software associated to these may also be improved, especially regarding noise barriers and facades. To find ways to decrease computational cost is desired from efficiency aspects as well as economical aspects.

2

Theory

2.1 On the properties of sound

Sound is not seldom described as wave motion propagating through a medium. Regardless of medium, whether it is a liquid, gas or solid the principle remains the same. Namely that the medium itself does not travel the distance of the waves, but it is rather the particles that are moving back and forth or up and down. This phenomenon can be seen when observing a wave propagating in water [1]. The displacement of the particles are not seldom caused by a vibrating body for example a the motor of a car or the string of a violin which has been excited by a musician. When the particles are displaced a change in density of the medium occurs, causing a compression of for example air or water. The vibrations cause the previously mentioned back and forth motion. As a result of the compressed medium an increase of pressure occur along the waves path further away from the initial source [2]. Consider air as the medium of propagation where the sound waves are assumed to travel at constant speed. Given the constant speed the sound waves will travel the shortest path since it is also the shortest, which lead to sound waves propagating along a straight line [1]. The velocity of the particles can be expressed as a velocity vector $\vec{v}$, which is calculated by taking the derivative with respect to time of the displacement vector $\vec{s}$ as seen in the following relation,

$$\vec{v} = \frac{\vec{s}}{\vec{t}} \tag{2.1}$$

It has been stated that a change in density occur as result of the particle movement, which is explained by the heterogeneous and anisotropic behaviour of the displacement in the medium. Namely the particle movement back and forth. The change in density is expressed as follows,

$$\rho = \rho_{tot} - \rho_0 \tag{2.2}$$

where ρ_0 is the density of the medium when no displacement occurs and ρ_{tot} is the resulting density of fluid due to temporally and spatially dependant change in density ρ. The density difference can also be expressed as difference in pressure,

$$p = p_{tot} - p_0 \tag{2.3}$$

Where p is usually referred to as sound pressure, which is also one of the most important parameters when quantifying sound since the human ear is able to register fluctuations in the sound pressure [3]. The area affected by the pressure differences or sound waves are usually called sound field [2].

As mentioned before sound propagates in waves. In the previous case the sound wave was assumed to travel from a given position to another, for example traversing the length between two Cartesian coordinates [11]. Considering a source that emits sound waves in all directions, that is an omnidirectional source. It has a directivity that affects the amplitudes to some extent, which means that a change in direction or angle will affect the measured sound level relative to the receiver. However in practical applications certain assumptions allows some sources to be considered uniformly omnidirectional that is the measured sound level is the same regardless of direction or angle of the source. This assumption is true for wavelengths larger than the size of the source [4]. The theory for omnidirectional sources can be generalised from two dimensional planes to three dimension spheres. Assuming that the source is located in the center of a sphere and using spherical coordinates instead of Cartesian the average sound power in a given point can be calculated by using the surface integral from the relation intensity multiplied with an area,

$$I_{avg} 4\pi r^2 = W_{avg} \tag{2.4}$$

where I_{avg} is the average intensity which i calculated with respect to the surface $4\pi r^2$. W_{avg} is the resulting average power corresponding to the coordinate. When inspecting the variables it is evident that for a measured intensity the sound power will be dependant on r^2. Thus the sound power is inversely proportional to the squared quantity of the travelled distance. Attenuation due to distance combined with influence of air absorption is visible in figure 2.2. The relation is usually referred to as the spherical spreading law [11].

The sound pressure level

When presenting quantification of sound pressure p, which usually corresponds to the rms-value of a signal in time domain, a logarithmic value is often used. This is defined as sound pressure level L (dB). This is calculated according to the following definition,

$$L = 10 \log_{10} \left(\frac{p}{p_0} \right)^2 = 20 \log_{10} \left(\frac{p}{p_0} \right) \tag{2.5}$$

where the reference value $p_0 = 2\ 10^{-5}$ N/m^2, corresponds to the lower limit of the range for perceived pressure by the human ear estimated at a frequency of 1 kHz. The upper limit is estimated to 200 N/m^2, which corresponds to the limit where the listener starts to experience pain caused by the pressure [4].

The sound intensity level

Sound intensity and it's corresponding sound intensity level are important quantities from a psychoacustical aspect. Sound intensity level L (dB) is calculated according to the following equation which also display the relation to previously defined pressure p,

$$L = 20\log_{10}\left(\frac{p}{p_0}\right) = 10\log_{10}\left(\frac{I}{I_0}\right) \tag{2.6}$$

were I W/m^2 is measured intensity and I_0 is a reference value estimated to 10^{-12} W/m^2 [5].

2.2 Outdoor sound

Sound propagation in an outdoor environment is affected by a number of factors. The total attenuating effect from these are assumed linear with the resulting sound pressure at a receiver being the total sum of the added factors. First the sound wave is attenuated by the distance travelled between source and receiver according to the previously defined spherical spreading law. Second the atmospheric circumstances influence the sound propagation. Wind speed usually increases with height, this cause the sound to be refracted in upward direction. If a model which is based on the assumption of the sound waves acting as rays this translates to the sound waves travel upwards. A similar phenomena occurs when the sound wave curve upwards due to the temperature which is lower at higher altitudes. Further attenuation occurs due to interference pattern which are caused by ground reflections. In the case of attenuation the interference is called destructive while the opposite effect is called constructive interference. Both these cases are usually referred to as ground effects. The interference pattern is dependant on the location of source as well as receiver position. The topography and ground material are also of importance since the reflected waves travel via the ground. Constructive interference can arise especially in the lower frequency ranges which lead to a somewhat higher sound pressure compared to the free field value. The ground effects does not only affect the sound waves through interference patterns. Dependant on the ground surface further attenuation can occur due to scattering effects. When a sound wave impinges a porous ground a shift in phase as well as amplitude occur due to viscous friction. These are the most prominent phenomena related to ground effects. Vegetation and trees also affect the sound propagation. The tree trunks have a scattering effect on sound waves while leafs vibrate due the forced excitation from the impinging sound wave. Bushed and shrubberies do not only display similar behaviour with respect to vibrating leafs, ground effects also occur due to the soft ground that is required for planting vegetation. In both cases for trees in forests as well as cultivated shrubberies the ground is to be considered porous to a great extent. This due to fallen leafs which are decaying on the ground [10].

2.2.1 Effects due to air absorption

As previously mentioned sound propagation is affected by the atmosphere. There are two main phenomena which contribute to absorption in air. These are referred to as classical dissipation and relaxation dissipation respectively. Classical dissipation describes the conversion from energy due to the motion of the molecules to either kinetic energy or heat energy. The latter that is relaxation describes a process which involves internal rearrangement of molecules. This process also contains a translational part which is related to displacement of the molecules. Resulting sound pressure $p(x)$ it given position x can be calculated by the following relation [10].

$$p = p_0 e^{-ax/2} \tag{2.7}$$

Where p_0 is the sound pressure at position x=0. The coefficient α determine the sound attenuation while considering frequency dependence, temperature and humidity. The distance dependence along with the strong spectral dependence is visible in figure 2.2. The sound attenuation is almost negligible at lower frequencies regardless of distance. However a noticeable absorption occur in the higher frequency bands with increasing distance. A method according to ISO 9613-1:1993 can be used to determine the coefficients. They are calculated as follows

$$\alpha \quad = \quad f^2 \left[\left(\frac{1.84x10^{-11}}{\left(\frac{T_0}{T}\right)^2 \frac{p_s}{p0}} \right) + \left(\frac{T_0}{T}\right)^{2.5} \left(\frac{0.10680 e^{-3352/T} fr,N}{f^2 + f_{r,N}^2} + \frac{0.01278 e^{-2239.1/T} fr,N}{f^2 + f_{r,O}^2} \right) \frac{\text{nepers}}{\text{m}\cdot\text{atm}} \right]$$

(2.8)

Where input f is given frequency. T is the surrounding temperature given as Kelvin, while T_0=293.15 also Kelvin is the reference temperature corresponding to T=20 given in Celsius. nepers is a dimensionless unit used for scaling to obtain the unit dB when using ratios based on the natural logarithm. The frequency $f_{r,N}$ consider the relaxation due to nitrogen content i the atmosphere while relaxation frequency $f_{r,O}$ is taking the oxygen level into account. The frequencies are calculated accordingly

$$f_{r,N} = \frac{p_s}{ps0} \left(\frac{T_0}{T}\right)^2 \left(9 + 280 H_e^{-4.17\left[(T_0/T)^{1/3} - 1\right]}\right) \tag{2.9}$$

$$f_{r,O} = \frac{p_s}{ps0} \left(24.0 + 4.04\text{x}10^4 H \frac{0.02 + H}{0.391 + H}\right) \tag{2.10}$$

Humidity is taken into consideration by the percentage of molar concentration of vapor in the surrounding air. The absolute humidity varies not only during seasons but also during day and night with peaks typically occurring in the afternoon. The attenuation due to variations of relative humidity is most significant in the higher frequency regions, which is visible in 2.1. Because of variations it is recommended to avoid calculations based on arithmetic means. H is defined as

$$H = \rho_{sat^r h} p_0 / p_s \tag{2.11}$$

p_0 is the atmospheric pressure at 1atm = $1.01325x10^5$ Pa while p_s is the ambient pressure. r_h given as percent is the relative humidity in the surrounding atmosphere. ρ_{sat} is the saturation vapor pressure. The coefficient C_{sat} which consider temperature is defined as follows

$$C_{sat} = -6.8346 \left(\frac{T_0}{T}\right)^{1.261} + 4.6151 \tag{2.12}$$

The precision of the method is estimated to ±10 % [10].

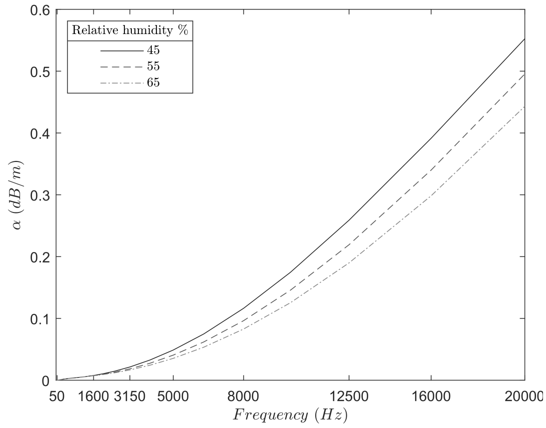

Figure 2.1: Air attenuation coefficient α per meter calculated at 20 C° and relative humidity at 45 %, 55 % and 55 %.

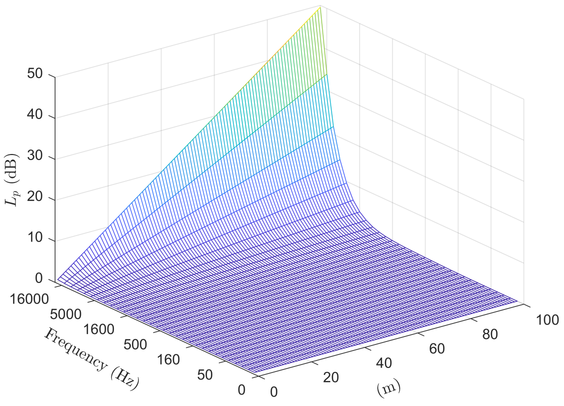

Figure 2.2: Sound attenuation with respect to distance and frequency using coefficient α calculated at 20 C° and relative humidity at 65 %.

2.3 Noise barriers

Previous section mentioned sound attenuation caused, with few exceptions, by environmental circumstances. Even though barriers with noise attenuating effect may exist as differences in topography caused by natural phenomena, a majority are man made. It is without doubt one of the most frequent measures taken to reduce disturbance from vehicles and trains. The main principle behind it's sound reducing capabilities is to obstruct the direct path of sound transmission thus creating a shadow behind the barrier whose sound field is characterised by the diffracted sound waves rather than the direct [10]. Consider a barrier with given height with a source and a receiver, both with a certain distance from the barrier, on each side of the barrier. Placing a barrier close to the source enlarge the shadow zone while greater length between source and barrier will have the opposite effect. This principle also apply for the receiver position thus having the same result. Therefore the barrier will be more effective at close range. This become specially important when designing barriers in densely built up areas where the space is limited. In most cases tall barriers are not suited for use in urban environments mostly since they are limiting visibility for drivers as well as pedestrians. The solution is barriers of lower height that are placed sufficiently close to the source, that is the cars passing by. Similarly the walkway should be placed close to the barrier thus assuring adequate acoustically shadowed zone. This is possible since most of the noise generated by the cars are close to ground level. According to the engineering model Calculation of road traffic noise (CRTN) the source height can be assumed to be at 0.5 (m) above the carriageway [12]. The updated version of NORD2000 suggest that the vehicle as a source can be seen as point sources divided into several parts with the following heights: 0.01 m, 0.30 m, 0.75 m or 3.5 m [13]. The first height 0.01 m describes the rolling noise which is assumed to represent 80 % of the emitted noise while propulsion at the height 0.30 m make up the last 20 %. For heavy vehicles the propulsion height is set to 0.75 m [14]. The noise barrier family range from simple straight edged to multiple edged barriers with an inclination [10]. An increasing interest has been shown towards sound barriers that are either constructed by natural means or built as a part of the surrounding environment. Typical constructions are earth berms and gabions. The latter can be described as a pile of stones arranged in a cage to form a barrier. Such solutions tend to blend in with the existing or planned surroundings and are not seldom more aesthetically pleasing than conventional straight barriers [12].

2.4 Scattering

Scattering occurs when a sound wave hits an object which obstructs the path of the wave resulting in the emission of secondary sound waves being spread from the object [11]. It is common to define these secondary waves as scattered [35]. Sound barriers or other obstacles belong to the more obvious objects which cause scattering. Other causes might be atmospherically turbulence or when a sound wave propagates along a rough surface. In general scattering is more common in the higher frequency regions than in the lower ones [11].

2.5 Diffraction

For frequencies where the wave length is considerably shorter than the object which obstructs the sound wave either reflection or diffraction will occur instead of scattering. Diffraction is characterised by amplitude differences in the regions surrounding the diffracting object. Considering a noise barrier such as in figure 2.3 with a sound wave emitted at the source position. In front of the barrier there will be a combination of emitted sound wave as well as reflected sound wave while behind the barrier there is a zone which is acoustically shadowed with considerably lower pressure amplitudes compared to the side at the front which is facing the source. In the regions between the shadowed area and the illuminated area the pressure amplitude of the sound from the illuminated region is oscillating. There is an increase of amplitude until the absolute edge of the illuminated area where it reaches it’s maximum value before displaying a monotonic decrease towards zero once inside the shadowed region. This phenomena is called diffraction bands [35].

2.6 Analytical approaches for diffraction by a barrier

Diffraction as a phenomena has been studied and investigated since the 18^{th} century, both from an empirical as well as theoretical approach. During the later parts of the 18^{th} century a solution was proposed which was considered as the first rigorous solution from a mathematical perspective. The solution by Sommerfeld was based on a 2-D model assuming a reflecting thin half plane which is impinged by a plane wave. The solution was based on two parts namely the direct part and the diffracted part, each with it's set of differential equations. The direct part was formulated with a geometrical acoustics approach. The diffracted was estimated using Fresnel integrals. The total sound field was estimated as the sum of the integrals. The solution was further developed by MacDonald among others to consider cylindrical as well as spherical waves in addition to the previous plane wave approach. Besides these solutions there have been approaches focusing on solving using an integral formulation with the Wiener-Hopf method. Tolstoy gave a solution to diffraction by a wedge based on the assumption that the sound field can be considered as a sum of infinite series. This gives an exact solution, but at a high computational cost especially in the higher frequency bands. Hadden and Pierce developed a method estimating the diffraction by a thin wedge using an integral formulation. Similar to the solution by MacDonald the diffracted pressure is calculated using Fresnel auxiliary functions. However the Pierce solution also takes barrier reflections into consideration. This feature is however optional [10]. Pierce also presented a solution for diffraction around corners and wide barriers by expanding the single edge problem to a double edged diffraction concept [37]. This is however outside the scope of this thesis.

2.6.1 General formulation of the geometries diffraction by a noise barrier

Figure 2.3 shows a screen obstructing a sound sound wave emitted at the source from reaching the receiving positioned symmetrically on the opposite side of the screen. The sound propagation with corresponding sound field is modelled according to the assumptions of geometrical acoustics. The thin screen is assumed to be of semi-infinite type, thus having a finite height as but infinite extension in the length dimension. Furthermore the edge is assumed to be a secondary source which can be expanded to a line source. The source and receiver in figure 2.3 are placed symmetrical with respect to the barrier, this is however not a prerequisite since the model permit a more free placement of the pair. Using cylindrical polar coordinates (r, θ, y). This y-axis is located along the right side of the thin barrier surface with $\theta = 0$ on the right side of the barrier while the opposite side has coordinate $\theta = 2\pi$. Coordinates expressed as distance in r have the edge as their origin and the arrows imply angles measured anticlockwise. The total sound field pressure consists of a summation with three parts. According to geometrical acoustics there will be contributions from incident sound wave as well as reflected sound waves. The last part is the diffracted waves which are also modelled according to the geometrical acoustics [10].

$$p_{\text{total}} = p_{\text{incident}} + p_{\text{reflected}} + p_{\text{diffracted}} \tag{2.13}$$

Where p_{incident} is the wave emitted from the source position while $p_{\text{reflected}}$ is the sound pressure from the reflected back towards the source. $p_{\text{diffracted}}$ is the sound field which is a result from the wave being scattered along the edge of the barrier. The sound field surrounding the barrier is divided into three regions, namely A, B and C. Region A is confined at the bottom by r_s which is the path belonging to the sound wave impinging on to the edge. The higher boundary is defined by the dotted line which. Due to geometrical assumptions the reflected sound is only present i region A, since the dependence of source position the reflected sound will have direction according to the line B_r and angular dependence $\theta = 3\pi - \theta_0$. Since diffraction occurs at the edge spreading scattering sound like an omnidirectional source the total sound pressure will have contributions from all parts. Thus the total sound pressure in region A is

$$p_{\mathrm{A}_{\mathrm{total}}} = p_{\mathrm{incident}} + p_{\mathrm{reflected}} + p_{\mathrm{diffracted}} \tag{2.14}$$

Region B is confined to the lower left by the line B_r with the angular dependence $\theta = 3\pi - \theta_0$. The right side boundary is defined as $\theta = \theta_0 - \pi$. It has already been stated that reflected sound can not enter region B while incident sound from the source along with diffracted sound form the total sound field accordingly

$$p_{\mathrm{B}_{\mathrm{total}}} = p_{\mathrm{incident}} + p_{\mathrm{diffracted}} \tag{2.15}$$

Region C which is shadowed by the line B_s defined by the angle $\theta = \theta_0 - \pi$ contain only diffracted sound pressure. The Reflections does not occur due to the geometrical shadow nor does the incident waves reach region C since the barrier obstruct the path. Sound however reach the region i diffracted form with the lower boundary of the line r_r. Therefore the sound field is defined as

$$p_{\mathrm{C}_{\mathrm{total}}} = p_{\mathrm{diffracted}} \tag{2.16}$$

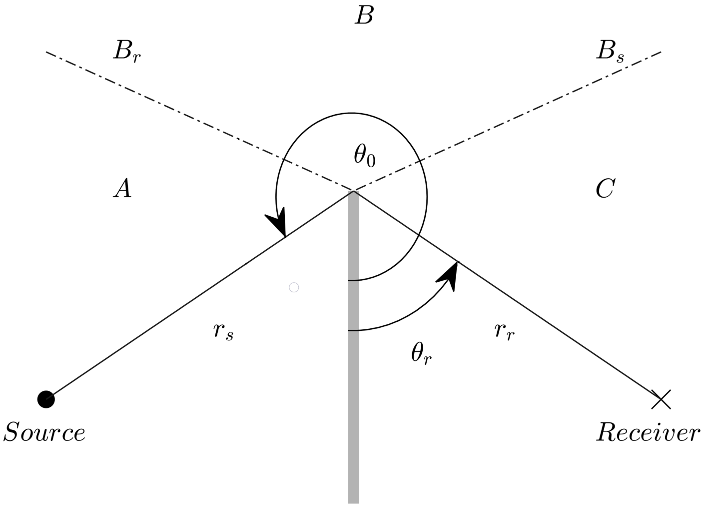

Figure 2.3: Diffraction by a semi-infinite barrier

2.7 The semi-infinite thin wedge

The thin infinite wedge is perhaps one the more straight-forward ways of approaching diffraction and without doubt one of the most classical ways of modelling this phenomenon [37]. The aforementioned Hadden and Pierce presented an integral based solution built upon on geometry and Fresnel auxiliary functions. The solution allows arbitrary placement of source as well as receiver. Figure 2.4 show the thin wedge with the corresponding geometries associated with the solution. Similarly to the previous model cylindrical polar coordinates (r, θ, y) are used with unchanged convention with respect to y-axis as well as angular direction. The exterior angle ϕ is determined by the thickness of the wedge. Assuming a thin wedge the angle is $\phi = 2\pi$. The solution does not differ to a great extent from the the assumption made in the previous section. The total sound field is composed of direct sound emitted from the source, reflected sound and a diffracted part. There is no contribution form the direct sound as long as the source is shadowed by the wedge. If the source is placed above the wedge in figure 2.4 thus making the source visible from the receiver there will be a direct contribution to the sound field along with the diffracted sound pressure. The sound field due to diffraction is divided into four parts depending on their path from receiver to source[10][37]. The geometry and paths for the image source and image receivers are visible in figure 2.5. The four parts are defined as follows

$$\zeta_1 = |\theta_r - \theta_0| \tag{2.17}$$

Which corresponds to the shortest path from source to receiver via the edge.

$$\zeta_2 = 2\phi - |\theta_r - \theta_0| \tag{2.18}$$

ζ_2 is the path from an image source in the in the wedge to the receiver.

$$\zeta_2 = \theta_r + \theta_0 \tag{2.19}$$

ζ_3 is defined as the path from the source via the edge to an image receiver in the wedge.

$$\zeta_4 = 2\phi - |\theta_r + \theta_0| \tag{2.20}$$

The last part ζ_4 is the path between an image source via the edge to an image receiver.

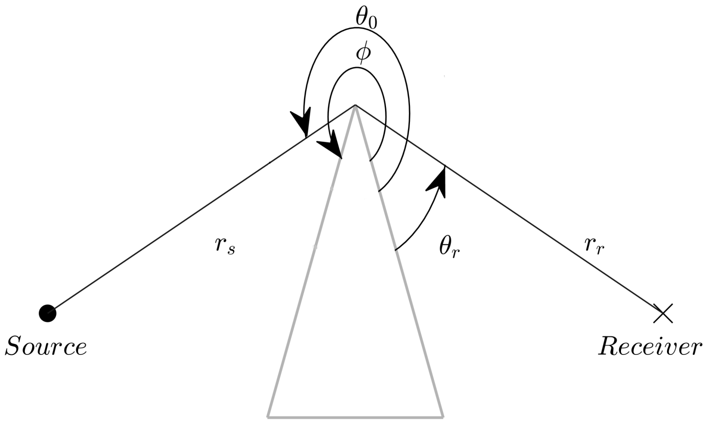

Figure 2.4: Spherical spreading sound and diffraction for a thin wedge

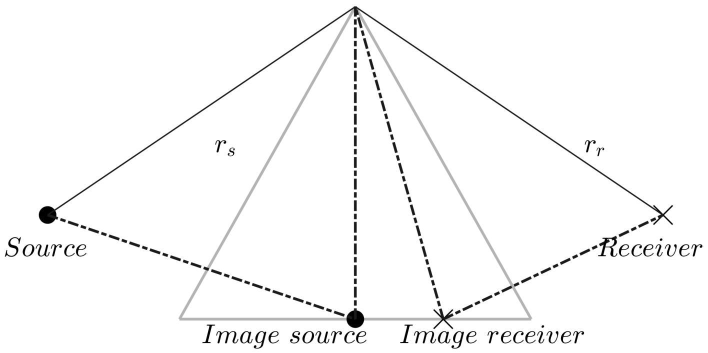

Figure 2.5: Image source with corresponding image receiver for a wedge

The diffracted sound can be estimated using each path via integration. However if the screen is assumed thin, which is the case that is investigated in this thesis, the expression can be simplified. The source and receiver should also be located sufficiently far away from the edge of the barrier, a couple of wavelengths [10]. Assuming these conditions are fulfilled the sound pressure from diffraction can be calculated using the following expression

$$p_d = \left[\frac{1+i}{2}\right]\left[\frac{e^{iKR'}}{4\pi R'}\right]\left[A_D(X_+) + A_D(X_-)\right] \tag{2.21}$$

Where R' is the image receiver position which is visible in figure 2.5. The wave number k consider the frequency dependence, while A_D is a diffraction integral which is based on the expressions 2.17,2.18,2.19 and 2.20. $A_D(X_-)$ include 2.17 and 2.20 while $A_D(X_+)$ consider 2.18 and 2.19. It is defined accordingly

$$A_D(X) = \mathrm{sgn(X)}\left[f(|X| - ig(|X|)\right] \tag{2.22}$$

It is calculated using auxiliary Fresnel functions $f(x)$ and $g(x)$

$$f(x) = \left[\frac{1}{2} - S(X)\right]\cos\left(\frac{\pi X^2}{2}\right) - \left[\frac{1}{2} - C(X)\right]\sin\left(\frac{\pi X^2}{2}\right) \tag{2.23}$$

$$g(x) = \left[\frac{1}{2} - C(X)\right]\cos\left(\frac{\pi X^2}{2}\right) + \left[\frac{1}{2} - S(X)\right]\sin\left(\frac{\pi X^2}{2}\right) \tag{2.24}$$

The sign function sgn(X) assume either the value +1 or -1 depending on the sign of the input. X has beside geometrical dependence θ and R' also frequency components in λ.

$$X(\Theta) = -2\sqrt{2r_0 r_r \lambda R'}\cos(\Theta/2) \tag{2.25}$$

$$X_+ = X(\theta_0 + \theta_r) \tag{2.26}$$

$$X_- = X(\theta_0 - \theta_r) \tag{2.27}$$

S(X) and C(X) are the Fresnel integrals

$$S(X) = \int_0^u \sin\left(\frac{\pi t^2}{2}\right) dt \tag{2.28}$$

$$C(X) = \int_0^u \cos\left(\frac{\pi t^2}{2}\right) dt \tag{2.29}$$

It is worth mentioning that the diffracted sound wave become discontinuous where the expressions 2.26 and 2.27 alter sign. Furthermore there are some advantages in using functions 2.23 and 2.24 instead of the ordinary Fresnel integrals 2.28 and 2.29 since they are easier to implement when performing numerical calculations. Since they are monotonic functions, in contrast o the Fresnel integrals, they depict the monotonic behaviour of the amplitudes which tend to decrease when the angles increase relative to the shadow zone [37].

When inspecting 2.21 it is clear that the insertion loss is dependent on frequency as well as the geometric relation between source and receiver. Figure 2.6 and figure 2.7 show the attenuation due to a screen when implementing the solution proposed by Hadden and Pierce. The situation is similar to the one depicted in figure 2.9 with point sources distributed along the road to simulate a line source. The receiver is located at the end of the screen, corresponding to 0 meters in figure 2.6 and figure 2.7, and 8 meters from the road. At the position 0 meters the source become visible to the receiver thus marking the end of the acoustical shadow zone. Inspecting 2.6 and figure 2.7 one finds that frequency seems to be more dominant than distance, although it is evident that distance is far from irrelevant. This is especially clear in 2.6. Higher octave bands are attenuated to a greater extent than the lower ones.

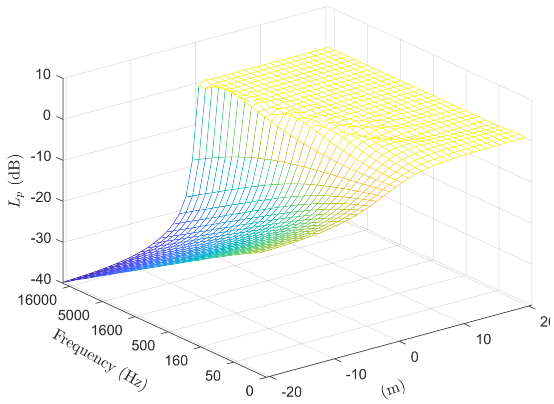

Figure 2.6: Insertions loss for with respect to distance and frequency a semi-infinite screen for a line source of distributed point sources. Position 0 indicate the end of the screen.

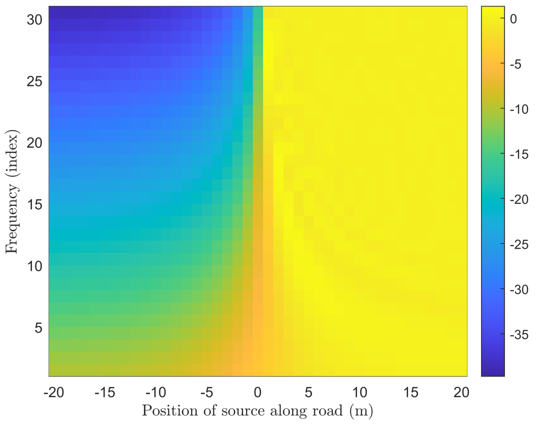

Figure 2.7: Insertions loss for with respect to distance and frequency a semi-infinite screen for a line source of distributed point sources. Position 0 indicate the end of the screen.

2.8 Sound waves emitted by a moving source

Previous equations have been based on the assumption of static positions for receiver as well as source. Which means no movement relative to each other. On the contrary most situations involve some moment between source and receiver, which is the case for most real worlds situations. Such events are for example an ambulance passing by or a jet plane. Furthermore there are some differences between a static source and moving source. The frequency is altered by the Doppler shift. An additional phenomena alter the amplitude in the acoustic field. Namely the convective effect along with the Doppler factor [32].

Cars, trains and other vehicles are without doubt non stationary sounds sources. However they are sometimes modelled as such or as quasi-static sources in order to simplify calculations. Traffic noise are for example often modelled as line of discrete monopole sources, which is a valid model for estimating noise impact of traffic along a road. The assumption of cars as being point sources along a line does not have any major implication on the estimation although it is a rather considerable simplification. With respect to motion the theory of a straight line is also valid, especially at low speeds where Mach number M can be neglected [10]. The Mach number M is defined as

$$M = \frac{v_{\text{particle}}}{c_0} \tag{2.30}$$

Where v_{particle} is the speed of a particle or sound source and c_0 is the speed of sound [33]. Although the the straight line consisting of static sources is less valid for higher M numbers it is still relevant to consider the effects of motion even at low speeds. The sound field is still affected by the motion [34]. During previous investigations and research on the topic some simplifications where done to simplify the calculations and analysis. Such simplifications include rectilinear movement which is seen in figure 2.8 and 2.9 with constant speed [33]. The vehicle moves along a fixed axis, e.g. a driving lane The velocity is also assumed to be well below c_0, which corresponds well with investigated velocities in this thesis.

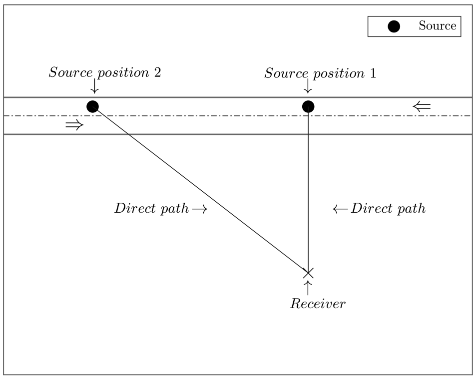

Figure 2.8: Source moving at two different position along a two lane road with varying distance with respect to receiver for each position.

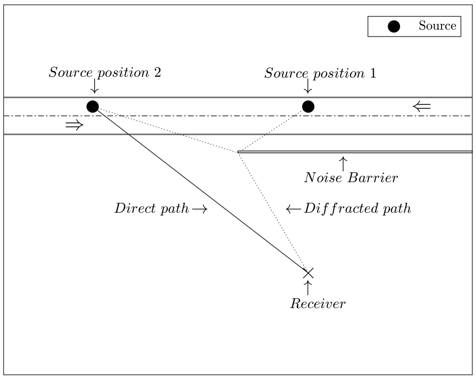

Figure 2.9: Source moving at two different position along a two lane road with varying distance with respect to receiver for each position. Barrier is introduced along with the diffracted paths.

2.8.1 Doppler effect

The Doppler effect is depicted in a comprehendible manner by considering a particle both at rest as well as moving with a constant speed along an axis, as seen is figure 2.10 and figure 2.11. Also visible in the figures are the generated wave fronts and the impact of speed. Assuming a monopole omnidirectional source, which is described in section 2.1, the waves have a spherical propagation [11]. Particle velocity is given by equation 2.1. Spherical interpretation with respect to radius is formulated as follows

$$c = \frac{\mathrm{d}r}{\mathrm{d}t} \tag{2.31}$$

Where c is the particle speed and also the speed of the wave crest as a result of travelled distance along radius r during time t.

The time between two wave crests is called a period T which is also defined as

$$T = \frac{1}{f} \tag{2.32}$$

Where f is the frequency which denotes the quantity of for example occurrence of a phenomena or oscillations during a certain time. A sound signal emitted at t_0 reach the receiving position at t_0+Δt. For a static source and receiver with no or negligible relative motion between them the signal will not be altered along the path, assuming no air attenuation, ground effects or other interfering phenomena. Considering a pure tone as in figure 2.12 the frequency will remain unaltered. However when there is a relative motion between source and receiver the distance between them will not be constant during the time Δt. The result is a difference between the emitted frequency and received frequency [4]. The frequency difference is a consequence of the changed radii of the wave crests. The distance between two wave fronts also related to the radius of a wave can also be represented by wavelength λ. The relation between λ and frequency is expressed according to the following relation

$$\lambda = \frac{c}{f} \tag{2.33}$$

Where c is the speed of the sound wave. The particle in figure 2.11 move with the constant speed v_{particle}, thus it will cover the distance $v_{\text{particle}}\mathrm{T}$ during a period while the emitted wave move the distance $c_0\mathrm{T}$, where c_0 the speed of sound. Considering a case where the source is moving in the towards the receiver the resulting difference between wave fronts which arise due to different velocities is calculated by combining equation 2.32 and equation 2.33 and expressed accordingly

$$\lambda_{\text{Doppler}} = (c_0 - v_{\text{particle}})T \tag{2.34}$$

Further manipulations of equations 2.33 and equation 2.34 gives a relation which describe the frequency shift

$$f_{\text{Doppler}} = \frac{f}{1 - \frac{v_{\text{particle}}}{c_0}} \tag{2.35}$$

By observing equation 2.35 it is clear that increasing particle velocity v_{particle} leads to an increase in frequency f_{Doppler}. In the opposite case where the source moves away from the receiver as seen in figure 2.11 the quantity v_{particle} will have the opposite sign. Insertion of negative v_{particle} into equation 2.35 yield a lowered frequency. This is also depicted in 2.11 while recalling the relation between radius r and wave length λ and equation 2.33 where increased wave length lead to lower frequencies and vice versa [2]. Thus the Doppler shift is solely governed by velocity of the source and emitted frequency. The Doppler effect still occurs even though the source is accelerating or displaying non rectilinear motion. However these circumstances require methods that will not be dealt with during these investigations [11].

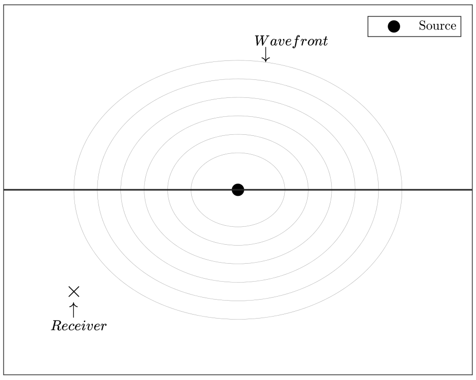

Figure 2.10: Particle at rest with no motion.

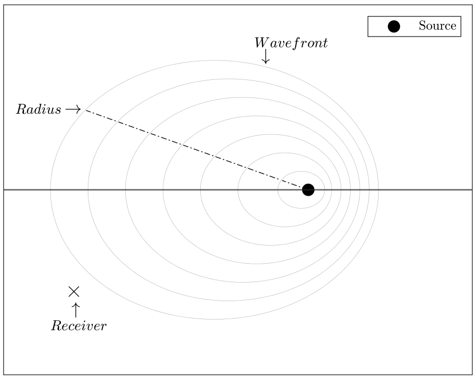

Figure 2.11: Particle propagating with velocity v_{particle}.

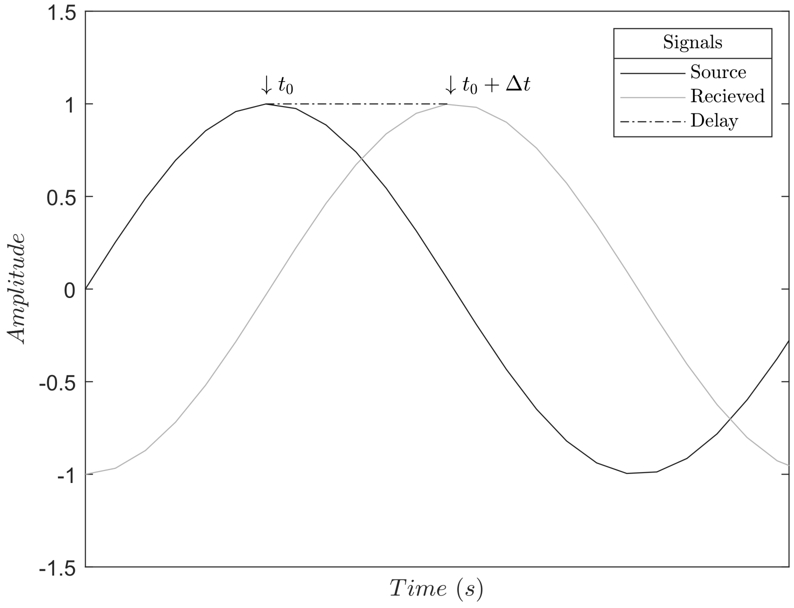

Figure 2.12: Time shifted sinusoidal wave, by delay Δt

2.8.2 The convective effect

While the Doppler effect mainly concerns a shift in frequency content the convective effect alters the amplitudes of the propagating sound. The changes in amplitude are a consequence of the source in motion which displaces molecules in the surrounding medium. Thus an additional effect on the sound field is created through forced excitation from the moving source. The time variation alters the shape of the sound field. This has to be considered even for very small particles. Moreover it is believed that the shape of the generated additional sound field is influenced by the geometry of the moving source [34]. Thus the amplitude change should be considered when estimating non-stationary sources. This is done by applying a scaling factor.

The Doppler factor

Solving the equations and arriving to an expression for the appropriate scaling factor is far from easy. However for the case of a particle moving along an axis at constant velocity the expressions can be simplified [33]. Figure 2.13, which is based on theories found in Sound field of sphere in motion by Leppington et al. [33] and Acoustic sources in motion by Dowling [34], show the kinematic properties of the particle previously displayed in figure 2.8 showing a particle passing by a receiver while travelling along an axis. These two references also contain detailed derivations along with important assumptions about the Doppler factor. Such assumptions concern whether the factor should be $(1-M\cos(\theta))^{-2}$ or $(1-M\cos(\theta))^{-1}$. It is suggested that the latter is to be used when the squared Mach quantity M^2 is considerably smaller than unity. This is also suggested elsewhere such as by Attenborough and van Renterghem [10]. Considering motion and distance and assuming $M^2 << 1$ the sound field at receiver point is scaled according to

$$\Phi = \frac{q(t)}{R(1 - M\mathrm{Cos}(\Theta_t))} \tag{2.36}$$

where $x(t)$ in Figure 2.13is the distance travelled along the road by the source at time t. Quantities R and $r(t)$ are distances from the source to receiver position. The former denotes the distance from start while the latter gives distance at time t. The cosine term with angle Θ_t, calculated as the ratio $x(t)/r(t)$, consider the direction towards the receiver relative to source. The volume acceleration is denoted as $q(t)$ The expression is valid for movement with uniform or approximately uniform motion [33].

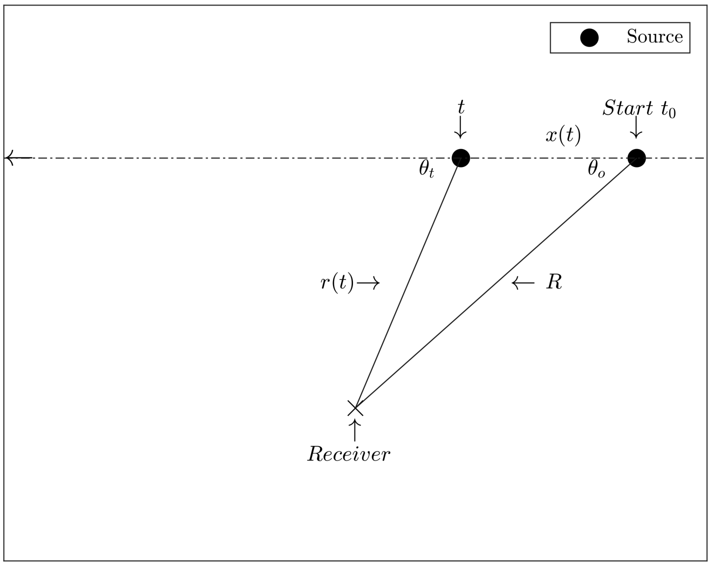

Figure 2.13: The rectilinear kinematics with geometric relations for a particle moving along an axis with constant velocity v_{particle}.

Figure 2.13 shows the angular dependence of the Doppler factor along with distance and time. Equation 2.36 estimates the scaled sound field while omitting the sound source strength $q(t)$ and distance dependence R to give the isolated effect of the Doppler factor. Omission of the factors yield the following relation

$$\phi = (1 - M\mathrm{Cos}(\Theta_t))^{-1} \tag{2.37}$$

The Doppler factor is exemplified for three common road traffic speeds used in Sweden. The chosen velocities are 30, 50 and 70 km/h. Inserting the velocities in equation 2.30 before insertion into equation 2.37 yield the results in table 2.1.

Table 2.1: Mach number M for velocities 30, 50 and 70 km/h.

v	M
30	0.0245
50	0.0408
70	0.0572

The estimates of the Doppler factors angular dependence at the three velocities are displayed in Figures 2.14 and 2.15. Recalling the properties of the cosine function along with the geometries in figure 2.13 it will inevitably yield a Doppler factor equal to zero when the vehicle is at the point of passage that is 90° relative to the receiver. It is not unusual to use this assumption when scaling sound sources. However it has been suggested, quite intuitively, that in reality the factor will not be equal to zero when passing by at 90 degrees [34]. Furthermore equation 2.37 gives the amplifying effect while the particle moves towards the receiver and away. This can be seen in figures 2.14 - 2.17, where the last two figures depict the pass-by for a situation similar to the one which has been described in section The Doppler factor.

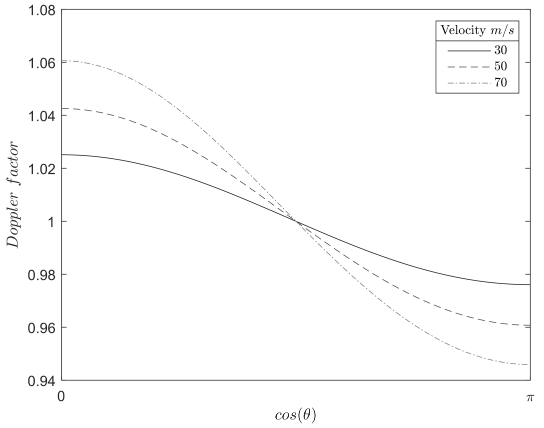

Figure 2.14: The Doppler factor as a function of angle θ.

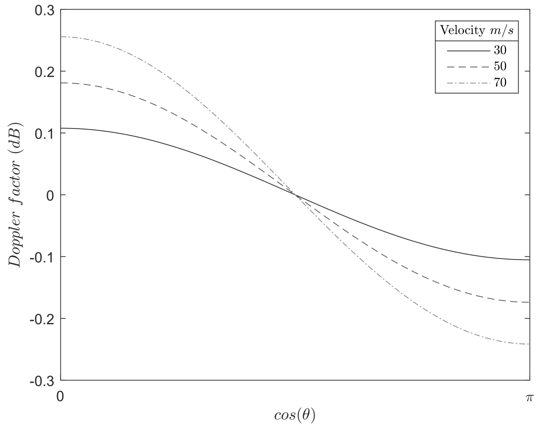

Figure 2.15: The Doppler factor as a function of angle θ in (dB).

The variation in amplification along a pass-by is visible in figures 2.16 and 2.17. For pass-by situations and geometries see figure 2.8 and 2.13. The amplification has its peak as the particle moves towards the receiver which is located at 12.8 meters along the axis. It is shown that when the particle is at the point of passage $\Theta = \pi/2$ there will be no amplification. After this point the change in sign of the cosine function yields a reduction. Representation in dB scale gives the attenuation from this effect. Insertion of unity into the logarithm with base 10 yield exactly zero, while values below one result in negative dB values thus the factor has an attenuating effect.

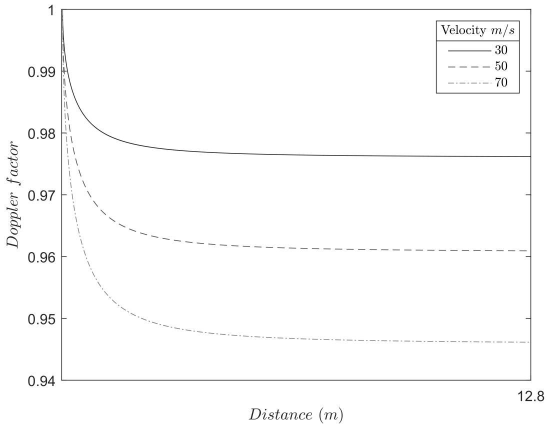

Figure 2.16: The Doppler factor as a function of distance and angle θ.

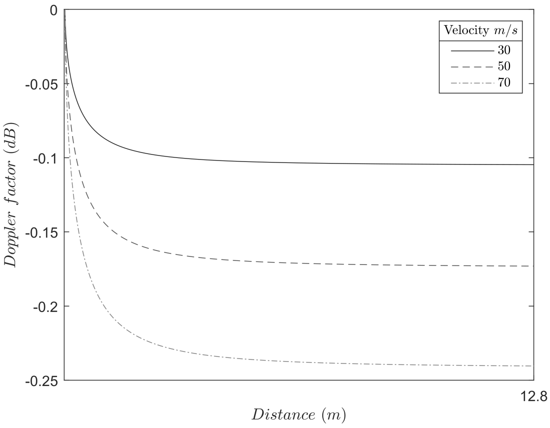

Figure 2.17: The Doppler factor as a function of distance and angle θ in (dB).

2.9 Auralisation

Auralisation which is one of the newer parts within acoustics is a method that allows a listener to experience and perceive sounds and signals describing different problems or solutions. This is particularly useful in many real world applications and typical topics are the effects of traffic planning in urban areas or how the acoustics in a room is perceived [3]. Thus it could be seen as the audible equivalent to the concept of visualisation since it makes architectural designs auditory perceivable [15]. Regarding practical applications there are numerous standards and engineering models that manage to quantify a solution or proposed design. Numerical values though tend to be somewhat abstract at least when presented to non experts. A-weighted values give an indication of the noise level from a frequency perspective with focus on human hearing. Psycho-acoustical parameters offer greater depth to the subject and roughness, sharpness and loudness give a more detailed understanding about the characteristics of a signal such as a car passing by or the impulse response of a concert hall. However some dimensions are still lacking since they do not describe how movement or speed of receiver as well as source in a clear way [3].

2.9.1 Auralisation in urban acoustics

While there are computer software that enables engineer to auralise the effects of problems and measures within rooms their the numbers of outdoor equivalents are limited. However there have been an increased focus and development of such tools, especially since decibel values alone are not sufficient to describe the perceived soundscape. Furthermore traffic noise is affected in frequency domain and in time domain by a noise barrier. These effects are not taken into consideration when presenting decibel levels but are important when evaluating noise attenuating measures and how they affect the soundscape [16].

2.10 Analysis in time and frequency domain

2.10.1 Signal

A general physical definition of a signal is a quantity with for example spatial or temporal variation. Mathematically this can be translated into single or multivariable functions of first degree or higher order which incorporate temporal or spatial dependence [6]. Thus the signal can be described as a carrier of information characterising a process or system [7]. The signals which are processed in acoustical engineering are however of a more complex character. A speech signal or the noise generated from a car cannot be characterized by only observing spatial and temporal behaviour. They are usually described by sinusoidal functions with different frequency and amplitudes. The amplitudes often show temporal variations [6]. The earlier mentioned system is closely connected to the signal since it not seldom change the character of the signal to some extent. A filter that reduce unwanted noise in earphones is an example of a system which use a digital filter to attenuate the noise level. In a physical sense and closely related to topic of thesis a street with with adjacent noise barrier and house facades constitute a system with a complex set of phenomena from diffraction to interference caused by ground effects. However these effects can be applied digitally on a signal to simulate their influence on the signal. This is usually done by applying different filters to the signal and form the basic concept of digital signal processing [6].

Impulse response

The character of a system and it's corresponding output, which are important components in auralisation for example, are quantified by studying the impulse response $h(\tau)$. The output $y(t)$ of the system with it's corresponding response is defined accordingly:

$$y(t) = \int_{-\infty}^{\infty} x(\tau)h(t-\tau)\mathrm{d}\tau \tag{2.38}$$

Where $x(\tau)$ is the input signal to the system and $h(\tau)$ is the systems response to the input signal [4]. The multiplication inside the integral is called convolution and usually written as,

$$y(t) = x(t) * h(t) \tag{2.39}$$

Where $x(t)$ similarly as previous is the input signal and $h(t)$ is the impulse response. [2]. Nota bene the convolution of the arguments inside the integral will yield the same result regardless of order [4].

2.10.2 Convolution

Previously $x(t)$ was convolved with $h(t)$ to yield an output of the system. Mathematically this is done in four main steps. Consider equation (2.7) with it's variables where x as well as h are dependant on τ. Multiplying them in this case is equivalent to sum over all values, thus the output will become a sequence of products[6]. This is done by folding

2.10.3 The Fourier analysis

The discrete Fourier transform

When processing a signal of finite length the discrete Fourier transform (DFT) is used. While Fourier transform is a function that yield a continuous output in frequency domain the DFT on the other hand is per se a sequence of finite length. The length of the DFT is determined by uniformly distributed samples in frequency domain of the continuous Fourier transform [7]. One of the main advantages with the DFT is it's efficiency when processing and analysing finite time signals frequency domain. However the relation between sampled signal $X(\omega)$ in frequency domain and the periodically sampled signal $x_p(n)$ does not necessarily mean that inverted operation will transform the sampled signal to the original frequency representation. This is due to aliasing in time domain. The original representation can be retrieved if attention is payed to the relation between the time length of $x(n)$ and the period samples N of $x_p(n)$.

2.10.4 Convolution in frequency domain

Convolution in frequency domain allow efficient multiplication between the frequency representations of an impulse response and a transfer function. This is usually preceded by Fourier transformation of the arguments. The general formula in frequency domain for convolution is defined as,

$$Y(\omega) = H(\omega)X(\omega) \tag{2.40}$$

Where $H(\omega)$ is transfer function of the system and $X(\omega)$ is the input to the system [4].

Just as in the case of the impulse response the transfer functions also gives detailed description of the system.

Linear filtering

The DFT has numerous applications. One of them are the suitability to be used while performing linear filtering. This is because linear systems can be analysed in frequency domain as discrete sequences of finite length. On of the main advantages of the frequency approach, when compared to the time domain filtering, is the computational efficiency [6]. Time domain convolution is not only considerably more computationally expensive, stability problems are also much more frequent compared to frequency domain filtering [16]. Frequency domain filtering is especially efficient when using algorithms like the Fast Fourier transform(FFT) [6].

Inserting two DFTs into equation 2.40 will yield a result which is the the same as convolving the signals in time domain. However the convolution will be circular thus not giving any information about the output of the system $Y(\omega)$ when the input signal $X(\omega)$ is convolved with the linear filter $H(\omega)$. The linear frequency domain filter which is equivalent to time domain convolution can be achieved if a sufficient amount of zeros is appended to the sequence [6]. Consider the following relation for a FIR filter

$$y(n) = \sum_{k=0}^{M-1} h(k)x(n-k) \tag{2.41}$$

Where $x(n)$ and $h(n)$ are convolved. Both signals are of finite length and the corresponding convolved output $y(n)$ is also of finite length. The length of $y(n)$ is L+M-1. Recalling equation 2.40 which is the sampled sequence in frequency domain of 2.41. Since $y(n)$ has the length L+M-1, the DFT must have a quantity of discrete samples that fulfill $N \geq L + M - 1$. Zero padding increases the total length of the signal, but it does not have an impact on spectra of $X(\omega)$ and $H(\omega)$. By appending zeroes such as $x(n)$ and $h(n)$ have the length N, the circular convolution will yield the same result as if they would have been linearly convolved. This is the main core behind the concept of using DFT to perform linear filtering [6].

2.11 Overlap and add method

The overlap and add method is a synthesis method based on the discrete Fourier transform. One of the main advantages with the method is the ability to efficiently filter longer sequences of data. Processing real world signals does not seldom involve inputs of considerable length. DFT processing allows division of the inputs into blocks determined by sample length. This is possible as long as the operations are linear. Linear filtering fulfil this condition and the the shorter initial input blocks of fixed size are concatenated into a long final output signal. If performed correctly this will yield the same result as if the signal would have been convoluted i time domain. The blocks are divided into segments consisting of L values or points. This will result in a DFT with corresponding inverse DFT that will be of length $N = L + M$-1 with M-1 zeros for each block. By adding M-1 zeros the blocks have the length N [6]. The blocks are formed by windowing with for example a Hanning or Hamming window. When the convolution has been executed the signal is transformed back to time domain by the inverse discrete Fourier transform [36]. These steps are due to the efficiency of the discrete Fourier transform and algorithm less computationally expensive than performing the calculations in time domain without these extra steps [6].

2.12 Interpolation

Interpolation is often used to give an estimate to the values of non explicitly calculated data points inside a range of known discrete data. This operation yields a new set of data based on the boundaries of the original data set. Various methods have been used and developed to interpolate data since antiquity, however the practice is becoming even more common and relevant during modern times. During the early days of interpolation it was used to estimate the movement of for example the sun and the moon. This was useful not only from an astronomical perspective but also had agricultural advantages. Nowadays modern methods are still used in geostatistics to map ground water level or density of minerals based on measured data [17]. From an acoustical perspective interpolation can be made spatially as well as temporally. The latter allows convenient re-sampling of signals while the spatial interpolation has the potential to determines the sound pressure level in a unknown point based on adjacent measured or calculated. This is useful during the early stages of urban planning process since it can give an estimate of the expected noise pollution in an area. Spatial interpolation has also been used to create a soundscape profiles with qualitative data collected from sound walks thus giving a holistic perspective to the planning process [18].

2.12.1 Interpolation methods

The methods can be divided into different families and distinguished by their general behaviour. The polynomial methods using linear interpolation along with piecewise cubic Hermite interpolation polynomial(pchip) and modified Akima cubic Hermite interpolation (makima) produce continuous curves while nearest-, next- and previous neighbour all are discontinuous [21]. Among polynomial methods the linear ones differs being constructed using segments of broken lines to construct the resulting curve. The result is a less smooth curve compared to pchip and makima which are polynomials with a continuous derivative in contrast to the linear method [22]. Among the polynomials there are differences between the piecewise types and the cubic Hermite versions. Evaluating a repeated quantity of cubic Hermites are usually more time consuming than the piecewise variants when executed the same amount of times. However they usually give more accurate representation of functions [27].

The three discontinuous methods are all based on a common principle which is assigning the value at a query point based on a value at a neighbouring sample point. In contrast to the smooth function obtained by the cubic splines seen in figures 2.20 and 2.21 the neighbour methods yield a piecewise step function depicted in figures 2.22 and 2.23. They are generally computationally cheaper and require less memory compared to the cubic splines however the result is less smooth and not as accurate in approximations.

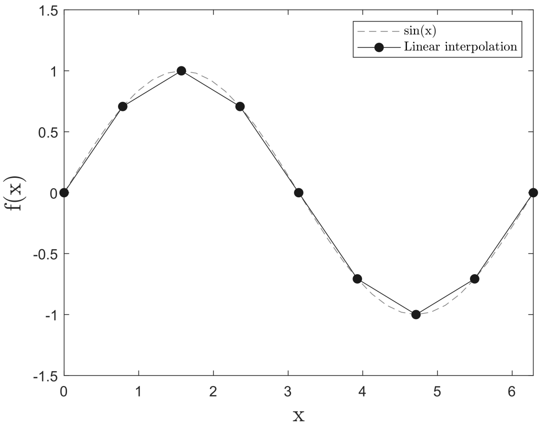

Figure 2.18: Linear interpolation at 9 sample points

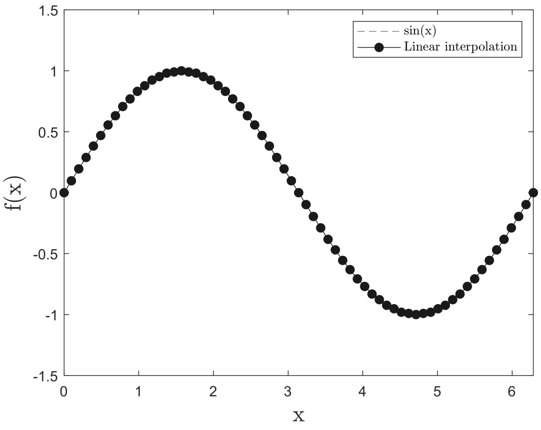

Figure 2.19: Linear interpolation at 65 sample points

Linear interpolation

Linear interpolation calculates the value for a given point which lies between adjacent points. The points are assumed to be the boundaries and the point can be placed on a straight line that connects the two boundary points. The method has been used since antiquity and is based on the equation of the straight line between the known points [19]. By using the linear polynomials piece wise a curve that describes the data points is constructed. A greater amount of sampling points increase the resolution of the curve [22]. This is especially evident in figure 2.18 whereas the curve in figure 2.19 resembles the sinusoidal curve rather than being constituted by segments. This behaviour is also visible in figure 2.20 and 2.21. The method yields a set of data points connected by a continuous line, however the derivative is discontinuous. The curve is constructed by adding fractions of straight lines calculated for each segment. A minimum of two sample data points are required to perform the interpolation. The method is computationally heavier and more demanding with respect to memory than for example Nearest or Next neighbour algorithms but faster than the more complex Piece-wise cubic Hermite interpolating polynomial and Modified Akima cubic Hermite interpolation [21].

Modified Akima cubic Hermite interpolation

The modified Akima cubic Hermite interpolation is a modified version of the method developed by Hiroshi Akima in 1970. One of the main objectives was limiting the wiggles in the resulting function, i.e. the curves have a more flat shape compared to ordinary cubic spline functions. However the curves are still less flat compared to pchip which can be seen by studying figurs 2.20 and 2.21. Makima is a local method which means that the interpolated point is only influenced by information from the interpolated interval or its proximity [22]. Thus making the result to a great extent indifferent to changes farther away in the data set. Just as the linear version the makima method is composed of at most cubic polynomials which are concatenated into a continuous curve. Their slopes are determined by the coordinates of the given data points which are five in total: The interpolated query point and two points on each side relative to the center point. By using two additional points adjacent to the end points the slope at the boundary points can be determined[23]. With respect to computational cost the makima is less expensive than most versions of splines but somewhat more costly than for example pchip. It also requires more memory than pchip [21]. The original version of Akima's method gives equal weight to the adjacent points relative to the center point when determining the undulation between the boundary points, thus evenly scaling the undulation. The modified version makima considers the derivative in the center point as a weighted average of nearby slopes thus further reducing undulations. The fewer undulations compared to for example splines make the makima more favourable when dealing with data that contain many flat regions or plateaus. The method is also well performing when dealing with oscillatory data [24].

Piecewise Cubic Hermite Interpolating Polynomial

The pchip method is just as its cubic relative makima a local method. [22]. It constructs a curve composed of piecewise polynomials just as in the case of linear and makima interpolants [25]. The function produced is continuous along with its first derivative which is a common characteristic for all third degree Hermite polynomials [27]. The method flattens the undulations and arches between points in an aggressive manner, which is visible in 2.20 and 2.21. This is not a coincidence since it is often demanded from a scientific perspective to use approximations that do not differ from reality to a great extent. Reducing wiggles and undulations is relevant when dealing with monotone data. When the algorithm was developed computational cost and memory usage were taken into consideration [26]. It is more demanding than linear interpolation with respect to both computational cost and memory usage. However it is more economic compared to makima in both cases [21]. It has been mentioned that piecewise polynomials are in most cases faster than Cubic Hermite interpolation with respect to execution time. [27].

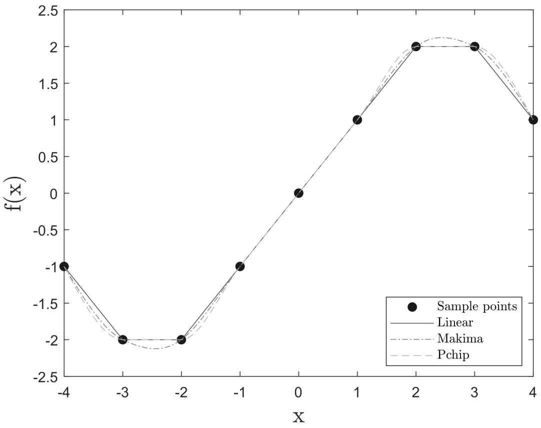

Figure 2.20: Continuous interpolation at 9 sample points.

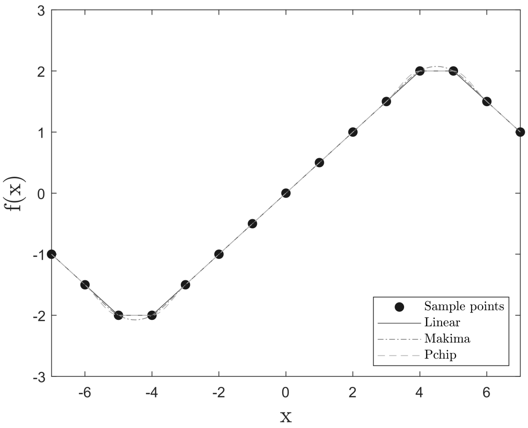

Figure 2.21: Continuous interpolation at 15 sample points.

Nearest neighbour

The Nearest neighbour method is less sophisticated compared to the previously mentioned methods. However the method is easy to comprehend and the algorithm is the computationally fastest among the evaluated in this report. The method requires a moderate amount of memory when executed [21]. The method estimates a value at a query point by assigning the value from the nearest known data points. This is done using perpendicular lines which construct polygons with the sample point in the centre [28]. When constructing the polygons at least two sample points are needed [21]. This is usually done by using Dirichlet or Voronoi diagrams. There are one polygon per sample and all points within the polygon have a shorter distance to the center point than any other point outside the polygon. The value at the interpolated point is estimated by only considering the nearest point [28]. It is not uncommon to use weighting to estimate the influence of the sample points on the estimated value. The weighting usually considers the distance to the sample point. The result is a discontinuous constant step function which is seen in figure 2.22 and 2.23. The effect of increasing sample points is also visible when inspecting the figures [28].

Next neighbour

The Next neighbour method is executed in a similar manner as the previously described Nearest neighbour method except it strictly considers the next value in a sequence of data points, the resulting function is visible in figure 2.22 and 2.23. The requirements are the same as in the previous method. A minimum of two sample points. Computational cost and memory usage are also the same as in Nearest neighbour method [21].

Previous neighbour

Previous method is also very similar to the Nearest neighbour method. Contrary to its close relative the Next neighbour it assigns a value to a query point by considering the sample point which is the previous value relative to the unknown query point in a sequence. The behaviour of the method along with the differences compared to Next neighbour is visible in 2.22 and 2.23. Computational cost and memory usage are the same as for Next neighbour method [21].

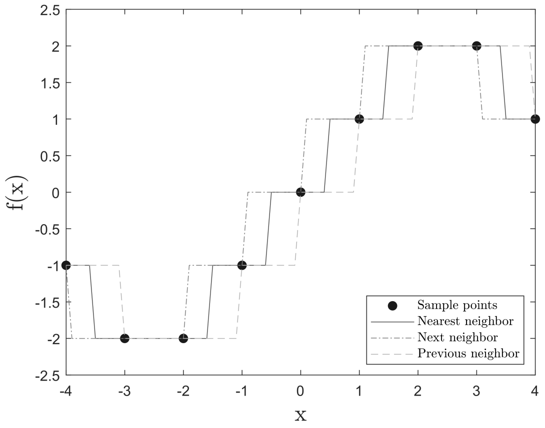

Figure 2.22: Non Continuous interpolation at 9 sample points.

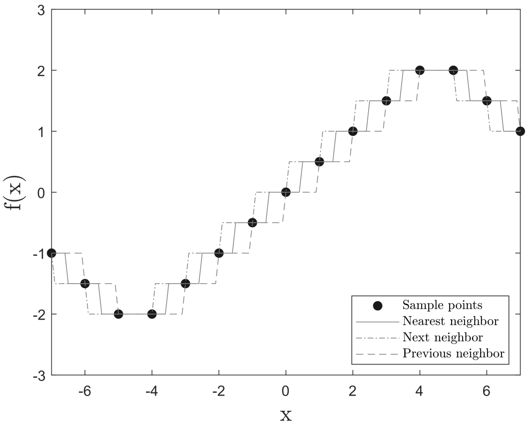

Figure 2.23: Non Continuous interpolation at 15 sample points.

2.12.2 Algorithm evaluation

When designing algorithms to solve a problem or perform a certain task some concepts are regarded as central. Particularly relevant when evaluating the finished program are for example clarity and simplicity. A simple algorithm is usually easier to comprehend than one that is complex. Clarity is sometimes related to simplicity but the concepts do not necessarily follow each other. Clarity often involves documentation of the algorithm which enables an outsider to understand the program. The third and most relevant part, at least in this report, is efficiency [29]. Since it is not within the scope of this thesis to neither program nor improve an algorithm, preprogrammed ones are used. One dimensional interpolation algorithms from Mathworks are employed [21]. Therefore the thesis will focus on efficiency besides other aspects for example psychoacoustical parameters and other sound metrics such as energy levels. It is also important to emphasize the distinction between computational time and computational cost. Measuring the former is a fairly straightforward task while the latter is a far more complex operation since it involves also memory use, and is outside the scope of this thesis [29]. Estimating the required time to execute a program can be made with a built in Matlab function [30]. Nevertheless the built in method is not immune against small errors that might occur due to hardware-dependant behaviour[31].

Furthermore, simplicity as well as clarity are not totally separated from subjective judgement, while time can be quantified in a more objective manner. Unfortunately there is no universal method to determine efficiency why some subjective preferences exist, such as choice of measurement method for example. Besides execution time, programs are evaluated according to their memory usage and amount of storage that needs to be allocated for variables. Efficiency is particularly important when an algorithm is to be executed with many repetitions. This is relevant e.g. when using interpolation with fine discretization for auralisation purposes. When dealing with a large amount of data the running time becomes the crucial factor when determining whether an algorithm is deemed efficient or not [29].

2.13 Psycho acoustical analysis

2.13.1 Just noticeable difference

Just noticeable difference (JND) is along with just noticeable change a concept of great importance when characterising and quantifying signals from a sound sensation perspective. Just noticeable change focuses on change in a given signal for example, while JND compares two signals with each other and the difference between the two are analysed [5].

2.13.2 A-weighting

A-weighting is based on the human hearing mechanism and its relation to frequency. The A-weighting curve is derived from equal loudness curves and the human perception of pitch. Acoustic loudness is in contrast to sound power level a subjective quantity. By studying the equal loudness contours it can be noted that the human ear is less sensitive to sound at the lower frequency bands below 2 kHz and compared to at the bands ones in the central region, e.g. 1 kHz. The same goes for higher frequencies at 5 kHz were the hearing is less sensitive. When using a A-weighting filter the full human audible range spectrum is covered and taken into account. However a one third octave version also exists which is derived from measurements in third octave bands.

It is not unusual practice to present measurements, simulations or acoustical properties of building elements as A-weighted values. These are usually summed over one third octave bands into a single value.

A-weighting offers an easy accessible and computationally cheap method of estimating perceived disturbance from various noise sources [4]. It is also an efficient method for determining overall sound pressure levels in a broad banded noise. However there has been indications that the model is somewhat unsophisticated for certain applications, especially when estimating noise emission from cars during traffic modelling. Traffic noise has considerable amounts of pronounced tonal components in the lower frequency range. A-weighting tends to not only underestimate these regions but also overestimate differences between two similar noise sources[5].

2.13.3 Loudness

Loudness is just as A-weighting a measure to estimate perceived sensations of a noise or a signal. By studying the loudness the discrepancies between two signals can be determined with better precision compared to regular magnitude calculations. When doing loudness comparison the quantity loudness level, with the unit phon, is used. Loudness has not only frequency and bandwidth dependence but also temporal dependence. Beside these two loudness is affected by the overall sound pressure to a great extent [5].

Spectral characteristics

The loudness parameter is as stated frequency dependant. Comparing to another important measure namely the A-weighting it becomes specially evident. Consider two signals, a uniform noise and a pure tone at for example 1 kHz, which are both played at 60 dB sound pressure level. While having the same A-weighting value, the uniform noise will have approximately a 3.5 times higher loudness value [5].

Temporal characteristics

A majority of the sounds that are of interest do not display a steady state behaviour, instead their levels vary with respect to time. Considering a chirp or a tone burst. When evaluating a single tone burst the loudness is a function of the temporal quantity of the burst. However if a sequence of equal bursts are considered it has been found that the loudness is determined by the rate of repetition. When the duration of the signal is sufficiently long it has been shown that the loudness becomes, to a large extent, temporally independent. For signals shorter than 100 ms the temporal behaviour is however present and a decrease in loudness is expected with decreasing time. Decreasing the duration with a factor 10 correspond to a decrease in 2 sone. This is valid down to approximately 1 ms. For shorter time lengths a larger spectrum is needed which greatly decrease the accuracy of the model [5].

2.13.4 Sharpness

Sharpness, measured in the unit (acum), is a sensation which to a great extent is dependant on the spectral envelope of sound. As a reference a narrow banded signal with a centre frequency at 1 kHz played at 60 dB will yield 1 acum. It is usually described as a measure of the spectral density of sound and the most important parameters are besides the spectral character also the centre frequency. Therefore a large portion of high frequency content will yield a higher sharpness value. The sharpness value has a small dependence on sound level. Considering an increase from 30 dB to 90 dB will only result in a doubled sharpness value and therefore level is usually neglected for small differences during initial less accurate estimations. Similarly a bandwidth does not affect sharpness to a great extent as long as it is considerably smaller than the critical band. As summary sharpness is a good measure of the portion of high frequency. It is also seen as the inverse of another sensation called pleasantness. Pleasantness is however a product of other parameters than just high frequency density. Both are however dependant on the parameter roughness.

2.13.5 Fluctuation strength

Acoustic fluctuation, measured as Vacils, which is related to acoustic roughness, to some extent is a quantity which describes modulation of sounds at certain frequencies. It is perceived as acoustic loudness which varies up and down. The siren mounted on a firetruck is a typical example of the phenomenon. At lower modulation at approximately 20 Hz fluctuation is usually perceived while beyond 20 Hz the sounds tend to have an acoustic roughness character. Fluctuation strength is to some extent dependent on sound pressure level and there is a correlation between increased fluctuation strength at higher sound pressure levels [5].

2.13.6 Roughness

As mentioned above the quantity acoustic roughness is the sensation which is perceived when a signal is modulated at high modulation frequencies. The roughness sensation usually start at approximately 15 Hz modulation frequency. Roughness usually reaches its Zenith when modulated at 70 Hz. Beyond this levels the roughness decreases.

2.13.7 Psychoacoustic annoyance

Psychoacoustic annoyance is quantity which is used to describe the overall sound quality of a signal considering the four previously mentioned metrics. Thus it has a temporal dependence along with a spectral dependence, while also taking loudness into consideration. The sound quality metric can be used to rank sounds according to subjective parameters such as aesthetic qualities as well as perceived pleasantness or annoyance. The metric was developed by Zwicker and Fastl by studying results from various pyschoacoustic experiments. It is used to describe naturally occurring sounds along with synthetic ones and is used to quantify annoyance from for example vehicles and air condition. Thus it is a valuable tool for sound engineers [5].

2.14 Edge diffraction toolbox

The EDT is composed of a set of functions which allows the user to compute the sound pressure for rigid objects of various polyhedral objects. Time domain as well as frequency domain analysis are available with the resulting sound pressure given as a sum of scattered geometrical components. Diffraction is considered from the first order to higher orders. Also specular reflections can be considered. The geometries can be modelled either as matrices directly in Matlab containing information about corners and planes of the object or as CAD-files which are interpreted by the EDT.

The user has the option to exclude desired parts of the objects such as planes and corner [5].

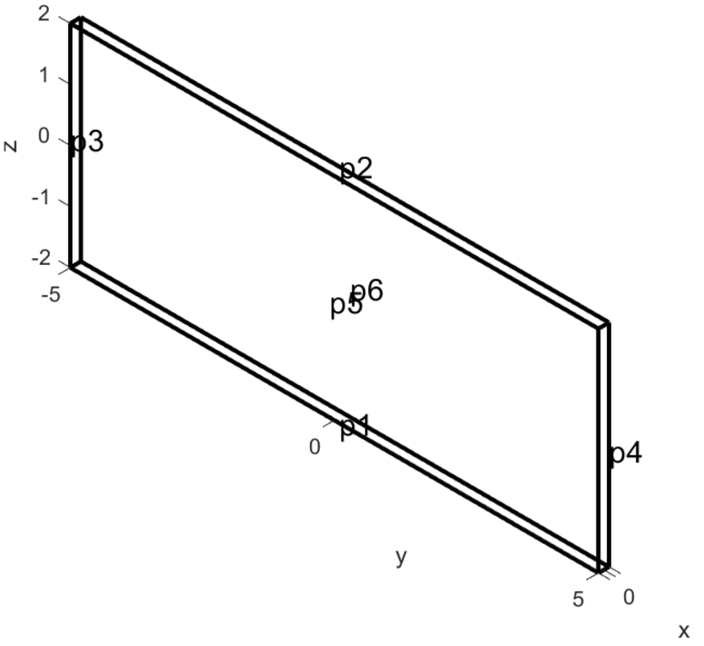

Figure 2.24: Barrier with numbered planes. Figure provided by the EDT function.

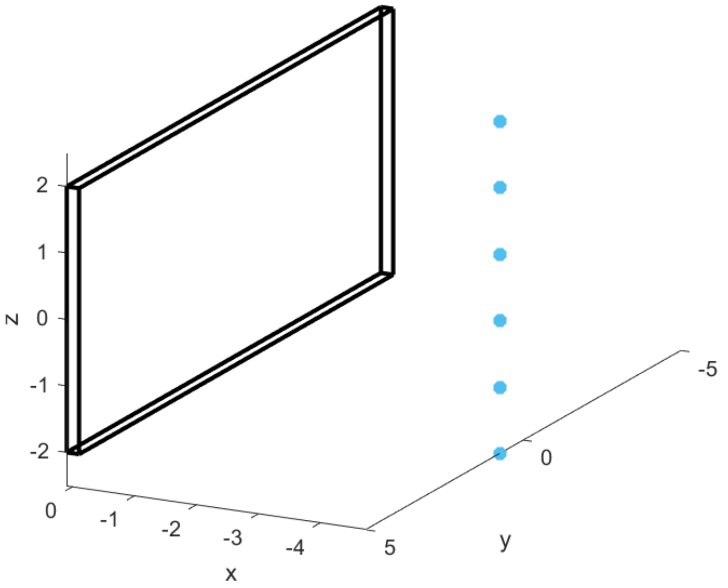

Figure 2.25: Barrier with sources placed with equidistant increments. Figure provided by the EDT function.

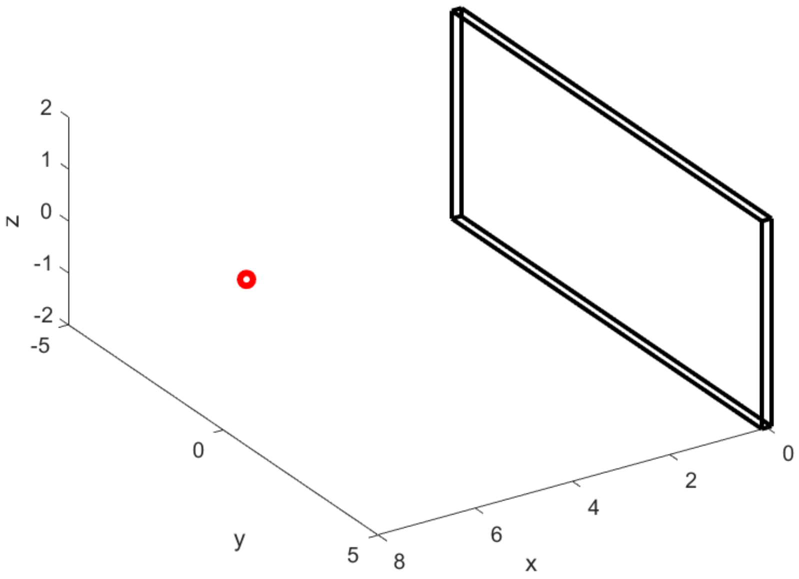

Figure 2.26: Barrier with receiver position located 8 meters behind the barrier. Figure provided by the EDT function.

3

Methods

3.1 Modelling of pass by situation

The pass by scenario, visible in Figure 3.1 was modelled by distribution of point sources along an axis thus creating a line source. Since one of the main objectives of this thesis was to investigate interpolation with different increments, denoted Δx in the figure and seen in Table 3.1, a total of 12 different step sizes were used. The source was placed in the middle of the driving line in order to simulate a car passing by. Since the main focus points were to investigate interpolation algorithms and the effect of the Doppler effect in combination with noise barriers rather than simulating an actual traffic situation only one lane was used a line source. Most likely there would be cars passing by in the opposite direction in addition to the simulated line source. The axis containing the point sources which were of length 20 meters had a mid point at zero in a coordinate system. The midpoint coincided with the end of the semi-infinite barrier, which spanned a total of 20 meters from -20 to the midpoint zero. The receiver was also located at the midpoint along the horizontal axis. The geometry of the road was chosen to represent a typical situation in Sweden. The receiver is placed 8 meters from the edge of the noise barrier thus fulfilling the criterion of a path length which is at least greater than wavelength $\lambda/2$. The cars were assumed to drive at a relative low speed.

Table 3.1: Increments used for evaluating interpolation algorithms

Δx	Step size					
(m)	0.0156	0.0313	0.0625	0.125	0.25	0.5
(m)	1	2	4	5	10	20

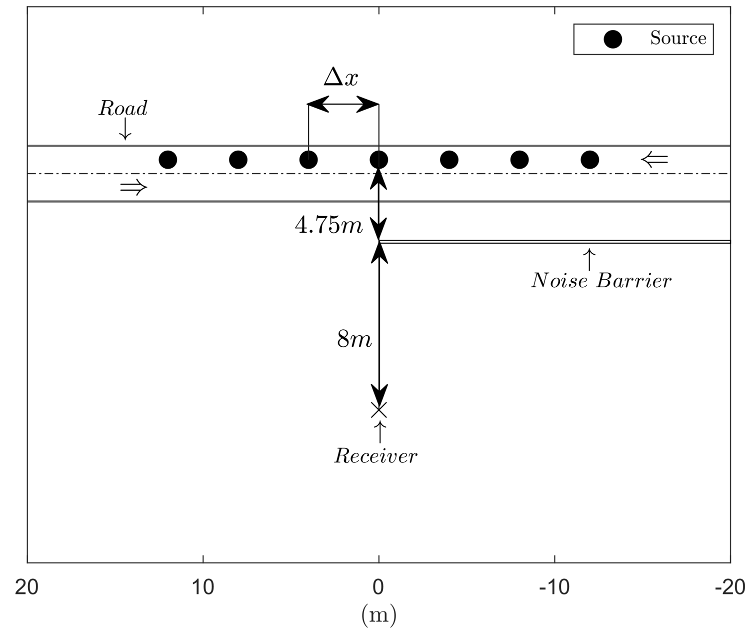

Figure 3.1: Schematic not-to-scale figure showing the pass by scenario.

When implementing the algorithms some assumption were made regarding environmental parameters. The ambient temperature was set to 20C° with a surrounding relative humidity of 45 %. The static atmospheric pressure was set to 101325 Pa. The speed of sound was assumed to be 340 m/s.

3.2 Modelling of different pass by situations

A total of four different situation were modelled in order to investigate the Doppler effect in a combination with noise barriers. During the first scenario neither barrier nor Doppler effect were considered. The second scenario considered the Doppler while the barrier was still excluded. The third scenario considered the barrier while the Doppler effect was not included. The fourth scenario considered the Doppler effect as well as the noise barrier.

3.3 Evaluation of interpolation methods

3.3.1 Quantifying running time

Running time for a program or algorithm are usually measured by the amount of repetitions during a certain time or inversely the time needed to execute a certain amount of repetitions. The latter was chosen during this investigation. When quantifying running time two different are used. First a worst case scenario considering the most computationally demanding type of input, since running time measurements are not solely dependant on input size but also type of input. Second an average over all inputs can be used [29]. Since this thesis not only investigates the usefulness of interpolation in urban auralisation but also discretization and type of method the average is preferred as measure. A total of 12 discretization steps were used. Because of this a worst case scenario was not considered relevant for this investigation.

3.4 Auralisation

The auralisation was performed by direct implementation in Matlab. The sound signals were adjusted by filtering either in time domain or frequency domain. Initially the propagation effects were calculated using the Pierce solution for diffraction of thin infinite barrier. Second the attenuating due to air absorption was added as a frequency domain filter. In order to avoid unnecessarily high computational cost associated with the time-varying filter the sound signal was processed in frequency domain by implementing an overlap and add method (OLA) which is based on short time Fourier synthesis and enable an equivalent to finite convolution at reduced computational cost. It allows efficient finite impulse response filtering of long signals by dividing the signal into segment. The filtering is performed segment per segment with a given overlap which allows the signal to be reassembled without loss of information. The interpolation was also performed while implementing the OLA algorithm. First the signals were interpolated spatially using the 6 different methods which were evaluated to simulate a vehicle moving along a road. Second the spatially interpolated signals were interpolated in frequency domain with a pchip interpolating method in order to implement the frequency domain filtering since the signals initially had one third octave resolution. Propagation effects such as distance dependence and Doppler related effects were modelled after the interpolation was performed. The attenuation due to distance was considered using the spherical spreading from Green's function. The Doppler effect was modelled by re-sampling the signal, taking into account the delay of the signal from moving source to receiver during while moving along the road. Thus the signal reaching the receiver is attenuated by air absorption and distance decay. Furthermore the spectral content is altered due to the Doppler effect while the convective effect related to the Doppler factor also has an influence in the amplitude.

3.5 Modelling with EDT

Recalling Figures 2.24 to 2.26 the situation was modelled to resemble the situations considering the Pierce solution. The same discretisation was used as for the Pierce solution. Since the EDT allow the thickness of a barrier to be equal to zero a thin barrier was modelled. To simulate an infinite barrier all planes except one were omitted in the calculation, thus the equivalent to only considering plane 2 in Figure 2.24. Since only one edge was considered, only the first order of diffraction was considered. The receiver was placed 8 meters behind the barrier while the source was placed in the same manner as in the Pierce scenario, that is 4.75 meter from the barrier. Spatial discretisation was also identical.

Figures 3.2 and 3.3 show the impulse response from the time domain analysis. The sources are placed with different distances relative to the receiver. Thus arriving with a delay corresponding to the difference in distance. This is also visible when studying the time axis in relation to when the impulse peaks and slopes for the impulse responses. In order to achieve the correct distance dependence while computing the auralisations the signal were arranged to arrive at the same time. This was done by estimating the their arrival time and cutting the signal containing the impulse response. The result was a matrix containing all impulse responses with the same arrival time. An example is seen in Figure 3.4 where the impulse responses all have the same arrival time. Since their length varied relative to each other zeros were appended in order to perform matrix operations while calculating the auralisations.

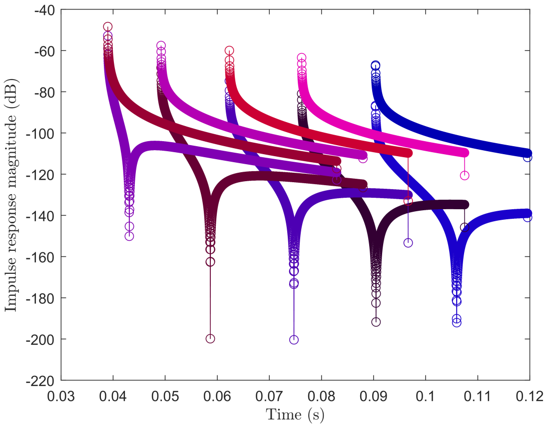

Figure 3.2: Impulse response considering only diffracted sound for sources with 0.25 meter spacing.

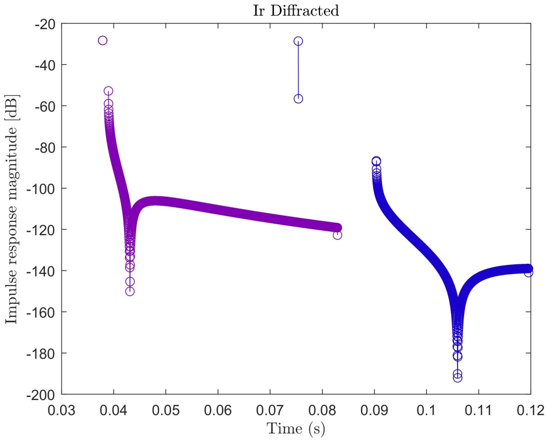

Figure 3.3: Impulse response considering direct as well as diffracted sound for sources spaced with 0.25 meter increments.

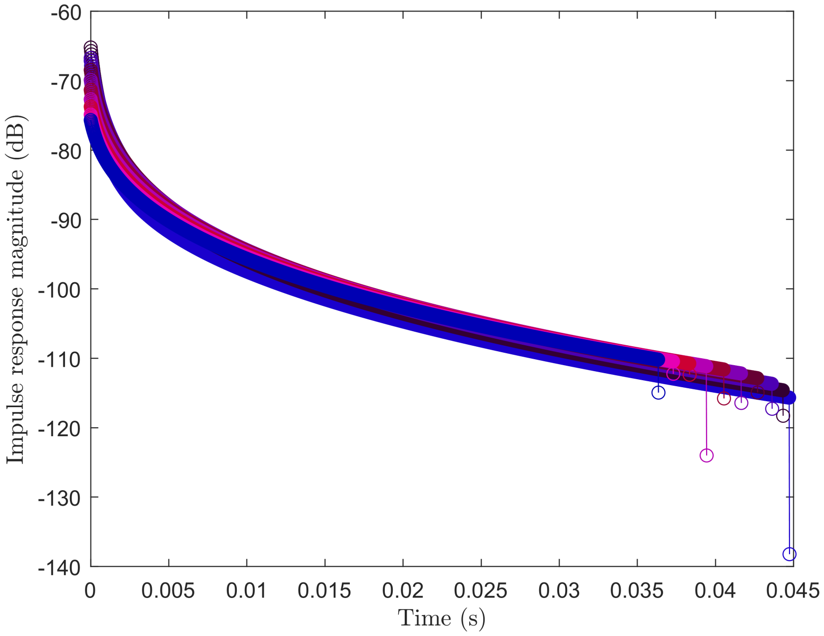

Figure 3.4: Example showing impulse response of diffracted sound waves spatially distributed with 1 meter increments arranged to arrive at the same time

3.6 Listening test

An informal listening test was conducted consisting only of the author of the report. The aim was to investigate whether there are audible differences between the methods and the different increments.

4

Implementation

4.1 Measuring running time

The 12 different discretizations were measured as incremental steps along the 40 meter long road where the car pass by is assumed to occur. The interpolation algorithm was isolated and measured with a built in function in Matlab called tic tic. Thus tic was placed before the function executing the interpolation algorithms while toc was placed after the function [30].

4.2 Stimuli

The stimuli consisted of prerecorded pass by signals. The velocities were 40 km/h and 50 km/h. In total 4 different vehicle recordings were used, a light vehicle with both electric motor and a light vehicle with internal combustion engine. An equivalent setup for heavy vehicles was also used. These input for the auralisation algorithm were modelled as steady state signals.

4.2.1 Modelling of signals

The recorded mono signals were transformed from time dependant to steady state signals by reversing the factors which affect the sound propagation. The time and frequency shifts caused by the Doppler effect was inverted along with the distance dependent attenuation from the spherical spreading. Environmental factors such as atmospheric spreading and topographical ground effects were also reversed. After these operations two directivity components were left. On forward while the other one backward pointing. The two directed signals where then fitted via interpolation to obtain a continuous signal.

4.2.2 Vehicles components

The vehicles were modelled in accordance with Harmonoise and Nord 2000 standard, which means that the vehicle source is divided into two components. The tyre which is modelled 0.01 meter above the road and the propulsion which is modelled 0.3 meters above the road. Heavy vehicles are modelled with a propulsion height at 1,75 meters.

4.2.3 Tonal components

Heavy vehicles along with light vehicles with diesel engines tend to have more distinct tonal components compared to lighter internal combustion vehicles. Tonal components from heavy vehicles vary with respect to time at a larger extent than light vehicles. They also show more variation compared to the directivity. The amplitudes and frequencies of tonal components was considered during the synthesis of the signals. Tonal components were also synthesised although with a slight different method.

4.3 A-weighting filter

In order to address human perception of frequency components an A-weighting filter was used. The filtering was performed in frequency domain with a frequency response filter implemented in accordance with ANSI S1.4 which gives specifications and coefficients used to design and implement A-weighting [9]. The frequency response filter for A-weighting which yield an output W_A in decibel is defined as follows,

$$W_A = 10log_{10}\left(\frac{K_3 f^4}{(f^2+f_2^2)^2(f^2+f_3^2)^2}\right) + 10log_{10}\left(\frac{K_1 f^4}{(f^2+f_1^2)^2(f^2+f_4^2)^2}\right) \tag{4.1}$$

Were f is the given frequency in hertz. Coefficients f_1,f_2,f_3 and f_4 along with scaling factors K_1 and K_3 are found in the table below.

Table 4.1: Coefficients and scaling factors.

f_1	20.598997
f_2	107.65256
f_3	737.86223
f_4	12194.22
k_1	$2.242881x10^{16}$
k_1	1.562339

The frequency response of the A-weighting filter is seen in figure 4.1.

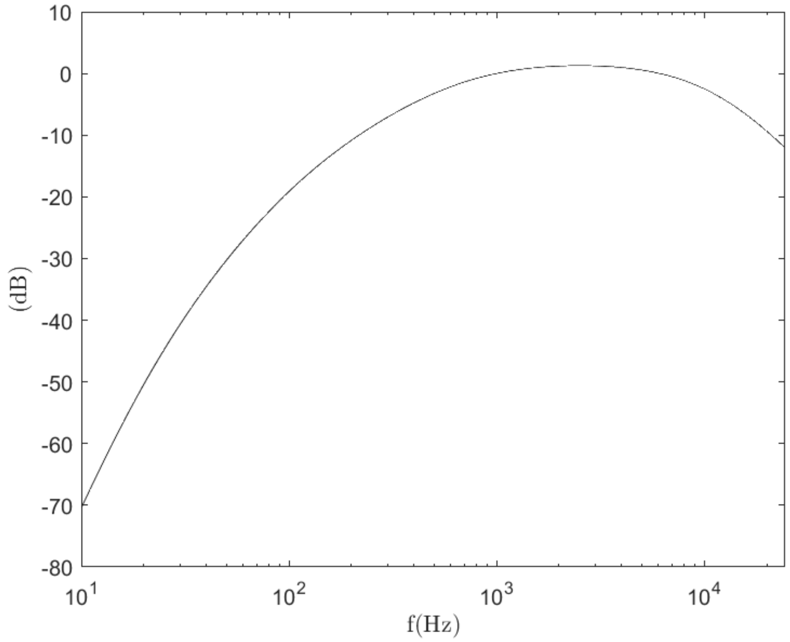

Figure 4.1: Frequency response of A-weighting filter.

4.3.1 Psychacoustic analysis

All four parameters Sharpness, roughness, fluctuation and loudness were analysed in Matlab using built in function provided by Mathworks via toolboxes. The psychoacoustic annoyance metric for annoyance was implemented direct via equations from Zwicker and Fastl:

$$PA = N_5\left(1 + \sqrt{w_S^2 + w_{FR}^2}\right) \tag{4.2}$$

Where N_5 is the percentile value of the acoustic Loudness calculations which is used along with Sharpness S in the term w_S;

$$w_s = \left(1 + \frac{S}{acum} - 1.75\right) 0.25lg\left(\frac{N_5}{sone} + 10\right) \tag{4.3}$$

The equation above assume S>1.75 acum. Fluctuation strength F and Roughness R is considered in the term w_{FR} and formulated as follows;

$$w_{FR} = \frac{2.18}{(N_5/sone)^{0.4}}\left(0.4\frac{F}{vacil} + 0.6\frac{R}{asper}\right) \tag{4.4}$$

Where R is the contribution from acoustic Roughness and F is the fluctuation strength. [5].

4.3.2 Comparison with EDT

The auralised signals estimated using the Pierce solution was compared to the wave equation based solution. This was done by estimating the root mean square error (RMSE) between the signals.

5

Results

5.1 Interpolations

In order to estimate the computation times for each methods a total of 15 iterations per method were performed. This was done for heavy as well as light vehicles at speeds 40 km/h and 50 km/h. The estimation also considered electric motors and internal combustion engines. The computation time presented as arithmetic mean values for each method at 12 discretisation steps are visible in Figure 5.1 to figure 5.8. Some trends are visible. When inspecting the figure it is clear that pchip requires more computation time than the others method, save for the outlier at 0.0313 meters for the previous neighbour method in figure which is not taken into consideration. The increase in computational time for pchip also has a steeper slope compared to the other methods. The longer computational time of pchip expected according the theory behind interpolation algorithms and the literature survey, especially the relation compared to linear interpolation and the three different neighbour methods. Furthermore the methods linear and nearest neighbour along with makima showed considerably lower computation times than pchip, next neighbour and previous neighbour. The corresponding slopes however showed a similar behaviour as the ones belonging to previous and next neighbour method. All results showed a consistent behaviour at least regarding the trends. When studying the slopes of next and previous neighbour some deviations are visible. This does however not affect the overall result and conclusion. The three methods with lowest computational times displayed a slightly more consistent behaviour.

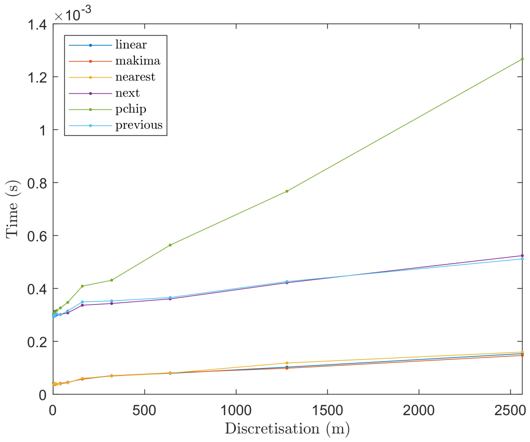

Figure 5.1: Arithmetic mean values for six interpolations for a heavy vehicle with electric motor passing by at 40 km/h

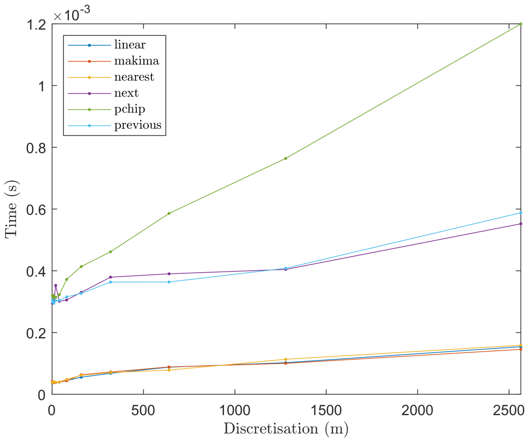

Figure 5.2: Arithmetic mean values for six interpolations for a heavy vehicle with internal combustion engine passing by at 40 km/h

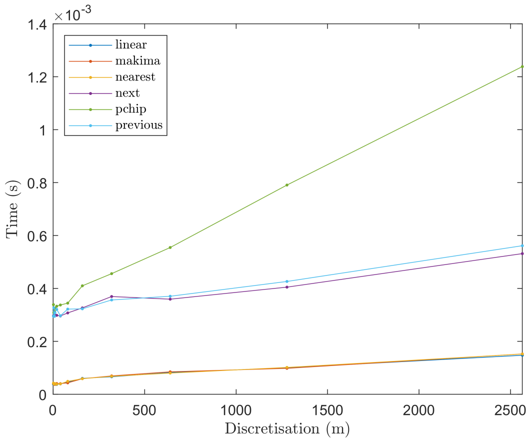

Figure 5.3: Arithmetic mean values for six interpolations for a light vehicle with electric motor passing by at 40 km/h

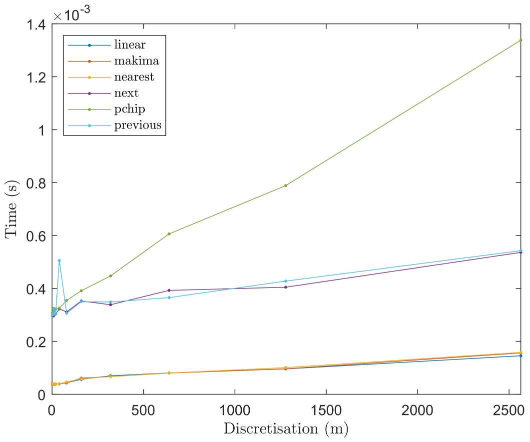

Figure 5.4: Arithmetic mean values for six interpolations for a light vehicle with internal combustion engine passing by at 40 km/h

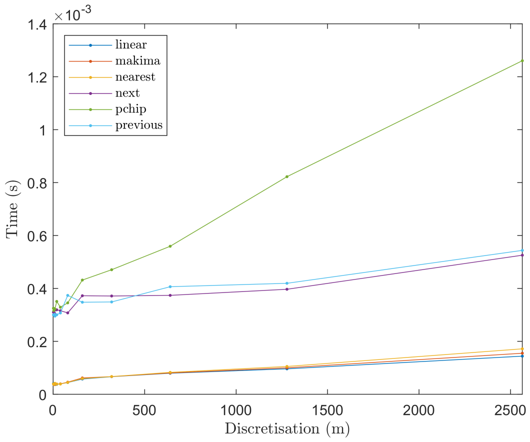

Figure 5.5: Arithmetic mean values for six interpolations for a heavy vehicle with electric motor passing by at 50 km/h

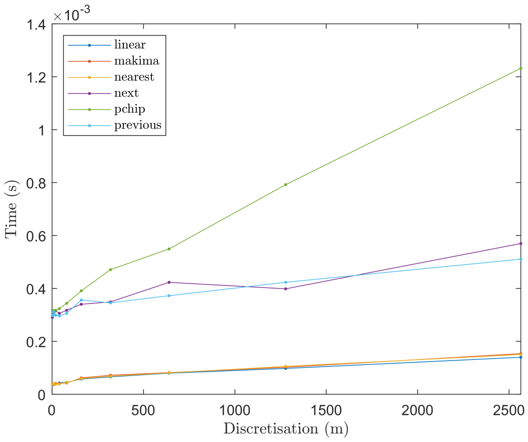

Figure 5.6: Arithmetic mean values for six interpolations for a heavy vehicle with internal combustion engine passing by at 50 km/h

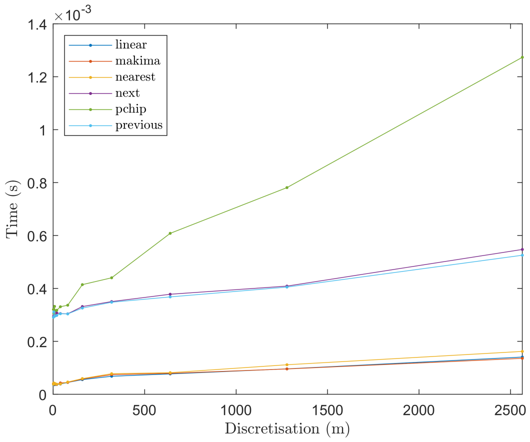

Figure 5.7: Arithmetic mean values for six interpolations for a light vehicle with electric motor passing by at 50 km/

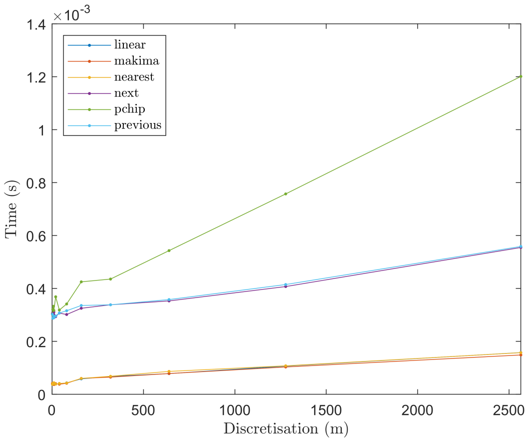

Figure 5.8: Arithmetic mean values for six interpolations for a light vehicle with internal combustion engine passing by at 50 km/h

5.2 Spectral analysis

The spectral content of the auralisation was analysed with spectogram using Matlab software. Auralisations of a vehicle with internal combustion engine passing by at 40 km/h were analysed. Discretisation steps 0.0156 m, 1 m and 20 meters were chosen to represent the spectral behaviour. Figure 5.9 to 5.11 show the spectral difference between the previous neighbour method and pchip for scenario with screen and Doppler effect considered. They clearly show that longer discretisation steps increase differences in spectral content. The difference between the discontinuous previous neighbour and the continuous pchip is particularly visible in 5.11. The point where the vehicle is passing by the edge of the barrier is also visible in the figures.

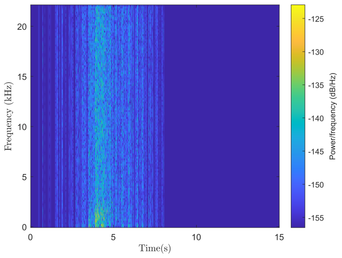

Figure 5.9: Linear interpolation at 0.0156m.

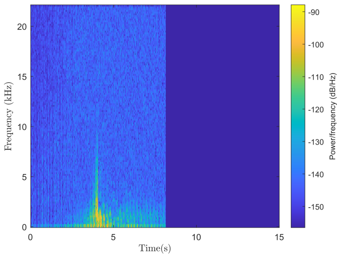

Figure 5.10: Linear interpolation at 1m.

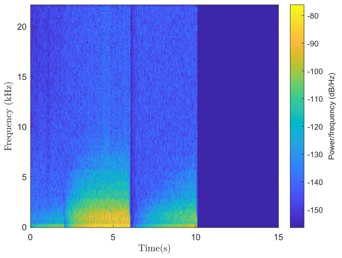

Figure 5.11: Linear interpolation at 20 m.

5.2.1 No Doppler effect and no barrier

Figure 5.12 to 5.14 show the spectral contents for a pass by without screen and Doppler effect was not considered. When comparing figure these some trends are visible. The short interpolation increments, that is 0.0156 m and 1 m yield a shorter signal while the 20 m step size gives a longer signal. With respect to spectral contents the shorter discretisation steps seem to have a more dense frequency content. Especially in the higher frequency bands. These trends are true for all interpolations. Save for mentioned observations there are no abundantly clear differences between the algorithms.

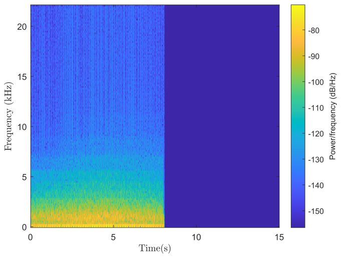

Figure 5.12: Linear interpolation at 0.0156 m.

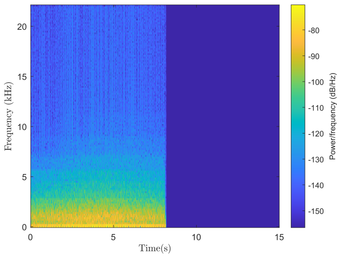

Figure 5.13: Linear interpolation at 1 m.

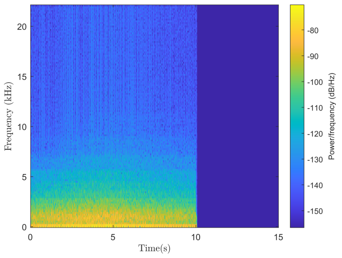

Figure 5.14: Linear interpolation at 20 m.

5.2.2 Doppler effect and noise barrier

The spectral content for a pass by situation containing a screen and Doppler effect considered is shown in figures 5.15 to 5.29. In contrast to the previous case where the screen was not included a clear difference is observed both with respect to method as well as interpolation distance. The difference in interpolation step size is visible when comparing the next neighbour with the nearest neighbour to each other. When observing figure 5.21 and figure 5.27 the spectral distribution is similar. For longer step sizes as seen in figure 5.23 and figure 5.29 an edge is visible for the next neighbour method when the car passes the screen. The previous method on the other hand has a steep edge in the end of the spectogram thus depicting the pass by in a smoother way. The Nearest neighbour method has a spectral content very similar to the nearest neighbour method. The observed difference is explained by the algorithms of the method, namely that the previous neighbour emphasize the values behind the interpolated point while next just as the name indicates does vice versa. At the point where the screen does not shield the sound there is a clear and steep edge in the spectograms belonging to the non continuous methods and the step like behaviour is clear. for smaller increments the steps become sufficiently small that the auralised sound become smooth. A spline method such as pchip , please see figures 5.24 ,5.25 and 5.26, manage to form a continuous time signal even at longer step sizes. When observing figures 5.24 and 5.25 more closely a small difference is notable with respect to frequency content, both in low frequencies and the higher bands. Shorter discretisation steps seem to catch more energy. Furthermore the spline interpolation like pchip or makima seems to smooth the barrier effect at longer step sizes which is visible in figure 5.26.

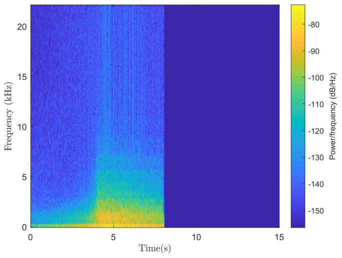

Figure 5.15: Linear interpolation at 0.0156 m.

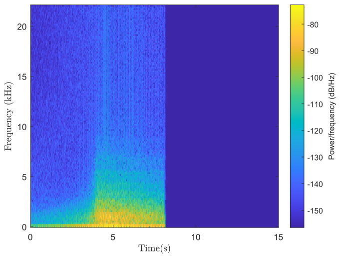

Figure 5.16: Linear interpolation at 1 m.

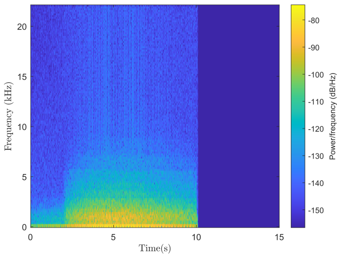

Figure 5.17: Linear interpolation at 20 m.

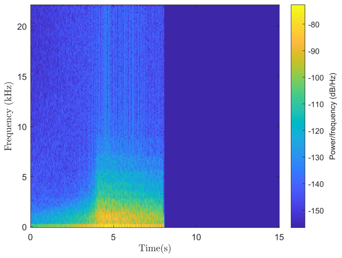

Figure 5.18: Nearest neighbour interpolation at 0.0156 m.

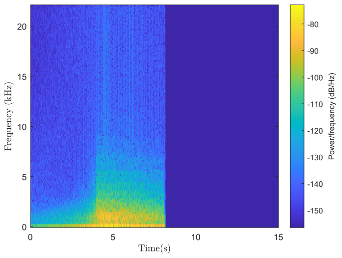

Figure 5.19: Nearest neighbour interpolation at 1 m.

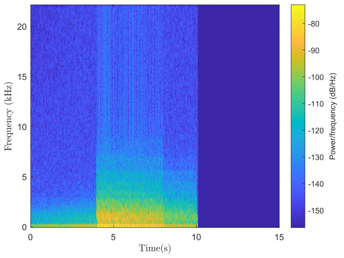

Figure 5.20: Nearest neighbour interpolation at 20 m.

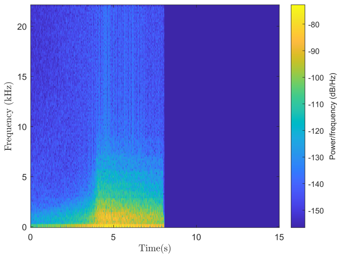

Figure 5.21: Next neighbour interpolation at 0.0156 m.

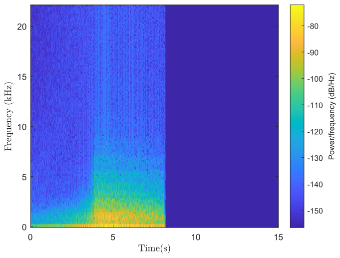

Figure 5.22: Next neighbour interpolation at 1 m.

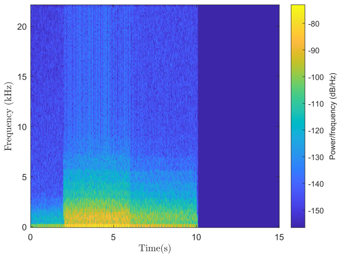

Figure 5.23: Next neighbour interpolation at 20 m.

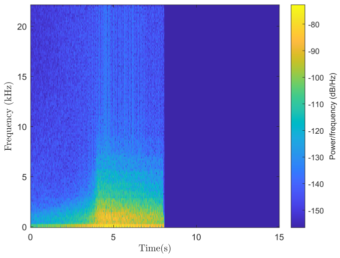

Figure 5.24: pchip interpolation at 0.0156 m.

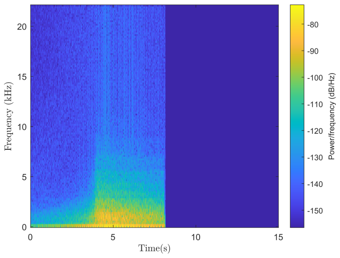

Figure 5.25: pchip interpolation at 1 m.

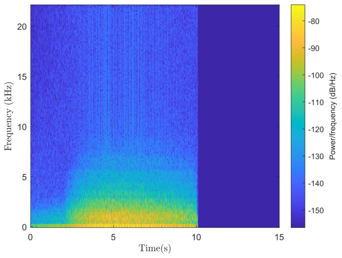

Figure 5.26: pchip interpolation at 20 m.

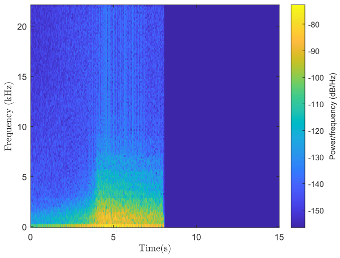

Figure 5.27: previous neighbour interpolation at 0.0156 m.

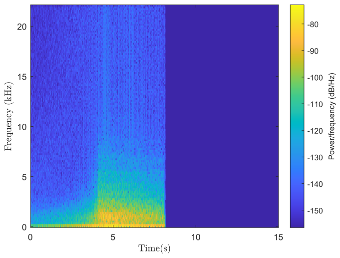

Figure 5.28: Nearest neighbour interpolation at 1 m.

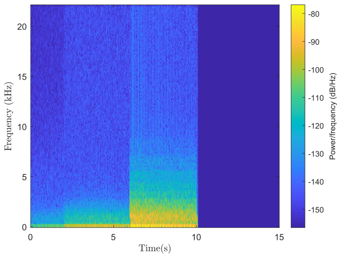

Figure 5.29: Nearest neighbour interpolation at 20 m.

5.2.3 Doppler and no screen

A situation depicting a pass by without screen and Doppler considered is shown in figure 5.30 to figure 5.32. Linear interpolation method is used in these figures as it is representative for the cases. Similar to the first situation when the pass by did not include Doppler related effects there are less differences between the the interpolation methods The overall trends are similar. Longer step sizes result in longer signals.

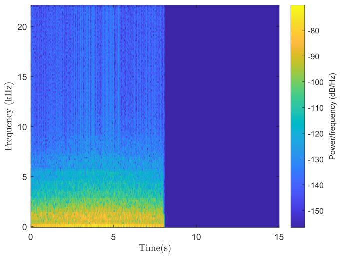

Figure 5.30: Linear interpolation at 0.0156 m.

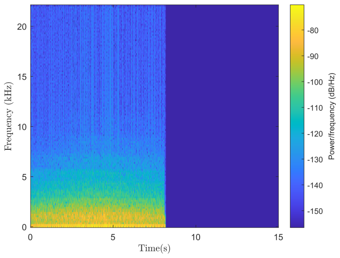

Figure 5.31: Linear interpolation at 1 m.

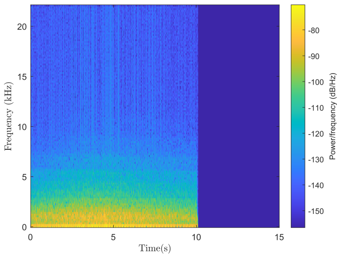

Figure 5.32: Linear interpolation at 20 m.

5.2.4 No Doppler screen

The fourth situation consist of a pass by including a screen but not considering the Doppler effect. The results in figure 5.33 to figure 5.47 show results that is similar to the case where the Doppler effect was considered while a car was passing by a screen. The discontinuous methods show clear edges for long interpolation steps while continuous methods such as splines clearly smooth the curves.

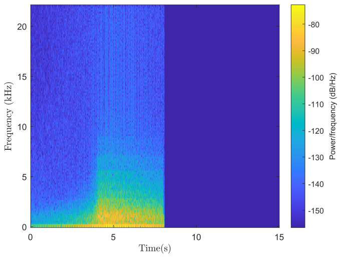

Figure 5.33: Linear interpolation at 0.0156 m.

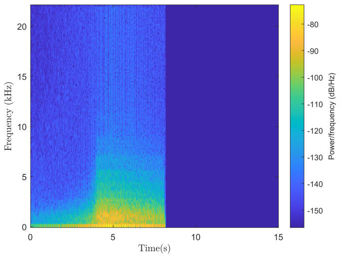

Figure 5.34: linear interpolation at 1 m.

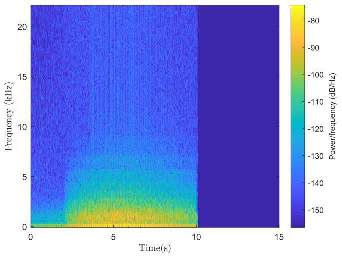

Figure 5.35: Linear interpolation at 20 m.

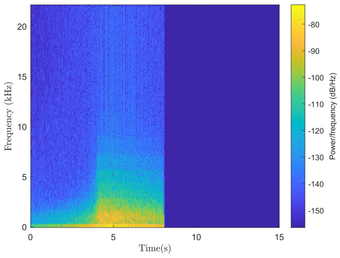

Figure 5.36: Nearest neighbour interpolation at 0.0156 m.

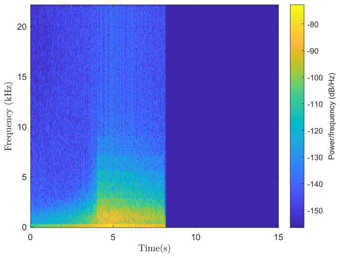

Figure 5.37: Nearest neighbour interpolation at 1 m.

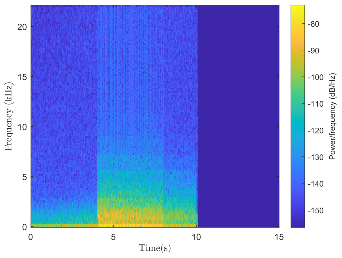

Figure 5.38: Nearest neighbour interpolation at 20 m.

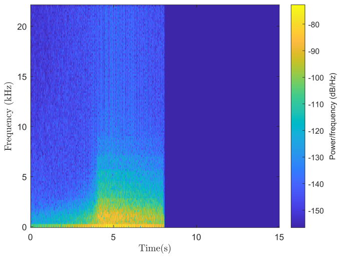

Figure 5.39: Next neighbour interpolation at 16 mm.

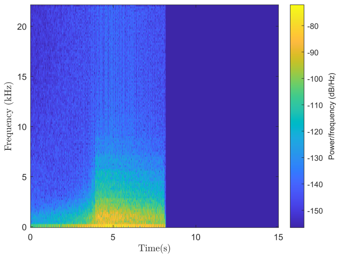

Figure 5.40: Next neighbour interpolation at 1 m.

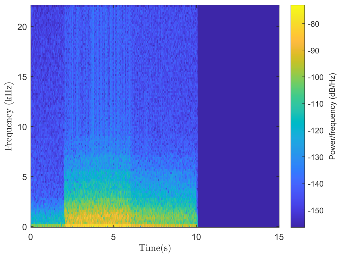

Figure 5.41: Next neighbour interpolation at 20 m.

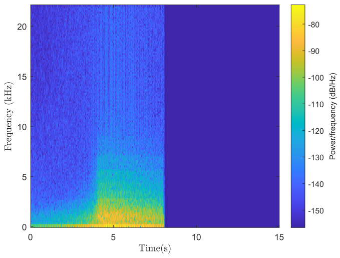

Figure 5.42: pchip interpolation at 0.0156 m.

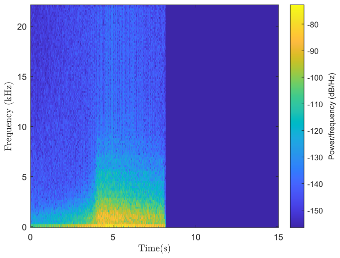

Figure 5.43: pchip neighbour interpolation at 1 m.

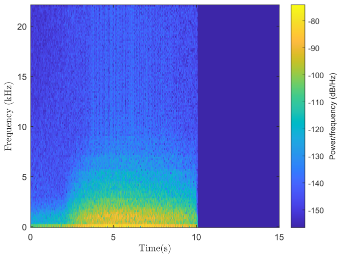

Figure 5.44: pchip interpolation at 20 m.

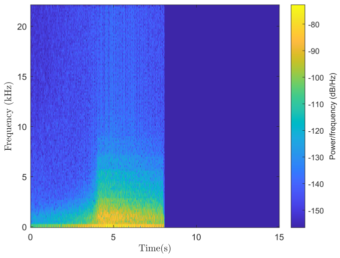

Figure 5.45: Previous neighbour interpolation at 0.0156 m.

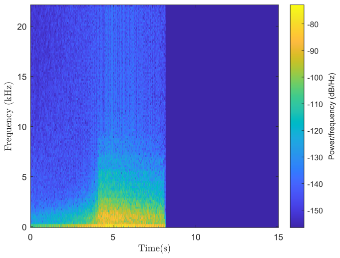

Figure 5.46: Previous neighbour interpolation at 1 m.

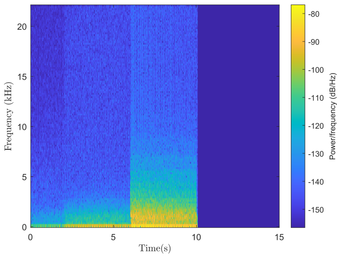

Figure 5.47: previous neighbour interpolation at 20 m.

5.3 Listening tests

A listening test was performed and it was found that the steep steps which were depicted in the previous sections for discontinuous methods were also audible. For finer increments they produced adequate auralisations. For increments greater than about 1 meter the threshold was clearly audible and could not be regarded as depicting a realistic pass by. The continuous methods such as splines and the linear interpolation which has a more sophisticated way of smoothing the functions all performed adequate auralisations even at long step sizes.

5.4 A-weighted levels

An A-weighting filter was designed according to ANSI-standard which performed frequency domain filtering. Table A.33 to table reftab:v50 lgt ice Aw. A noticeable difference with respect to A-weighted levels is defined as 1 DB(A). Only Previous neighbour method displays such a value at 20 meter discretisation when comparing to other incremental values within the method as well as compared to the other methods. Overall for all methods there is a correlation between smaller increments and larger density of energy. At a distance of 0.125 m and smaller the incremental steps seem to have less impact on the energy content. The correlation in this case is higher for the continuous methods such as linear interpolation, makima spline and pchip interpolation method. These trends are consistent regardless of vehicle type or velocity. It is however worth to notice that the A-weighted levels are for vehicles with internal combustion engine than the ones which are driven by electric motor. The difference is just below 1 dB(A). The same difference was also noticed between the two different speeds. Vehicles at 50 km/h showed higher dB(A) values compared to the ones travelling at 40 km/h.

5.5 Comparison with Edge diffraction toolbox

Table 5.1 shows the RMS error between the signals from EDT and the signals obtained by using the Pierce solution. Some differences are seen in the table along with some trends. The Next neighbour method display the largest differences compared to the EDT for all discretisation steps. Furthermore there is indications of increasing RMS error with larger incremental steps, save for the largest step size which is 20 m. This however is not valid in the case Previous neighbour method which display the opposite behaviour.

Table 5.1: Root mean square error comparison for all interpolation methods at 12 discretisations between infinite barrier model according to Pierce solution and Edge diffraction model.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.00073362	0.00073362	0.0007336	0.00073379	0.00073362	0.00073348
0.0313	0.00073361	0.00073361	0.00073363	0.00073389	0.00073361	0.00073329
0.0625	0.00073364	0.00073364	0.00073359	0.00073428	0.00073364	0.00073307
0.125	0.00073366	0.00073366	0.00073382	0.00073459	0.00073367	0.0007322
0.25	0.00073375	0.00073372	0.0007336	0.00073661	0.00073372	0.00073166
0.5	0.00073447	0.00073447	0.00073435	0.00073905	0.00073448	0.00072956
1.0	0.00073512	0.00073519	0.00073422	0.00074527	0.00073519	0.00072632
2.0	0.00074054	0.0007409	0.00073998	0.00075831	0.00074095	0.0007194
4.0	0.00074159	0.00074312	0.00073774	0.00077816	0.00074301	0.00070704
5.0	0.00074265	0.0007445	0.00073973	0.00078244	0.00074441	0.00069647
10.0	0.00075798	0	0.00075931	0.00082497	0.00076468	0.0006536
20.0	0.00070641	0	0.00071644	0.00080845	0.0007329	0.00051613

5.6 Psychacoustical analysis

The difference between the psychoacoustic values was determined in two different ways. Consider table B.1 as an example which consists of interpolated values for 6 methods arranged horizontally at 12 interpolation increments which are vertically ordered. First analysis consisted of calculating the difference between the values vertically for each column and comparing with JND, please see table 5.2, for each psychoacoustic metric to determine if there is an adequate difference between them and at which increment it occur. In practice this is done by for example subtracting the value at Δ =20 with the previous result at Δ =10. The first case thus aims at determining if there is distance within the interpolation algorithm which indicate an audible difference.

Second the interpolation algorithms were compared with each other thus calculating the difference between the algorithms for a fixed length to investigate if there are distances of certain interest. The differences were calculated for the psychoacoustic metrics which are mentioned in table 5.2.

Table 5.2: Just noticeable differences (JND) for psychoacoustic metrics.

Metric	M
Loudness	0.5 (sone)
Sharpness	0.04 (acum)
Roughness	0.03 (asper)
Fluctuation	0.01 (vacil)

Two different scenarios where evaluated. One of them including a barrier while the other where without barrier. Furthermore the effects of the Doppler factor and the Doppler effect where evaluated. Auralised signals consisted of a heavy vehicles and a light vehicles, driving at 40 km/h and 50 km/h. Two different engines, a internal combustion engine and an electric engine, where evaluated. In total 32 scenarios were evaluated.

5.6.1 No barrier and no Doppler effect

When investigating the differences between the signals with respect to the metrics shown in table 5.2 some trends are clear. Analysis of acoustic sharpness showed no values larger than 0.04 acum. The loudness analysis showed the same results. The Roughness analysis however showed notable differences for the scenarios with light vehicles. The case with electric engine showed that the Next neighbour differed relative to all the other methods in the step-size 10 to 20 meters. The case with internal combustion engine showed such difference for previous neighbour versus all other methods at step-size 4 to 5 meters. This interval also showed a value larger than JND intra method for the same method. Regarding fluctuation, differences intra method were noticed for all scenarios and all methods in the two intervals 5 to 10 and 10 to meters.

5.6.2 No barrier and Doppler effect

The scenario with a barrier and also considering the Doppler effect showed that fluctuation was affected to a great extent in the same manner as during the previous scenario save for light vehicles passing by at 40 km/h. Acoustic roughness showed notable differences in the interval 0.0625 to 0.125 and 0.125 to 0.5 meters , within the method.

5.6.3 Barrier and no Doppler effect

The third analysis which included a barrier while not considering effects of the Doppler factor showed results which differed considerably compared to the previous cases without barrier. Differences larger than JND was more frequent regardless of metric. Regarding acoustic loudness the previous neighbour method showed such values for the interval 10 to m´20 meters. For electric motors the differences occurred relative to the other methods while internal combustion motors showed differences intra method. Regarding fluctuation the methods Nearest neighbour and next neighbour differed intra method in the interval 10 to 20 meters. For the same interval all differed larger than JND relative to each other. In the interval 5 to 10 meters some differences where noticed between continuous methods relative to the discontinuous ones. During the acoustic sharpness investigation differences were only noticed for the heavy vehicle with internal combustion engine at both speeds. This was noticed for previous method relative to all the other methods at the interval 10 to 20 meters. Differences with respect acoustic roughness were less frequent and the only occurrence was noticed for the previous neighbour method relative to all other methods at the distance 10 to 20 meters, for light vehicle with electric motor.

5.6.4 Barrier and Doppler effect

The fourth scenario showed some trends. The loudness analysis showed that all methods differed relative to each other in the interval 10 to 20 meters. The scenarios with heavy vehicle with internal combustion engine at 40 and 50 km/h also had differences at the interval 5 to 10 meters for previous neighbour relative to the others. Differences intra method was also noticed in the interval 10 to 20 meters for the same method at these velocities. Fluctuation analysis showed that in the interval 10 to 20 that all methods differed relative to each other for all vehicles cases except heavy vehicle with electric motor at 40 km/h. Furthermore the nearest and next neighbour method showed differences intra method for all cases in the interval 10 to 20 meters. While acoustic sharpness did not yield any significant differences they where more frequent in the case of acoustic roughness. All methods differed relative to each other at the interval 10 to 20 meters for heavy vehicle ´with internal combustion engine at 40 km/h along with light vehicle at 50 km/h both types of motor. Nearest and previous method showed differences relative to other methods as well as intra method at shorter distances such as 1 to 2 meters for the case with a light vehicle at both 40 km/h and 50 km/h. At 50 km/h nearest also differed relative to linear method at the distance 0.125 to 0.5 meters. This velocity showed that the discontinuous methods previous and nearest method had a tendency to differ within the method at 2 to 4 meters.

5.6.5 Psychoacoustic annoyance

The results from the psychoacoustic annoyance metric are shown in table B.1 to table B.32. Four different scenarios where analysed. There where two different pass by scenarios, namely one including a noise barrier while the other depicted a pass by without a noise barrier. Each of them where analysed with the Doppler effect as well as without the Doppler effect. A correlation between size of increments and increased annoyance is with some exceptions observed for all cases. This is visible in Figure 5.48 to 5.55. For electric motors small discretisation steps the choice of method seem to be of less importance compared to larger increments. This is visible in figure 5.48 and 5.50. This behaviour is far less pronounced for the cases including an internal combustion engine. Please see table B.1 and table B.2, which show a scenario without barrier and not considering the Doppler effect, as reference for this comparison. The behaviour is visible in figure 5.51 Furthermore it is clear that an internal combustion engine is more annoying than an electric motor. Speed also has an impact which is visible in table B.1 and table B.5. When comparing table B.1 with B.9 where the first one shows a pass by without screen and not considering the Doppler effect and the later one shows results for the same scenario but the Doppler effect considered, some differences are visible. Namely that the Psychoacoustic annoyance values are somewhat larger when the Doppler effect is considered. The discontinuous method also shows slightly higher values compared to Linear interpolation and the splines. It is also noticed when comparing figures 5.49 and 5.51 to figures 5.48 and 5.50 that internal combustion engines are perceived as more annoying with larger incremental steps compared to the electric ones which display opposite behaviour

Introducing a sound barrier results in larger variations between methods for a wider range of discretisation steps. This is especially evident in for example table B.17 and B.17 where there is less consistency between increments size and method. These results are also visible in figure 5.52 to 5.55. For internal combustion engines the results are however more similar to the case without barrier with respect to stable values. The choice of method is of less importance at least for small step sizes. Just as in the previous case without barrier the Doppler effect give slightly larger values compared to the same scenario without Doppler. The auralised signals with a wall does not show the same tendencies as the case without a wall. All cases show that larger discretisation steps lead to less acoustic annoyance compared to smaller steps

Figure 5.48 and 5.50 also show the differences noticed in the analysis of JND. Namely that introducing a barrier leads to larger discrepancies between the methods. Since acoustic annoyance metric is combination of the four previously analysed metrics it is intuitive that the these differences will also occur in this combined metric.

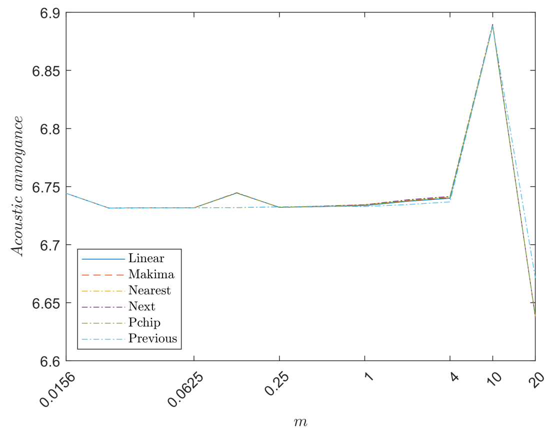

Figure 5.48: Heavy vehicle with electric motor 40 km/h. Without barrier.

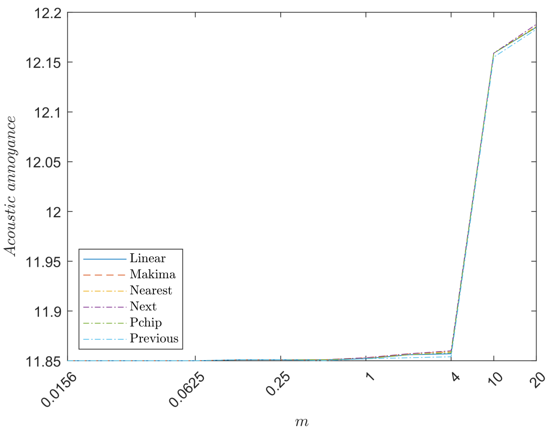

Figure 5.49: Heavy vehicle with internal combustion engine 40 km/h. Without barrier.

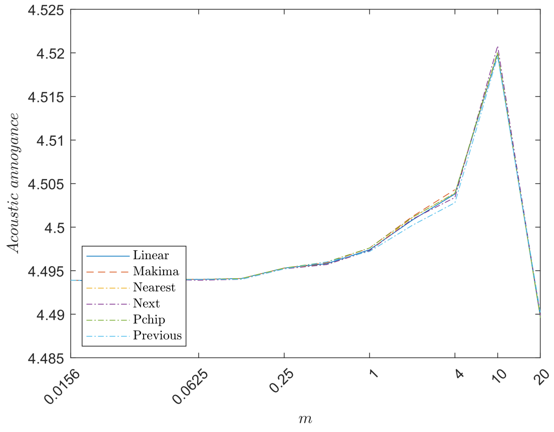

Figure 5.50: Light vehicle with electric motor 40 km/h. Without barrier.

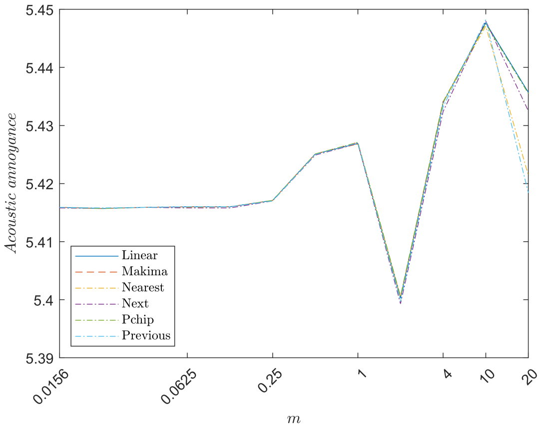

Figure 5.51: Light vehicle with internal combustion engine 40 km/h. Without barrier.

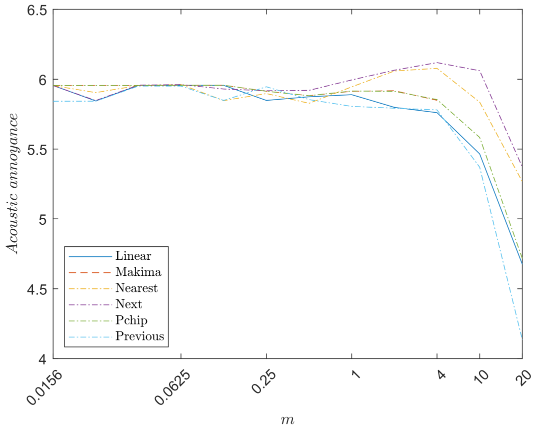

Figure 5.52: Heavy vehicle with electric motor 40 km/h. With barrier.

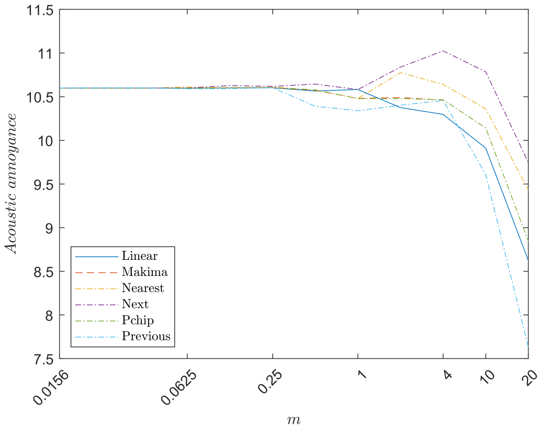

Figure 5.53: Heavy vehicle with internal combustion engine 40 km/h. With barrier.

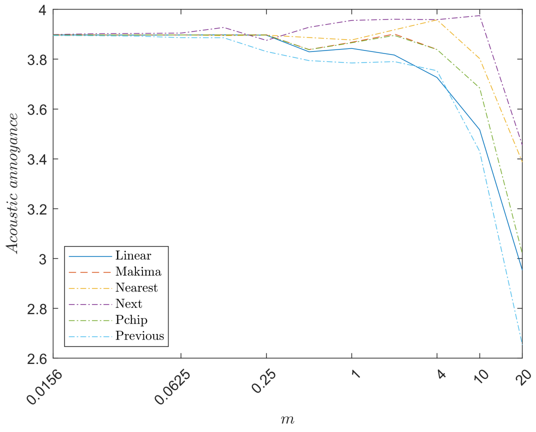

Figure 5.54: Light vehicle with electric motor 40 km/h. With barrier.

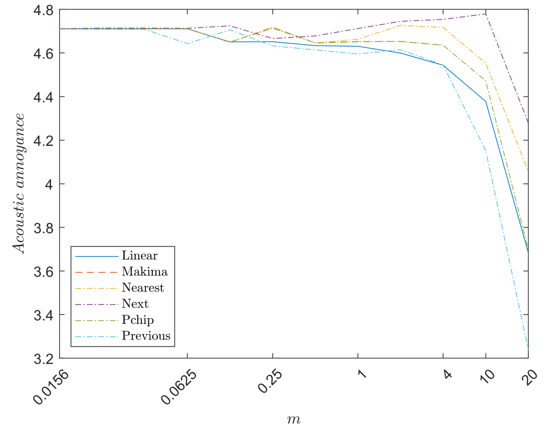

Figure 5.55: Light vehicle with internal combustion engine 40 km/h. With barrier.

5.7 Doppler effect

The investigation compared two scenarios. A pass by with a noise barrier which has been described in the Theory part. The other case depicted a pass by without noise barrier. The scenario with a a pass by at 40 km/h was chosen.

5.8 Psychoacoustical analysis

During the psychoacoustical analysis of the Doppler effect sound signals from the 40 km/h pass by were used. By calculating the difference between estimated psychoacoustic values from the previous section it is possible to determine whether there are noticeable differences between a situation considering the Doppler effect and a situation neglecting the Doppler effect. The result were compared to table 5.2. Furthermore the results also yield information about the Doppler effects overall impact on loudness, sharpness, roughness and acoustic annoyance.

5.8.1 No barrier

5.8.2 Acoustic loudness

Table B.33 displays the result of subtracting values in the table A.41 from table A.1. Analogous B.34 is the result of subtraction of A.41 from A.2. When inspecting table B.33 along with B.34 while comparing with JND for acoustic loudness it evident that the single values of loudness calculation did not yield any results higher than JND. These differences are also shown in figure 5.56 to 5.59. The largest difference however a factor 10 less than JND was found for heavy vehicle with internal combustion engine. The difference increased with longer discretization steps. This trend was true for all types of vehicles and all methods in table. The tables B.33 to B.36 indicate that neglecting the Doppler effect and the Doppler factor overestimate acoustic loudness, however to an extent significantly lower than JND. Results for all methods seem to converge for smaller increments. Furthermore the dicretization steps seem to have larger impact on the difference than choice of interpolation method. It has been noticed that considering the Doppler effect increase the acoustic loudness. Since the Doppler shift alter the wave length thus also shifting the frequency to higher levels a larger portion of the noise is attenuated by air absorption. The air absorption is significant in the higher frequency regions. Since the loudness sensation is along with intensity dependant on frequency it is possible that the Doppler effect has an indirect attenuating effect on the noise. It is also evident when inspecting the mentioned tables that neglecting the Doppler effect has a bigger impact when assessing noise from heavy vehicles.

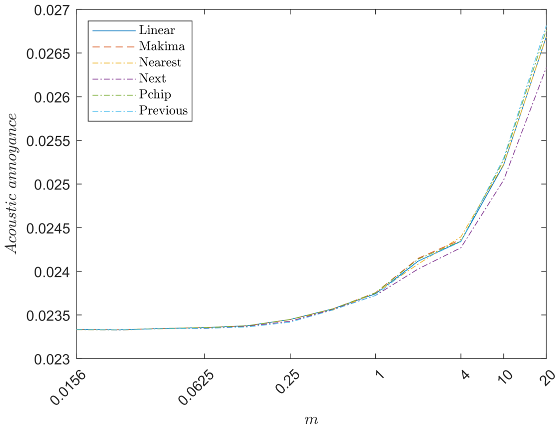

Figure 5.56: Heavy vehicle with electric motor 40 km/h.

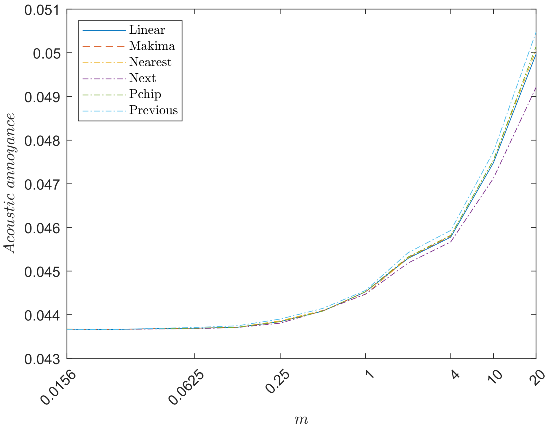

Figure 5.57: Heavy vehicle with internal combustion engine 40 km/h.

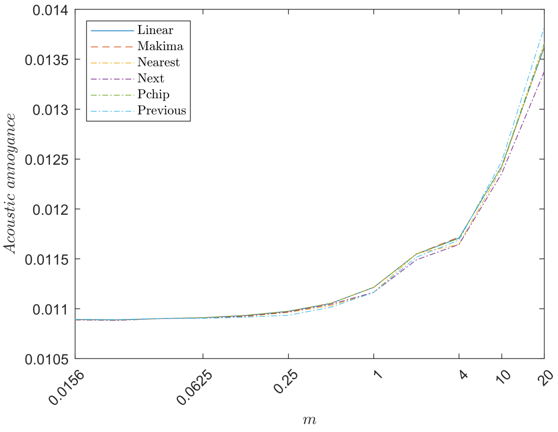

Figure 5.58: Light vehicle with electric motor 40 km/h.

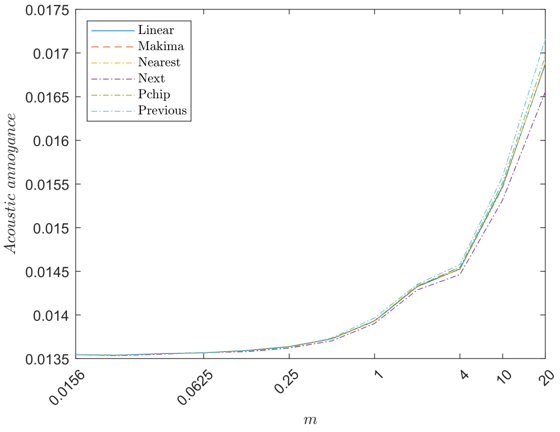

Figure 5.59: Light vehicle with internal combustion engine 40 km/h.

5.8.3 Acoustic sharpness

The analysis for acoustic sharpness was done in the same manner as in the previous section. Table B.37 to B.40 all show the result of subtracting sharpness values found in Appendix A. These differences are shown in figure 5.60 to 5.63. Similar to the case of acoustic loudness there were no values larger than JND. The trends was similar to loudness analysis indicating higher values with increasing increments and smaller differences for shorter step sizes. Choice of method was also found less important than incremental steps when assessing the effect of Doppler effect. The values in the B.37 to B.40 indicate that the density of higher frequency content is higher when the Doppler effect is not considered. The Doppler effect is known for shifting frequencies, which has been mentioned in the previous sections. The shift along with air absorption is a plausible explanation to the lower sharpness values when considering the Doppler effect. Just as in the previous case the values a larger for heavy vehicles compared to lighter vehicles.

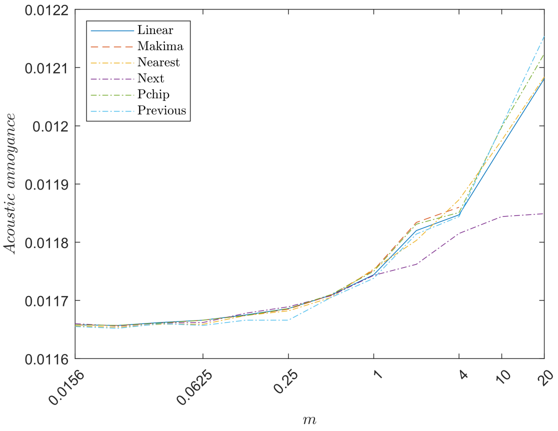

Figure 5.60: Heavy vehicle with electric motor 40 km/h.

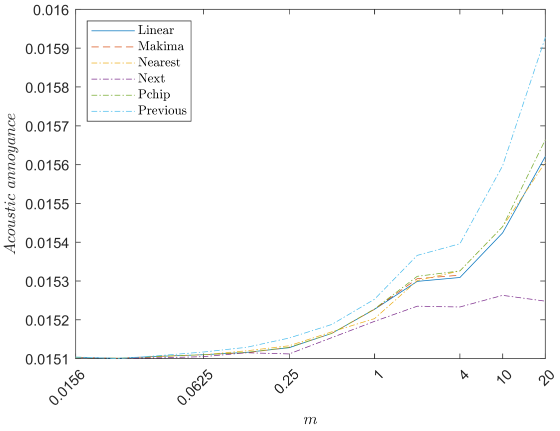

Figure 5.61: Heavy vehicle with internal combustion engine 40 km/h.

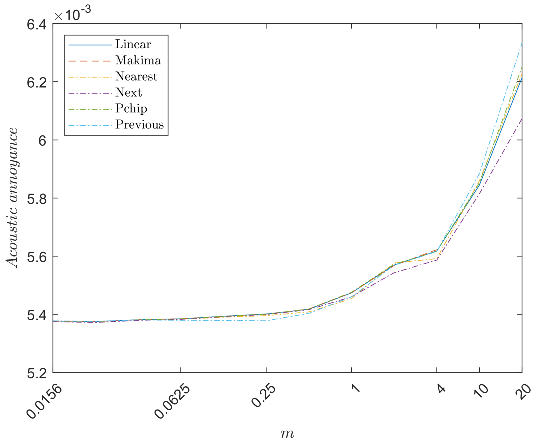

Figure 5.62: Light vehicle with electric motor 40 km/h.

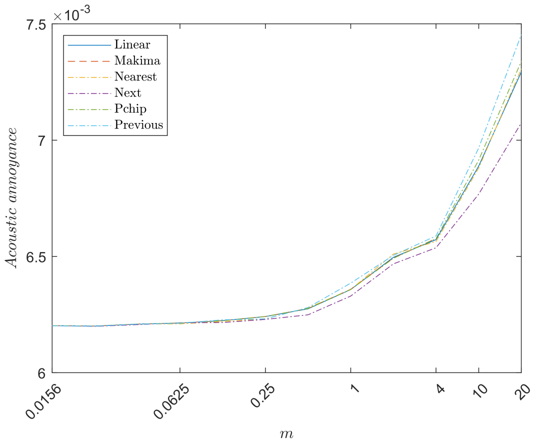

Figure 5.63: Light vehicle with internal combustion engine 40 km/h.

5.8.4 Acoustic roughness

The results from the difference between considering the Doppler effect and not considering it are visible in tables B.41 to ref B.44. The results are compared to the just noticeable value for acoustic roughness which is 0.03 asper. These differences are shown in figure 5.64 to 5.67. For a pass by without screen with electric motor no values larger then 0.003 were found. Differences were however largest for increasing incremental steps. For the same scenario but with an internal combustion engine such differences were found for all step sizes. The character of the internal combustion engine and more rough sound is a possible explanation for the difference between the motor types.

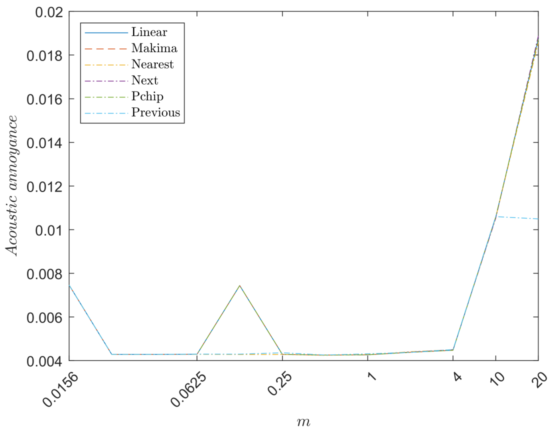

Figure 5.64: Heavy vehicle with electric motor 40 km/h.

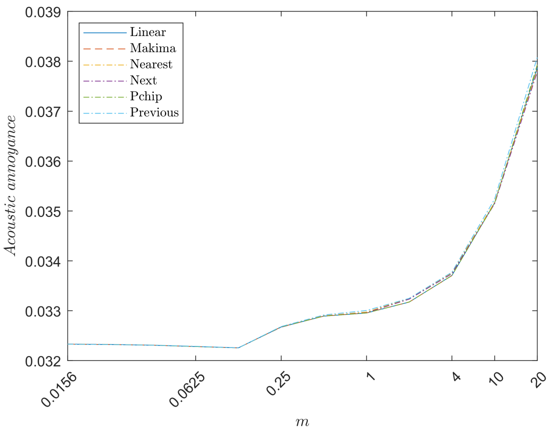

Figure 5.65: Heavy vehicle with internal combustion engine 40 km/h.

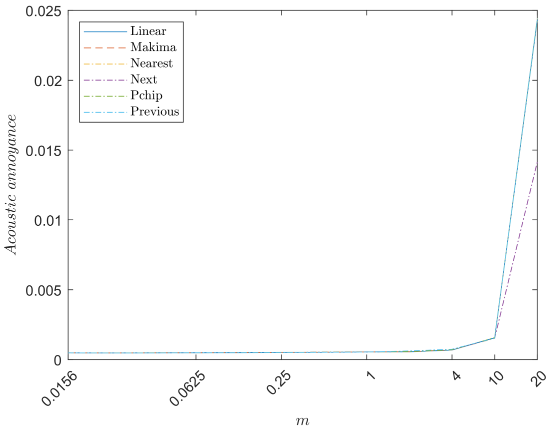

Figure 5.66: Light vehicle with electric motor 40 km/h.

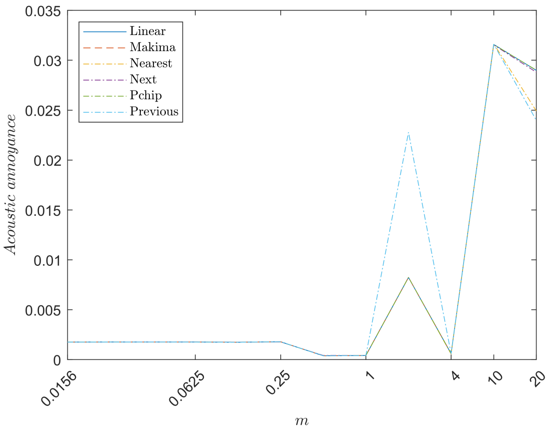

Figure 5.67: Light vehicle with internal combustion engine 40 km/h.

5.8.5 Fluctuation

When acoustic fluctuation was compared no values larger than the JND of Vacil were found regardless of scenario or motor type. The differences however seem to increase for shorter discretisation steps which is visible in figure 5.68 to 5.71. Just as in the case of Psychoacoustic annoyance the choice of method also seems to be of less importance for shorter step sizes.

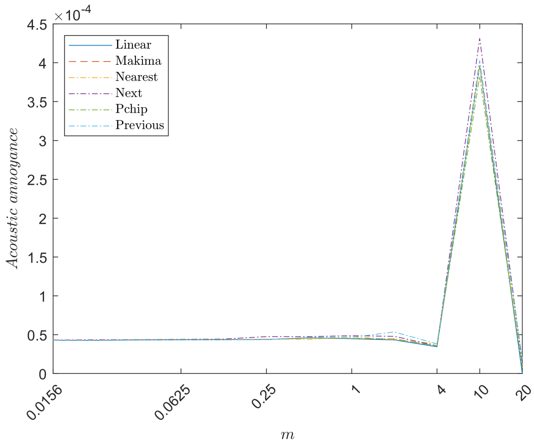

Figure 5.68: heavy vehicle with electric motor 40 km/h.

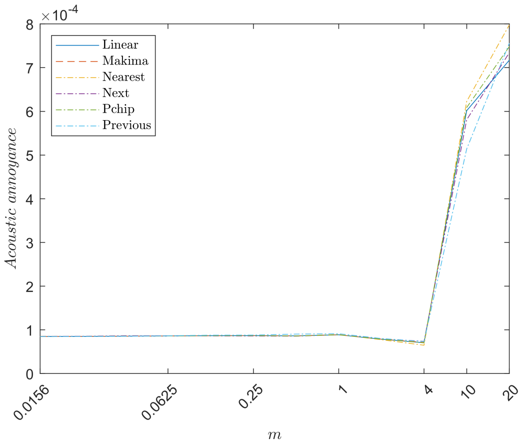

Figure 5.69: Heavy vehicle with internal combustion engine 40 km/h.

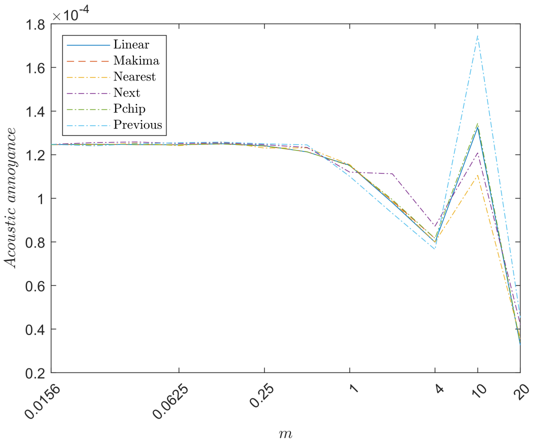

Figure 5.70: Light vehicle with electric motor 40 km/h.

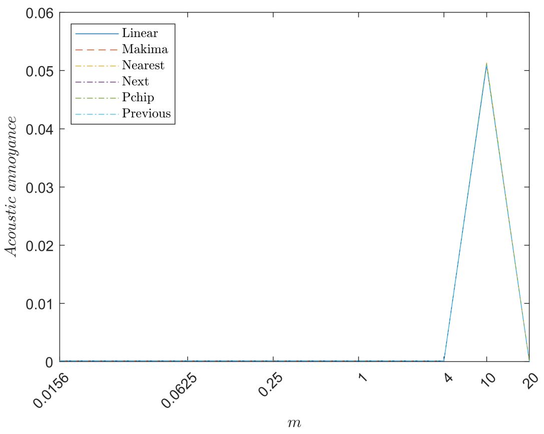

Figure 5.71: Light vehicle with internal combustion engine 40 km/h.

5.8.6 Barrier

Introducing a barrier does not affect the difference to an extant large enough to produce a value larger than JND for any of the metrics. The figures for non barrier case are also representative for the with barrier. The differences in loudness however increase with larger step sizes. Just as in the cases for the scenario without barrier the differences are larger for the car with internal combustion engine, especially the heavy type.

The differences in acoustic roughness were somewhat smaller compared to the scenario without a barrier and no value larger than 0.03 asper was found. However the trend points towards increasing differences for larger step sizes.

The analysis of fluctuation and sharpness did not yield any differences larger than JND. There were no significant trends that differed with respect to the case without barrier.

5.9 General recommendations

For discretisation steps larger than 0.25 meters it is advised to use continuous methods such the Makima spline or linear interpolation since they perform more realistic auralisations. Since real world application sometimes require larger increments than 0.25 when calculating sound propagation one of these two above mentioned should be used as a default method instead of the discontinuous ones.

6

Conclusion

Interpolation of sound propagation transfer functions in frequency domain for a moving source has been studied with application to auralisation of vehicle pass-by. Six different interpolation algorithms have been investigated,namely Linear interpolation, modified Akima spline (makima), nearest neighbour, next neighbour, pchip and previous neighbour. The resulting auralised sounds have been evaluated by quantification with physical parameters as well as psychoacoustical parameters. The Doppler effect and Doppler factor was also analysed. Regarding the quantification of computational time it is safe to conclude that the pchip method is computationally heavier compared to the other methods. It is followed by the next and previous neighbour methods which are both discontinuous methods. However, the nearest neighbour method, which is also a discontinuous method, showed computation times similar to linear interpolation and the makima spline. Computational time is of great importance in noise mapping applications. However, the quality has to be considered in addition to the computational cost. Quantitative informal listening tests were performed, where the discontinuous methods were clearly distinguishable from the continuous ones when step sizes grew larger. The effects of the discretisation steps where clearly audible and also visible in plotted spectrograms, and one can without effort distinguish an auralisation calculated with a continuous method from an auralisation made by a discontinuous method. For smaller step sizes however, the signals become more similar to each other both from an audible perspective as well as from a quantitative aspect, e.g. the spectogram analysis. This also strengthens the conclusion that choice of method becomes less important for shorter step sizes. It was also noticed that the continuous methods produced better auralisations than the non-continuous ones.

From a psychoacoustical perspective, with the sounds evaluated with respect to just noticeable difference (JND), it is also safe to conclude that smaller step sizes lead to increasing similarity between the methods. Overall the differences were smaller than JND when comparing between methods as well as intra-methods. Some trends were however observed. The differences were larger when a barrier was introduced or when considering the Doppler effect. Overall, regardless of scenario and Doppler effect, the differences usually occur at step sizes from 10 meters and up to 20 meters. This was especially pronounced in the case of acoustic fluctuation and roughness both displaying the cases where values larger than their respective JND appeared. Overall the differences were larger intra-method between the sizes of increments than between the methods at the same step size, which further indicates that differences become more pronounced at increasing step sizes. The methods which were most frequently involved when differences occurred were the nearest neighbour and next neighbour methods, which are both discontinuous. The psychoacoustic annoyance, considering the combined effect of the four psychoacoustic metrics, also points towards increased dependence on method at larger step sizes. This was especially pronounced for internal combustion engine sounds. The cases which included a barrier showed somewhat more varying values but the trend still points towards the previous conclusion about shorter step sizes and less dependence on method. At the largest step size the variation seems to decrease. This is most probably a result of the large step size which does not manage to catch enough frequency and energy content and the validity of these values is judged as low. A comparison using the Edge Diffraction Tool box was also performed, as well giving results indicating similarity for smaller increments. However for large step sizes the results showed inconsistent behaviour.

The influences of the Doppler effect and the Doppler factor were also evaluated separately. Some differences were noticed between a scenario considering the Doppler effect and not considering it. Just as in the previous cases without Doppler related effects the differences between methods increased with larger step sizes. Larger differences were usually noticed when an electric motor was simulated. As previously mentioned in the theory part the Doppler effect and especially the Doppler factor has a strong velocity dependence and the impact increases when the ratio between source velocity and speed of sound approaches unity. The low velocities compared to the speed of sound offer a plausible explanation to the different results which were observed when evaluating the differences between a case with Doppler factor and a case without Doppler factor.

In conclusion it has been noticed that there are considerable differences between the method and the choice of step size. Optimizing the algorithms saves time as well as money. It can be achieved by using efficient interpolation algorithms. The investigation of interpolation performance can be improved by using listening tests with a large number of participants. Even though some of the differences, such as comparing discontinuous methods to continuous ones at larger increments, are obvious and do not require a large set of listeners, it is possible that further conclusions may be drawn. Regarding the impact of the Doppler factor it is suggested to perform evaluations at slightly higher velocities, which would enhance its impact on the signal, both by spectral analysis and with listening tests. However one can conclude that the Doppler factor had an impact but not to a large extent.

Taking both computational time and auralisation quality into consideration the modified Akima spline along with linear interpolation distinguish themselves by managing to perform auralisations of good quality at a low computational times. This was verified by listening tests. The nearest neighbour method displays similar computation times as the modified Akima spline and linear interpolation, however the method demands shorter step sizes to be able to perform adequate auralisations thus increasing the computational time. Overall the continuous methods were shown to outperform the discontinuous methods for step sizes of 1 to 20 meter, for the situations studied.

During the analysis of the acoustic annoyance metric it was noticed that annoyance for electric motors, passing by without a barrier, were considerably lower at large step sizes compared to short ones. The opposite was noticed for internal combustion engines. When a barrier was introduced the acoustic annoyance was considerably lower at larger step sizes compared to short ones, regardless of motor type. Choosing a large step sizes might lead to either an overestimation or underestimation of the annoyance depending on situation and vehicle type. Taking this into account, longer discretisation steps than 0.25 meter should be avoided. Considering a limit at 0.25 meter, the nearest neighbour is a potential contender since it performed adequate at shorter step sizes, however it does not match the modified Akima spline and linear interpolation.

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A

Appendix 1

A.1 No barrier and no Doppler effect

A.1.1 Loudness values

Table A.1: Acoustic loudness (sones) for heavy vehicle with an electric motor at a pass-by recorded at 40 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	3.5804	3.5804	3.5804	3.5804	3.5804	3.5804
0.0313	3.5802	3.5802	3.5802	3.5802	3.5802	3.5802
0.0625	3.5806	3.5806	3.5806	3.5806	3.5806	3.5806
0.125	3.5809	3.5809	3.5809	3.5809	3.5809	3.5809
0.25	3.5814	3.5814	3.5814	3.5813	3.5814	3.5814
0.5	3.5837	3.5837	3.5837	3.5837	3.5837	3.5837
1	3.5871	3.5871	3.5871	3.5871	3.5871	3.5871
2	3.5934	3.5935	3.5935	3.5933	3.5935	3.5934
4	3.6054	3.6057	3.6055	3.605	3.6056	3.6053
5	3.6123	3.6126	3.6125	3.6117	3.6126	3.6122
10	3.6386	0	3.6393	3.6364	3.6398	3.6381
20	3.6785	0	3.6809	3.6717	3.6813	3.6769

Table A.2: Acoustic loudness (sones) for heavy vehicle with an internal combustion engine at a pass-by recorded at 40 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	6.8672	6.8672	6.8672	6.8672	6.8672	6.8672
0.0313	6.867	6.867	6.867	6.867	6.867	6.867
0.0625	6.8676	6.8676	6.8676	6.8676	6.8676	6.8676
0.125	6.8678	6.8678	6.8678	6.8678	6.8678	6.8678
0.25	6.8684	6.8684	6.8684	6.8684	6.8684	6.8685
0.5	6.872	6.872	6.872	6.872	6.872	6.8721
1	6.8777	6.8777	6.8777	6.8776	6.8777	6.8777
2	6.8886	6.8887	6.8885	6.8884	6.8887	6.8886
4	6.911	6.9114	6.9111	6.9102	6.9114	6.9109
5	6.9235	6.9241	6.9237	6.9224	6.9241	6.9234
10	6.967	0	6.9683	6.9631	6.9691	6.9661
20	7.03	0	7.0346	7.0175	7.0351	7.027

Table A.4: Acoustic loudness (sone) for light vehicle with an internal combustion engine at a pass-by recorded at 40 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	2.7111	2.7111	2.7111	2.7111	2.7111	2.7111
0.0313	2.711	2.711	2.711	2.711	2.711	2.711
0.0625	2.7113	2.7113	2.7113	2.7113	2.7113	2.7113
0.125	2.7116	2.7116	2.7116	2.7115	2.7116	2.7116
0.25	2.7121	2.7121	2.7121	2.7121	2.7121	2.7121
0.5	2.7144	2.7144	2.7144	2.7144	2.7144	2.7144
1	2.7171	2.7171	2.7171	2.7171	2.7171	2.7172
2	2.7232	2.7232	2.7232	2.723	2.7232	2.7233
4	2.735	2.7352	2.7351	2.7346	2.7352	2.7353
5	2.7415	2.7417	2.7416	2.7408	2.7417	2.7417
10	2.7654	0	2.7658	2.7635	2.7661	2.7657
20	2.8026	0	2.804	2.7974	2.8045	2.8029

Table A.3: Acoustic loudness (sone) for light vehicle with an electric motor at a pass-by recorded at 40 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	2.1841	2.1841	2.1841	2.1841	2.1841	2.1841
0.0313	2.1839	2.1839	2.1839	2.1839	2.1839	2.1839
0.0625	2.1842	2.1842	2.1842	2.1842	2.1842	2.1842
0.125	2.1844	2.1844	2.1844	2.1844	2.1844	2.1844
0.25	2.1849	2.1849	2.1849	2.1849	2.1849	2.1849
0.5	2.1869	2.1869	2.1869	2.1869	2.1869	2.1869
1	2.1895	2.1895	2.1895	2.1895	2.1895	2.1896
2	2.1946	2.1946	2.1946	2.1944	2.1946	2.1946
4	2.2052	2.2054	2.2053	2.2049	2.2054	2.2054
5	2.2107	2.2109	2.2108	2.2102	2.2109	2.2109
10	2.2305	0	2.2309	2.229	2.2311	2.2307
20	2.2624	0	2.2636	2.2581	2.2640	2.2626

Table A.5: Acoustic loudness (sones) for heavy vehicle with an electric motor at a pass-by recorded at 50 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	4.2948	4.2948	4.2948	4.2948	4.2948	4.2948
0.0313	4.2947	4.2947	4.2947	4.2947	4.2947	4.2947
0.0625	4.295	4.295	4.295	4.2949	4.295	4.2949
0.125	4.2953	4.2953	4.2953	4.2953	4.2953	4.2953
0.25	4.2958	4.2958	4.2958	4.2958	4.2958	4.2958
0.5	4.2989	4.2989	4.2989	4.2989	4.2989	4.2989
1	4.3029	4.3029	4.3029	4.3028	4.3029	4.3029
2	4.3099	4.31	4.3099	4.3098	4.31	4.3099
4	4.3245	4.3247	4.3246	4.324	4.3247	4.3244
5	4.332	4.3324	4.3322	4.3313	4.3324	4.3319
10	4.3608	0	4.3617	4.3584	4.3622	4.3602
20	4.4047	0	4.4075	4.397	4.4079	4.4028

Table A.6: Acoustic loudness (sones) for heavy vehicle with an internal combustion engine at a pass-by recorded at 50 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	6.8272	6.8272	6.8272	6.8272	6.8272	6.8272
0.0313	6.827	6.827	6.827	6.827	6.827	6.827
0.0625	6.8276	6.8276	6.8276	6.8276	6.8276	6.8276
0.125	6.8279	6.8279	6.8279	6.8279	6.8279	6.8279
0.25	6.8287	6.8287	6.8287	6.8287	6.8287	6.8287
0.5	6.8325	6.8325	6.8325	6.8325	6.8325	6.8325
1	6.8376	6.8377	6.8376	6.8376	6.8377	6.8376
2	6.8486	6.8487	6.8487	6.8484	6.8487	6.8487
4	6.8695	6.8699	6.8697	6.8688	6.8699	6.8695
5	6.881	6.8816	6.8813	6.8799	6.8816	6.8809
10	6.9234	0	6.9246	6.9194	6.9254	6.9224
20	6.9857	0	6.9901	6.9735	6.9906	6.9828

Table A.7: Acoustic loudness (sone) for light vehicle with an electric motor at a pass-by recorded at 50 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	2.8587	2.8587	2.8587	2.8587	2.8587	2.8587
0.0313	2.8586	2.8586	2.8586	2.8586	2.8586	2.8586
0.0625	2.8589	2.8589	2.8589	2.8589	2.8589	2.8589
0.125	2.8591	2.8591	2.8591	2.8591	2.8591	2.8591
0.25	2.8595	2.8595	2.8595	2.8595	2.8595	2.8596
0.5	2.8618	2.8618	2.8618	2.8618	2.8618	2.8619
1	2.8648	2.8648	2.8648	2.8647	2.8648	2.8648
2	2.871	2.8711	2.8711	2.8709	2.8711	2.8712
4	2.8836	2.8838	2.8837	2.8832	2.8838	2.8839
5	2.8898	2.89	2.8899	2.8891	2.89	2.8901
10	2.9137	0	2.9141	2.9117	2.9144	2.9141
20	2.952	0	2.9535	2.9468	2.9539	2.9524

Table A.8: Acoustic loudness (sone) for light vehicle with an internal combustion engine at a pass-by recorded at 50 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	3.6131	3.6131	3.6131	3.6131	3.6131	3.6131
0.0313	3.6129	3.6129	3.6129	3.6129	3.6129	3.6129
0.0625	3.6132	3.6132	3.6132	3.6132	3.6132	3.6132
0.125	3.6135	3.6135	3.6135	3.6135	3.6135	3.6135
0.25	3.6139	3.6139	3.6139	3.6139	3.6139	3.6139
0.5	3.6166	3.6166	3.6166	3.6166	3.6166	3.6167
1	3.6204	3.6205	3.6205	3.6204	3.6205	3.6205
2	3.6281	3.6282	3.6282	3.6279	3.6282	3.6283
4	3.6432	3.6433	3.6432	3.6426	3.6433	3.6434
5	3.6513	3.6515	3.6514	3.6506	3.6515	3.6516
10	3.6815	0	3.682	3.6794	3.6823	3.6819
20	3.7296	0	3.7311	3.724	3.7316	3.73

A.1.2 Sharpness calculations

Table A.9: Acoustic sharpness (acum) for heavy vehicle with an electric motor at a pass-by recorded at 40 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.1474	1.1474	1.1474	1.1474	1.1474	1.1474
0.0313	1.1474	1.1474	1.1474	1.1474	1.1474	1.1474
0.0625	1.1475	1.1475	1.1475	1.1475	1.1475	1.1475
0.125	1.1475	1.1475	1.1475	1.1475	1.1475	1.1475
0.25	1.1476	1.1476	1.1476	1.1476	1.1476	1.1476
0.5	1.1475	1.1475	1.1475	1.1475	1.1475	1.1475
1.0	1.1476	1.1476	1.1476	1.1476	1.1476	1.1476
2.0	1.1477	1.1478	1.1478	1.1477	1.1478	1.1478
4.0	1.1481	1.1482	1.1481	1.1479	1.1482	1.1481
5.0	1.1479	1.1481	1.148	1.1477	1.1481	1.1479
10.0	1.148	0	1.1483	1.1471	1.1485	1.1478
20.0	1.1463	0	1.1473	1.1436	1.1474	1.1457

Table A.10: Acoustic sharpness (acum) for heavy vehicle with an internal combustion engine at a pass-by recorded at 40 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.2561	1.2561	1.2561	1.2561	1.2561	1.2561
0.0313	1.2561	1.2561	1.2561	1.2561	1.2561	1.2561
0.0625	1.2561	1.2561	1.2561	1.2561	1.2561	1.2561
0.125	1.2562	1.2562	1.2562	1.2562	1.2562	1.2562
0.25	1.2563	1.2563	1.2563	1.2563	1.2563	1.2563
0.5	1.2562	1.2562	1.2562	1.2562	1.2562	1.2562
1.0	1.2564	1.2564	1.2564	1.2564	1.2564	1.2564
2.0	1.2566	1.2567	1.2566	1.2566	1.2567	1.2567
4.0	1.2564	1.2565	1.2564	1.2562	1.2565	1.2564
5.0	1.256	1.2562	1.256	1.2557	1.2562	1.256
10.0	1.2557	0	1.2559	1.2546	1.2562	1.2555
20.0	1.2535	0	1.2547	1.25	1.2548	1.2527

Table A.11: Acoustic sharpness (acum) for a light vehicle with an electric engine at a pass-by recorded at 40 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.0543	1.0543	1.0543	1.0543	1.0543	1.0543
0.0313	1.0543	1.0543	1.0543	1.0543	1.0543	1.0543
0.0625	1.0544	1.0544	1.0544	1.0544	1.0544	1.0544
0.125	1.0544	1.0544	1.0544	1.0544	1.0544	1.0544
0.25	1.0545	1.0545	1.0545	1.0545	1.0545	1.0545
0.5	1.0543	1.0543	1.0543	1.0543	1.0543	1.0543
1.0	1.0543	1.0543	1.0543	1.0543	1.0543	1.0544
2.0	1.0546	1.0546	1.0546	1.0545	1.0546	1.0546
4.0	1.0548	1.0548	1.0548	1.0546	1.0548	1.0549
5.0	1.0547	1.0548	1.0548	1.0545	1.0548	1.0549
10.0	1.0556	0	1.0558	1.055	1.0559	1.0559
20.0	1.056	0	1.0564	1.0543	1.0566	1.0564

Table A.12: Acoustic sharpness (acum) for a light vehicle with an internal combustion engine at a pass-by recorded at 40 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.0267	1.0267	1.0267	1.0267	1.0267	1.0267
0.0313	1.0267	1.0267	1.0267	1.0267	1.0267	1.0267
0.0625	1.0268	1.0268	1.0268	1.0268	1.0268	1.0268
0.125	1.0268	1.0268	1.0268	1.0268	1.0268	1.0268
0.25	1.0269	1.0269	1.0269	1.0269	1.0269	1.0269
0.5	1.0268	1.0268	1.0268	1.0268	1.0268	1.0268
1.0	1.027	1.027	1.027	1.0269	1.027	1.027
2.0	1.0272	1.0273	1.0273	1.0272	1.0273	1.0273
4.0	1.0279	1.0279	1.0279	1.0276	1.0279	1.028
5.0	1.028	1.0281	1.028	1.0277	1.0281	1.0281
10.0	1.0293	0	1.0294	1.0284	1.0295	1.0295
20.0	1.0303	0	1.0307	1.0282	1.031	1.0307

Table A.13: Acoustic sharpness (acum) for heavy vehicle with an electric motor at a pass-by recorded at 50 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.2029	1.2029	1.2029	1.2029	1.2029	1.2029
0.0313	1.2029	1.2029	1.2029	1.2029	1.2029	1.2029
0.0625	1.203	1.203	1.203	1.203	1.203	1.203
0.125	1.203	1.203	1.203	1.203	1.203	1.203
0.25	1.2031	1.2031	1.2031	1.2031	1.2031	1.2031
0.5	1.2029	1.2029	1.2029	1.2029	1.2029	1.2029
1	1.203	1.203	1.203	1.2029	1.203	1.2029
2	1.2031	1.2032	1.2031	1.2031	1.2032	1.2031
4	1.2033	1.2034	1.2033	1.2031	1.2034	1.2032
5	1.2031	1.2033	1.2032	1.2029	1.2033	1.2031
10	1.2032	0	1.2035	1.2024	1.2036	1.2029
20	1.2015	0	1.2024	1.199	1.2026	1.2009

Table A.14: Acoustic sharpness (acum) for heavy vehicle with an internal combustion engine at a pass-by recorded at 50 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.281	1.281	1.281	1.281	1.281	1.281
0.0313	1.281	1.281	1.281	1.281	1.281	1.281
0.0625	1.281	1.281	1.281	1.281	1.281	1.281
0.125	1.2811	1.2811	1.2811	1.2811	1.2811	1.2811
0.25	1.2812	1.2812	1.2812	1.2811	1.2812	1.2812
0.5	1.2811	1.2811	1.2811	1.2811	1.2811	1.2811
1	1.2811	1.2811	1.2811	1.2811	1.2811	1.2811
2	1.2812	1.2813	1.2813	1.2812	1.2813	1.2813
4	1.2812	1.2813	1.2812	1.281	1.2813	1.2812
5	1.2808	1.281	1.2809	1.2805	1.281	1.2808
10	1.2806	0	1.2809	1.2796	1.2811	1.2804
20	1.2786	0	1.2796	1.2756	1.2798	1.278

Table A.15: Acoustic sharpness (acum) for light vehicle with an electric motor at a pass-by recorded at 50 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.1155	1.1155	1.1155	1.1155	1.1155	1.1155
0.0313	1.1155	1.1155	1.1155	1.1155	1.1155	1.1155
0.0625	1.1155	1.1155	1.1155	1.1155	1.1155	1.1155
0.125	1.1156	1.1156	1.1156	1.1156	1.1156	1.1156
0.25	1.1156	1.1156	1.1156	1.1156	1.1156	1.1157
0.5	1.1155	1.1155	1.1155	1.1155	1.1155	1.1156
1	1.1157	1.1157	1.1157	1.1156	1.1157	1.1157
2	1.1158	1.1158	1.1158	1.1157	1.1158	1.1158
4	1.1161	1.1161	1.1161	1.1159	1.1161	1.1162
5	1.1161	1.1162	1.1162	1.1159	1.1162	1.1163
10	1.1171	0	1.1172	1.1164	1.1173	1.1173
20	1.1178	0	1.1181	1.1163	1.1183	1.1182

Table A.16: Acoustic sharpness (acum) for light vehicle with an internal combustion engine at a pass-by recorded at 50 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.97898	0.97898	0.97898	0.97898	0.97898	0.97898
0.0313	0.97895	0.97895	0.97895	0.97895	0.97895	0.97895
0.0625	0.97901	0.97901	0.97901	0.97901	0.97901	0.97901
0.125	0.97905	0.97905	0.97905	0.97905	0.97905	0.97905
0.25	0.97914	0.97914	0.97914	0.97913	0.97914	0.97914
0.5	0.97907	0.97907	0.97908	0.97906	0.97907	0.97909
1	0.97914	0.97915	0.97914	0.97911	0.97915	0.97918
2	0.97924	0.97925	0.97925	0.97917	0.97925	0.97931
4	0.97962	0.97966	0.97964	0.97945	0.97966	0.97974
5	0.97959	0.97965	0.97962	0.97937	0.97964	0.97974
10	0.98026	0	0.98037	0.97966	0.98044	0.9805
20	0.98075	0	0.98106	0.97925	0.98124	0.98112

A.1.3 Roughness calculations

Table A.17: Acoustic roughness (aspers) for a heavy vehicle with an electric motor at a pass-by recorded at 40 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.064288	0.064288	0.064286	0.064288	0.064288	0.064287
0.0625	0.064282	0.064282	0.064283	0.064284	0.064282	0.064281
0.0313	0.06434	0.06434	0.06434	0.064341	0.06434	0.064339
0.125	0.06435	0.06435	0.064354	0.064351	0.06435	0.064351
0.25	0.064397	0.064397	0.064403	0.064398	0.064397	0.064396
0.5	0.064633	0.064633	0.064638	0.064632	0.064633	0.064637
1	0.064999	0.064999	0.065007	0.064993	0.064999	0.065003
2	0.06558	0.065577	0.065582	0.065571	0.065577	0.065538
4	0.066989	0.066984	0.066984	0.067	0.066984	0.067008
5	0.067942	0.067936	0.067922	0.067949	0.067934	0.067944
10	0.071626	0	0.071632	0.071612	0.071607	0.071591
20	0.070857	0	0.070929	0.070908	0.070884	0.070752

Table A.18: Acoustic roughness (aspers) for a heavy vehicle with an internal combustion engine at a pass-by recorded at 40 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.094768	0.094768	0.094771	0.094771	0.094768	0.094769
0.0313	0.094761	0.094761	0.094764	0.094764	0.094761	0.094762
0.0625	0.094785	0.094785	0.094786	0.094788	0.094785	0.094784
0.125	0.094783	0.094783	0.094785	0.094786	0.094783	0.094784
0.25	0.094848	0.094848	0.094849	0.09485	0.094848	0.094847
0.5	0.095457	0.095457	0.095457	0.095456	0.095457	0.095461
1	0.095998	0.095998	0.096002	0.096005	0.095998	0.096007
2	0.096748	0.096749	0.096754	0.096752	0.096749	0.096785
4	0.098496	0.098496	0.098534	0.098541	0.098498	0.098526
5	0.099823	0.099825	0.099868	0.099868	0.099824	0.099857
10	0.10493	0	0.10493	0.10494	0.10493	0.10495
20	0.11503	0	0.1151	0.11512	0.11503	0.11494

Table A.19: Acoustic roughness (aspers) for light vehicle with an electric motor at a pass-by recorded at 40 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.075422	0.075422	0.075423	0.075422	0.075422	0.075422
0.03136	0.075393	0.075393	0.075394	0.075394	0.075393	0.075396
0.0625	0.075449	0.075449	0.075449	0.075452	0.075449	0.075447
0.125	0.075478	0.075478	0.075475	0.075474	0.075478	0.075469
0.25	0.075503	0.075503	0.075495	0.075501	0.075503	0.075499
0.5	0.07598	0.07598	0.075979	0.075977	0.07598	0.075975
1	0.076328	0.076327	0.076314	0.076314	0.076327	0.076329
2	0.077127	0.077126	0.077112	0.077118	0.077126	0.077128
4	0.078741	0.078745	0.078738	0.078743	0.078744	0.078706
5	0.07993	0.079931	0.079927	0.07992	0.079927	0.079902
10	0.08395	0	0.083939	0.083951	0.083953	0.083891
20	0.05498	0	0.054939	0.093534	0.054928	0.054949

Table A.20: Acoustic roughness (aspers) for light vehicle with an internal combustion engine at a pass-by recorded at 40 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.076943	0.076943	0.076944	0.076942	0.076943	0.076945
0.0313	0.076912	0.076912	0.076911	0.07691	0.076912	0.076915
0.0625	0.076969	0.076969	0.076971	0.076969	0.076969	0.076973
0.125	0.076999	0.076999	0.077002	0.077	0.076999	0.076999
0.25	0.077016	0.077016	0.07702	0.077012	0.077016	0.077016
0.5	0.0775	0.077501	0.077493	0.077495	0.077501	0.077498
1	0.077807	0.077807	0.077796	0.077793	0.077808	0.077809
2	0.078643	0.078644	0.078641	0.078644	0.078645	0.078632
4	0.08019	0.080204	0.080217	0.080197	0.080201	0.049191
5	0.081336	0.081355	0.081376	0.081326	0.081347	0.081341
10	0.052262	0	0.052227	0.052279	0.052285	0.05228
20	0.057302	0	0.057356	0.057374	0.057273	0.057275

Table A.21: Acoustic roughness (aspers) for a heavy vehicle with an electrical motor at a pass-by recorded at 50 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.085679	0.085679	0.085679	0.08568	0.085679	0.085678
0.0313	0.085655	0.085655	0.085656	0.085657	0.085655	0.085656
0.0625	0.085698	0.085698	0.085698	0.085699	0.085698	0.085697
0.125	0.085754	0.085754	0.085753	0.085756	0.085754	0.08575
0.25	0.085784	0.085784	0.085779	0.085783	0.085784	0.085786
0.5	0.086122	0.086121	0.086118	0.086115	0.086121	0.086123
1	0.086466	0.086465	0.080376	0.086467	0.086465	0.086475
2	0.081279	0.081278	0.081284	0.081275	0.081278	0.081287
4	0.083305	0.083305	0.083301	0.083294	0.083304	0.083313
5	0.084269	0.084268	0.084261	0.084273	0.084267	0.084295
10	0.095492	0	0.09545	0.088641	0.088678	0.095562
20	0.10468	0	0.10457	0.10474	0.10464	0.10495

Table A.22: Acoustic roughness (aspers) for a light vehicle with an elctrical engine at a pass-by recorded at 50 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.084354	0.084354	0.084353	0.084356	0.084354	0.08435
0.0313	0.084346	0.084346	0.084346	0.084348	0.084346	0.084344
0.0625	0.084359	0.084359	0.084359	0.084359	0.084359	0.084358
0.125	0.084387	0.084387	0.08438	0.08439	0.084387	0.084373
0.25	0.084481	0.084481	0.084472	0.084481	0.084481	0.084462
0.5	0.084768	0.084768	0.08475	0.084776	0.084768	0.084742
1	0.085178	0.08518	0.085165	0.08516	0.08518	0.085134
2	0.086223	0.086226	0.086203	0.086214	0.086226	0.086182
4	0.087906	0.087916	0.087888	0.08789	0.087908	0.087861
5	0.089051	0.089068	0.089061	0.08903	0.08906	0.089006
10	0.093653	0	0.093637	0.093653	0.093653	0.09361
20	0.10306	0	0.10307	0.10298	0.10306	0.10312

Table A.23: Acoustic roughness (aspers) for a light vehicle with an electric motor at a pass-by recorded at 50 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.084354	0.084354	0.084353	0.084356	0.084354	0.08435
0.0313	0.084346	0.084346	0.084346	0.084348	0.084346	0.084344
0.0625	0.084359	0.084359	0.084359	0.084359	0.084359	0.084358
0.125	0.084387	0.084387	0.08438	0.08439	0.084387	0.084373
0.25	0.084481	0.084481	0.084472	0.084481	0.084481	0.084462
0.5	0.084768	0.084768	0.08475	0.084776	0.084768	0.084742
1	0.085178	0.08518	0.085165	0.08516	0.08518	0.085134
2	0.086223	0.086226	0.086203	0.086214	0.086226	0.086182
4	0.087906	0.087916	0.087888	0.08789	0.087908	0.087861
5	0.089051	0.089068	0.089061	0.08903	0.08906	0.089006
10	0.093653	0	0.093637	0.093653	0.093653	0.09361
20	0.10306	0	0.10307	0.10298	0.10306	0.10312

Table A.24: Acoustic roughness (aspers) for a light vehicle with an internal combustion engine at a pass-by recorded at 50 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.081778	0.081777	0.081778	0.081777	0.081777	0.081779
0.0313	0.081773	0.081772	0.081771	0.081778	0.081773	0.081775
0.0625	0.081789	0.081789	0.081793	0.081791	0.081789	0.081791
0.125	0.081816	0.081816	0.08182	0.081822	0.081816	0.081819
0.25	0.081917	0.081916	0.081915	0.081915	0.081916	0.081918
0.5	0.082227	0.082227	0.082237	0.082235	0.082227	0.082234
1	0.082649	0.082647	0.082622	0.082635	0.082647	0.082638
2	0.083671	0.083669	0.083657	0.083649	0.083669	0.083658
4	0.085368	0.085368	0.085363	0.085374	0.085364	0.085356
5	0.086411	0.086414	0.086422	0.086413	0.086415	0.08644
10	0.090998	0	0.091008	0.091012	0.091006	0.091021
20	0.10003	0	0.10003	0.099997	0.10002	0.10001

A.1.4 Fluctuation strength

Table A.25: Fluctuation strength (vacil) presented as average values for a heavy vehicle with an electric motor at a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0076516	0.0076516	0.0076518	0.0076516	0.0076516	0.0076518
0.0313	0.0076628	0.0076628	0.0076631	0.0076632	0.0076628	0.0076629
0.0625	0.0076332	0.0076332	0.0076333	0.0076332	0.0076332	0.0076333
0.125	0.0076132	0.0076132	0.0076131	0.0076135	0.0076132	0.0076125
0.25	0.0075735	0.0075734	0.0075732	0.007574	0.0075734	0.0075725
0.5	0.0073646	0.0073646	0.0073642	0.0073662	0.0073646	0.0073637
1	0.0070961	0.007096	0.0070946	0.0070966	0.0070959	0.0070955
2	0.0066082	0.0066084	0.006608	0.0066069	0.0066084	0.0066119
4	0.0057703	0.0057719	0.0057636	0.0057715	0.0057725	0.0057869
5	0.0053394	0.005342	0.0053309	0.0053404	0.0053436	0.0053525
10	0.079542	0	0.079388	0.079814	0.079534	0.07997
20	0.0044527	0	0.0042803	0.0043121	0.0043703	0.0047401

Table A.26: Fluctuation strength (vacil) presented as average values for a heavy vehicle with an internal combustion engine at a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0084346	0.0084346	0.0084351	0.0084349	0.0084346	0.0084346
0.0313	0.008448	0.008448	0.0084482	0.0084483	0.008448	0.0084479
0.0625	0.0084126	0.0084126	0.0084131	0.0084129	0.0084126	0.0084124
0.125	0.008392	0.008392	0.008392	0.0083918	0.008392	0.0083922
0.25	0.0083428	0.0083428	0.0083425	0.0083415	0.0083428	0.0083438
0.5	0.008086	0.008086	0.0080856	0.0080839	0.008086	0.0080876
1	0.0077293	0.0077292	0.0077273	0.0077249	0.0077291	0.0077323
2	0.0070874	0.0070873	0.0070832	0.0070823	0.0070872	0.0070914
4	0.0060081	0.006008	0.0059973	0.0060021	0.0060054	0.0060143
5	0.0054645	0.005465	0.0054458	0.0054648	0.005458	0.0054756
10	0.081672	0	0.081725	0.081731	0.081681	0.081574
20	0.085119	0	0.085296	0.085426	0.085069	0.084847

Table A.27: Fluctuation strength (vacil) presented as average values for light vehicle with an electric motor at a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0065874	0.0065874	0.0065873	0.0065878	0.0065874	0.0065877
0.0313	0.0065946	0.0065946	0.0065945	0.0065955	0.0065946	0.0065944
0.0625	0.0065738	0.0065738	0.0065746	0.0065754	0.0065738	0.0065744
0.125	0.0065587	0.0065587	0.0065592	0.0065599	0.0065587	0.0065602
0.25	0.0065287	0.0065286	0.0065305	0.0065311	0.0065286	0.0065298
0.5	0.0063487	0.0063485	0.0063483	0.0063497	0.0063485	0.0063508
1	0.0061257	0.0061258	0.0061274	0.0061271	0.0061257	0.0061303
2	0.0057105	0.0057101	0.0057097	0.0057074	0.0057098	0.005713
4	0.0049612	0.0049616	0.0049569	0.0049632	0.0049613	0.0049697
5	0.004545	0.0045467	0.0045325	0.004549	0.0045458	0.0045521
10	0.010384	0	0.010141	0.01052	0.010314	0.010612
20	0.0041569	0	0.0040659	0.0040905	0.0041129	0.0043056

Table A.28: Fluctuation strength (vacil) presented as average values for light vehicle with an internal combustion engine at a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0074997	0.0074997	0.0074995	0.0074998	0.0074996	0.0074998
0.0313	0.0075079	0.0075079	0.0075085	0.0075082	0.0075079	0.0075082
0.0625	0.0074853	0.0074852	0.0074854	0.0074857	0.0074853	0.0074854
0.125	0.0074694	0.0074694	0.0074702	0.00747	0.0074693	0.0074704
0.25	0.0074379	0.0074379	0.0074388	0.0074374	0.0074379	0.0074398
0.5	0.0072353	0.0072353	0.0072363	0.0072363	0.0072353	0.0072389
1	0.0069924	0.0069927	0.0069927	0.0069922	0.0069926	0.0069943
2	0.0065278	0.0065281	0.0065276	0.0065259	0.006528	0.0065387
4	0.0057081	0.0057087	0.0057032	0.0057043	0.0057081	0.0057307
5	0.005248	0.0052479	0.0052316	0.005246	0.0052469	0.0052708
10	0.060206	0	0.060227	0.060155	0.060225	0.060232
20	0.0043244	0	0.0042343	0.0031679	0.0042818	0.0044731

Table A.29: Fluctuation strength (vacil) presented as average values for a heavy vehicle with an electrical motor at a pass-by recorded at 50 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0088367	0.0088368	0.0088368	0.0088368	0.0088367	0.0088367
0.0313	0.008845	0.008845	0.0088453	0.0088446	0.008845	0.008845
0.0615	0.0088149	0.0088149	0.0088151	0.0088146	0.0088149	0.0088151
0.125	0.0087876	0.0087876	0.0087878	0.0087868	0.0087876	0.0087891
0.25	0.0087413	0.0087413	0.008741	0.0087394	0.0087413	0.0087434
0.5	0.0084897	0.0084897	0.0084902	0.0084881	0.0084897	0.008494
1	0.0081732	0.0081731	0.0081733	0.0081698	0.0081731	0.0081808
2	0.0075855	0.0075853	0.0075866	0.0075755	0.0075852	0.0075979
4	0.0065799	0.0065801	0.006574	0.0065604	0.0065798	0.0066079
5	0.0060784	0.0060787	0.0060688	0.0060601	0.0060804	0.0061183
10	0.0063674	0	0.0061155	0.0074888	0.0063465	0.0073559
20	0.0046002	0	0.004431	0.0044536	0.0045151	0.0048877

Table A.30: Fluctuation strength (vacil) presented as average values for a heavy vehicle with an internal combustion engine at a pass-by recorded at 50 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0089984	0.0089984	0.0089984	0.0089983	0.0089984	0.0089981
0.0313	0.0090122	0.0090122	0.0090121	0.0090121	0.0090122	0.009012
0.0625	0.0089745	0.0089745	0.0089744	0.0089745	0.0089745	0.0089748
0.125	0.00895	0.00895	0.0089495	0.0089492	0.00895	0.0089506
0.25	0.0088979	0.0088979	0.0088982	0.0088976	0.0088979	0.0088982
0.5	0.0086283	0.0086283	0.0086288	0.0086273	0.0086284	0.0086292
1	0.0082596	0.0082596	0.0082601	0.0082577	0.0082596	0.0082631
2	0.0075784	0.0075783	0.0075776	0.0075721	0.0075783	0.0075832
4	0.0064124	0.0064119	0.0064048	0.0064055	0.0064116	0.0064283
5	0.020052	0.020051	0.020051	0.020051	0.020051	0.02005
10	0.021081	0	0.021083	0.021079	0.02108	0.021074
20	0.023224	0	0.023233	0.023218	0.023225	0.023209

Table A.31: Fluctuation strength (vacil) presented as average values for a light vehicle with an electrical motor at a pass-by recorded at 50 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.007129	0.007129	0.007129	0.0071288	0.007129	0.007129
0.0313	0.0071365	0.0071365	0.0071361	0.0071364	0.0071365	0.0071365
0.0625	0.0071177	0.0071177	0.0071176	0.0071174	0.0071177	0.007118
0.125	0.007102	0.007102	0.0071022	0.0071011	0.007102	0.0071026
0.25	0.0070739	0.0070739	0.007073	0.0070725	0.0070739	0.007073
0.5	0.0068758	0.006876	0.0068751	0.0068758	0.006876	0.0068746
1	0.0066479	0.006648	0.006647	0.0066463	0.006648	0.0066483
2	0.006194	0.0061943	0.006192	0.0061902	0.0061941	0.006195
4	0.0053924	0.0053922	0.0053855	0.0053877	0.0053913	0.0053948
5	0.0049621	0.0049622	0.0049512	0.0049608	0.0049609	0.0049664
10	0.067179	0	0.067195	0.067131	0.067178	0.067179
20	0.0041041	0	0.0040142	0.0030717	0.0040611	0.0033369

Table A.32: Fluctuation strength (vacil) presented as average values for a light vehicle with an internal combustion engine at a pass-by recorded at 50 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0085813	0.0085813	0.0085814	0.0085812	0.0085813	0.0085814
0.0313	0.0085889	0.0085889	0.008589	0.0085887	0.0085889	0.0085891
0.0625	0.0085692	0.0085692	0.0085693	0.0085689	0.0085692	0.0085696
0.125	0.0085531	0.0085531	0.0085535	0.0085531	0.0085531	0.0085533
0.25	0.0085236	0.0085236	0.0085239	0.0085225	0.0085236	0.0085239
0.5	0.0083108	0.0083107	0.0083117	0.0083108	0.0083107	0.0083129
1	0.0080461	0.008046	0.0080454	0.0080445	0.0080461	0.0080496
2	0.0075483	0.0075483	0.0075463	0.0075432	0.0075485	0.0075523
4	0.0066739	0.0066742	0.0066674	0.0066655	0.0066733	0.0066842
5	0.0061962	0.0061974	0.0061918	0.0061922	0.0061961	0.0062067
10	0.062748	0	0.062802	0.062744	0.062762	0.062821
20	0.004489	0	0.0044052	0.0037728	0.0044486	0.0046401

A.1.5 A-weighted values

Table A.33: A-weighted values (dB) presented as single numbers for a heavy vehicle with electric motor at a pass-by recorded at 40 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-30.384	-30.384	-30.384	-30.384	-30.384	-30.384
0.0313	-30.384	-30.384	-30.384	-30.384	-30.384	-30.384
0.0625	-30.383	-30.383	-30.383	-30.383	-30.383	-30.383
0.125	-30.383	-30.383	-30.383	-30.383	-30.383	-30.383
0.25	-30.382	-30.382	-30.382	-30.382	-30.382	-30.382
0.5	-30.378	-30.378	-30.378	-30.378	-30.378	-30.378
1.0	-30.373	-30.373	-30.373	-30.373	-30.373	-30.373
2.0	-30.363	-30.363	-30.363	-30.363	-30.363	-30.363
4.0	-30.343	-30.343	-30.343	-30.343	-30.343	-30.343
5.0	-30.332	-30.331	-30.331	-30.332	-30.331	-30.332
10.0	-30.289	0	-30.288	-30.291	-30.288	-30.29
20.0	-30.223	0	-30.22	-30.228	-30.22	-30.224

Table A.34: A-weighted values (dB) presented as single numbers for a heavy vehicle with an internal combustion engine at a pass-by recorded at 40 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-26.621	-26.621	-26.621	-26.621	-26.621	-26.621
0.0313	-26.622	-26.622	-26.622	-26.622	-26.622	-26.622
0.0625	-26.621	-26.621	-26.621	-26.621	-26.621	-26.621
0.125	-26.621	-26.621	-26.621	-26.621	-26.621	-26.621
0.25	-26.62	-26.62	-26.62	-26.62	-26.62	-26.62
0.5	-26.617	-26.617	-26.617	-26.617	-26.617	-26.617
1.0	-26.611	-26.611	-26.611	-26.611	-26.611	-26.611
2.0	-26.6	-26.6	-26.6	-26.6	-26.6	-26.6
4.0	-26.579	-26.579	-26.579	-26.579	-26.579	-26.579
5.0	-26.567	-26.566	-26.567	-26.567	-26.566	-26.567
10.0	-26.523	0	-26.522	-26.525	-26.522	-26.524
20.0	-26.458	0	-26.455	-26.465	-26.455	-26.46

Table A.35: A-weighted values (dB) presented as single numbers for a light vehicle with electric motor at a pass-by recorded at 40 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-32.07	-32.07	-32.07	-32.07	-32.07	-32.07
0.0313	-32.07	-32.07	-32.07	-32.07	-32.07	-32.07
0.0625	-32.069	-32.069	-32.069	-32.069	-32.069	-32.069
0.125	-32.069	-32.069	-32.069	-32.069	-32.069	-32.069
0.25	-32.067	-32.067	-32.067	-32.067	-32.067	-32.067
0.5	-32.064	-32.064	-32.064	-32.064	-32.064	-32.064
1.0	-32.058	-32.058	-32.058	-32.058	-32.058	-32.058
2.0	-32.047	-32.047	-32.047	-32.047	-32.047	-32.047
4.0	-32.023	-32.023	-32.023	-32.024	-32.023	-32.023
5.0	-32.012	-32.012	-32.012	-32.012	-32.012	-32.012
10.0	-31.967	0	-31.966	-31.969	-31.966	-31.967
20.0	-31.894	0	-31.892	-31.9	-31.892	-31.895

Table A.36: A-weighted values (dB) presented as single numbers for a light vehicle with internal combustion engine at a pass-by recorded at 40 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-31.143	-31.143	-31.143	-31.143	-31.143	-31.143
0.0313	-31.143	-31.143	-31.143	-31.143	-31.143	-31.143
0.0625	-31.142	-31.142	-31.142	-31.142	-31.142	-31.142
0.125	-31.142	-31.142	-31.142	-31.142	-31.142	-31.142
0.25	-31.14	-31.14	-31.14	-31.14	-31.14	-31.14
0.5	-31.136	-31.136	-31.136	-31.136	-31.136	-31.136
1.0	-31.131	-31.131	-31.131	-31.131	-31.131	-31.131
2.0	-31.12	-31.12	-31.12	-31.12	-31.12	-31.12
4.0	-31.096	-31.096	-31.096	-31.097	-31.096	-31.096
5.0	-31.085	-31.085	-31.085	-31.086	-31.085	-31.085
10.0	-31.04	0	-31.039	-31.042	-31.039	-31.04
20.0	-30.968	0	-30.966	-30.973	-30.965	-30.969

Table A.37: A-weighted values (dB) presented as single numbers for a heavy vehicle with electric motor at a pass-by recorded at 50 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-29.229	-29.229	-29.229	-29.229	-29.229	-29.229
0.0313	-29.229	-29.229	-29.229	-29.229	-29.229	-29.229
0.0625	-29.229	-29.229	-29.229	-29.229	-29.229	-29.229
0.125	-29.228	-29.228	-29.228	-29.228	-29.228	-29.228
0.25	-29.227	-29.227	-29.227	-29.227	-29.227	-29.227
0.5	-29.223	-29.223	-29.223	-29.223	-29.223	-29.223
1.0	-29.217	-29.217	-29.217	-29.217	-29.217	-29.217
2.0	-29.207	-29.207	-29.207	-29.207	-29.207	-29.207
4.0	-29.185	-29.185	-29.185	-29.186	-29.185	-29.186
5.0	-29.175	-29.174	-29.174	-29.175	-29.174	-29.175
10.0	-29.133	0	-29.132	-29.135	-29.132	-29.133
20.0	-29.066	0	-29.064	-29.072	-29.064	-29.068

Table A.38: A-weighted values (dB) presented as single numbers for a heavy vehicle with an internal combustion engine at a pass-by recorded at 40 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-26.613	-26.613	-26.613	-26.613	-26.613	-26.613
0.0313	-26.613	-26.613	-26.613	-26.613	-26.613	-26.613
0.0625	-26.612	-26.612	-26.612	-26.612	-26.612	-26.612
0.125	-26.612	-26.612	-26.612	-26.612	-26.612	-26.612
0.25	-26.611	-26.611	-26.611	-26.611	-26.611	-26.611
0.5	-26.607	-26.607	-26.607	-26.607	-26.607	-26.607
1.0	-26.602	-26.602	-26.602	-26.602	-26.602	-26.602
2.0	-26.591	-26.591	-26.591	-26.592	-26.591	-26.592
4.0	-26.571	-26.57	-26.571	-26.571	-26.57	-26.571
5.0	-26.559	-26.559	-26.559	-26.56	-26.559	-26.56
10.0	-26.516	0	-26.515	-26.518	-26.514	-26.516
20.0	-26.452	0	-26.449	-26.459	-26.449	-26.454

Table A.39: A-weighted values (dB) presented as single numbers for a light vehicle with electric motor at a pass-by recorded at 50 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-30.242	-30.242	-30.242	-30.242	-30.242	-30.242
0.0313	-30.242	-30.242	-30.242	-30.242	-30.242	-30.242
0.0625	-30.242	-30.242	-30.242	-30.242	-30.242	-30.242
0.125	-30.241	-30.241	-30.241	-30.241	-30.241	-30.241
0.25	-30.241	-30.241	-30.241	-30.241	-30.241	-30.241
0.5	-30.237	-30.237	-30.237	-30.237	-30.237	-30.237
1.0	-30.232	-30.232	-30.232	-30.232	-30.232	-30.232
2.0	-30.22	-30.22	-30.22	-30.22	-30.22	-30.22
4.0	-30.195	-30.195	-30.195	-30.196	-30.195	-30.195
5.0	-30.184	-30.183	-30.184	-30.184	-30.183	-30.184
10.0	-30.139	0	-30.139	-30.141	-30.138	-30.14
20.0	-30.064	0	-30.062	-30.07	-30.062	-30.065

Table A.40: A-weighted values (dB) presented as single numbers for a light vehicle with internal combustion engine at a pass-by recorded at 50 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-29.737	-29.737	-29.737	-29.737	-29.737	-29.737
0.0313	-29.737	-29.737	-29.737	-29.737	-29.737	-29.737
0.0625	-29.736	-29.736	-29.736	-29.736	-29.736	-29.736
0.125	-29.736	-29.736	-29.736	-29.736	-29.736	-29.736
0.25	-29.735	-29.735	-29.735	-29.735	-29.735	-29.735
0.5	-29.731	-29.731	-29.731	-29.731	-29.731	-29.731
1.0	-29.726	-29.726	-29.726	-29.726	-29.726	-29.726
2.0	-29.714	-29.714	-29.714	-29.714	-29.714	-29.714
4.0	-29.69	-29.69	-29.69	-29.691	-29.69	-29.69
5.0	-29.678	-29.678	-29.678	-29.679	-29.678	-29.678
10.0	-29.633	0	-29.633	-29.635	-29.632	-29.634
20.0	-29.559	0	-29.557	-29.564	-29.556	-29.559

A.2 No barrier with Doppler effect

A.2.1 Loudness calculations

Table A.41: Acoustic loudness (sones) for heavy vehicle with electric motor at a pass-by recorded at 40 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	3.557	3.557	3.557	3.557	3.557	3.557
0.0313	3.5569	3.5569	3.5569	3.5569	3.5569	3.5569
0.0625	3.5573	3.5573	3.5573	3.5573	3.5573	3.5573
0.125	3.5575	3.5575	3.5575	3.5575	3.5575	3.5575
0.25	3.558	3.558	3.558	3.558	3.558	3.558
0.5	3.5603	3.5603	3.5603	3.5603	3.5603	3.5603
1	3.5635	3.5635	3.5635	3.5635	3.5635	3.5635
2	3.5697	3.5698	3.5697	3.5696	3.5698	3.5697
4	3.5813	3.5815	3.5814	3.581	3.5815	3.5812
5	3.5879	3.5883	3.5881	3.5874	3.5883	3.5878
10	3.6134	0	3.6141	3.6113	3.6145	3.6128
20	3.6518	0	3.6543	3.6454	3.6545	3.6501

Table A.42: Acoustic loudness (sones) for heavy vehicle with internal combustion engine at a pass-by recorded at 40 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	6.8235	6.8235	6.8235	6.8235	6.8235	6.8235
0.0313	6.8234	6.8234	6.8234	6.8234	6.8234	6.8234
0.0625	6.8239	6.8239	6.8239	6.8239	6.8239	6.8239
0.125	6.8241	6.8241	6.8241	6.8241	6.8241	6.8241
0.25	6.8247	6.8247	6.8247	6.8247	6.8247	6.8247
0.5	6.8282	6.8282	6.8282	6.8282	6.8282	6.8282
1	6.8336	6.8336	6.8336	6.8335	6.8336	6.8336
2	6.844	6.8441	6.8441	6.8439	6.8441	6.8441
4	6.8657	6.8661	6.8658	6.865	6.8661	6.8655
5	6.8777	6.8783	6.8779	6.8767	6.8783	6.8775
10	6.9195	0	6.9208	6.9159	6.9216	6.9184
20	6.98	0	6.9845	6.9683	6.9849	6.9766

Table A.43: Acoustic loudness (sones) for a light vehicle with electric motor at a pass-by recorded at 40 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	2.1732	2.1732	2.1732	2.1732	2.1732	2.1732
0.0313	2.1731	2.1731	2.1731	2.1731	2.1731	2.1731
0.0625	2.1733	2.1733	2.1733	2.1733	2.1733	2.1733
0.125	2.1735	2.1735	2.1735	2.1735	2.1735	2.1735
0.25	2.174	2.174	2.174	2.174	2.174	2.174
0.5	2.1759	2.1759	2.1759	2.1759	2.1759	2.176
1	2.1785	2.1785	2.1785	2.1784	2.1785	2.1785
2	2.1834	2.1834	2.1834	2.1833	2.1834	2.1835
4	2.1937	2.1938	2.1937	2.1934	2.1938	2.1939
5	2.199	2.1992	2.1991	2.1986	2.1992	2.1992
10	2.2181	0	2.2185	2.2167	2.2187	2.2182
20	2.2488	0	2.25	2.2448	2.2503	2.2488

Table A.44: Acoustic loudness (sones) for a light vehicle with internal combustion engine at a pass-by recorded at 40 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	2.6976	2.6976	2.6976	2.6976	2.6976	2.6976
0.0313	2.6975	2.6975	2.6975	2.6975	2.6975	2.6975
0.0625	2.6978	2.6978	2.6978	2.6978	2.6978	2.6978
0.125	2.698	2.698	2.698	2.698	2.698	2.698
0.25	2.6985	2.6985	2.6985	2.6985	2.6985	2.6985
0.5	2.7008	2.7008	2.7008	2.7007	2.7008	2.7008
1	2.7034	2.7034	2.7034	2.7034	2.7034	2.7035
2	2.7092	2.7093	2.7093	2.7091	2.7093	2.7093
4	2.7207	2.7208	2.7208	2.7203	2.7209	2.7209
5	2.7269	2.7272	2.727	2.7264	2.7271	2.7272
10	2.7499	0	2.7504	2.7481	2.7506	2.7501
20	2.7857	0	2.7871	2.7808	2.7875	2.7857

Table A.45: Acoustic loudness (sones) for heavy vehicle with electric motor at a pass-by recorded at 50 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	4.2678	4.2678	4.2678	4.2678	4.2678	4.2678
0.0313	4.2677	4.2677	4.2677	4.2677	4.2677	4.2677
0.0625	4.2679	4.2679	4.2679	4.2679	4.2679	4.2679
0.125	4.2683	4.2683	4.2683	4.2683	4.2683	4.2683
0.25	4.2688	4.2688	4.2688	4.2688	4.2688	4.2688
0.5	4.2718	4.2718	4.2718	4.2718	4.2718	4.2718
1.0	4.2756	4.2756	4.2756	4.2756	4.2756	4.2756
2.0	4.2825	4.2825	4.2825	4.2824	4.2825	4.2824
4.0	4.2966	4.2968	4.2967	4.2962	4.2968	4.2965
5.0	4.3039	4.3043	4.3041	4.3033	4.3043	4.3037
10.0	4.3317	0	4.3326	4.3295	4.3331	4.331
20.0	4.374	0	4.3768	4.3668	4.3771	4.3719

Table A.46: Acoustic loudness (sones) for heavy vehicle with internal combustion at a pass-by recorded at 50 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	6.7841	6.7841	6.7841	6.7841	6.7841	6.7841
0.0313	6.7839	6.7839	6.7839	6.7839	6.7839	6.7839
0.0625	6.7845	6.7845	6.7845	6.7845	6.7845	6.7845
0.125	6.7848	6.7848	6.7848	6.7848	6.7848	6.7848
0.25	6.7856	6.7856	6.7856	6.7856	6.7856	6.7856
0.5	6.7893	6.7893	6.7893	6.7892	6.7893	6.7893
1.0	6.7942	6.7942	6.7943	6.7942	6.7942	6.7942
2.0	6.8048	6.8049	6.8049	6.8047	6.8049	6.8048
4.0	6.8251	6.8255	6.8252	6.8245	6.8255	6.825
5.0	6.8363	6.8369	6.8365	6.8353	6.8368	6.836
10.0	6.8773	0	6.8786	6.8737	6.8793	6.8762
20.0	6.9374	0	6.9418	6.926	6.9422	6.9341

Table A.47: Acoustic loudness (sones) for light vehicle with electric motor at a pass-by recorded at 50 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	2.8454	2.8454	2.8454	2.8454	2.8454	2.8454
0.0313	2.8453	2.8453	2.8453	2.8453	2.8453	2.8453
0.0625	2.8455	2.8455	2.8455	2.8455	2.8455	2.8455
0.125	2.8458	2.8458	2.8458	2.8457	2.8458	2.8458
0.25	2.8462	2.8462	2.8462	2.8461	2.8462	2.8462
0.5	2.8484	2.8484	2.8484	2.8484	2.8484	2.8484
1.0	2.8513	2.8513	2.8513	2.8512	2.8513	2.8513
2.0	2.8573	2.8574	2.8574	2.8572	2.8574	2.8575
4.0	2.8696	2.8697	2.8696	2.8691	2.8697	2.8698
5.0	2.8755	2.8758	2.8757	2.8749	2.8757	2.8758
10.0	2.8986	0	2.8991	2.8968	2.8993	2.8989
20.0	2.9355	0	2.9369	2.9305	2.9374	2.9357

Table A.48: Acoustic loudness (sones) for light vehicle with internal combustion engine at a pass-by recorded at 50 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	3.5986	3.5986	3.5986	3.5986	3.5986	3.5986
0.0313	3.5985	3.5985	3.5985	3.5985	3.5985	3.5985
0.0625	3.5988	3.5988	3.5988	3.5988	3.5988	3.5988
0.125	3.599	3.599	3.599	3.599	3.599	3.599
0.25	3.5994	3.5994	3.5995	3.5994	3.5994	3.5995
0.5	3.6021	3.6021	3.6021	3.6021	3.6021	3.6021
1.0	3.6058	3.6058	3.6058	3.6057	3.6058	3.6058
2.0	3.6133	3.6133	3.6133	3.6131	3.6133	3.6134
4.0	3.6278	3.628	3.6279	3.6273	3.628	3.6281
5.0	3.6357	3.6359	3.6358	3.635	3.6359	3.6359
10.0	3.6649	0	3.6653	3.6629	3.6656	3.6651
20.0	3.711	0	3.7125	3.7056	3.7129	3.7111

A.2.2 Sharpness calculations

Table A.49: Acoustic sharpness (acum) for a heavy vehicle with electric motor at a pass-by recorded at 40 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.1358	1.1358	1.1358	1.1358	1.1358	1.1358
0.0313	1.1357	1.1357	1.1357	1.1357	1.1357	1.1357
0.0625	1.1358	1.1358	1.1358	1.1358	1.1358	1.1358
0.125	1.1358	1.1358	1.1358	1.1358	1.1358	1.1359
0.25	1.1359	1.1359	1.1359	1.1359	1.1359	1.1359
0.5	1.1359	1.1359	1.1359	1.1358	1.1359	1.1359
1	1.1359	1.1359	1.1359	1.1359	1.1359	1.1359
2	1.136	1.136	1.136	1.136	1.136	1.136
4	1.1363	1.1363	1.1363	1.1361	1.1363	1.1362
5	1.1361	1.1362	1.1361	1.1359	1.1362	1.136
10	1.136	0	1.1363	1.1352	1.1365	1.1358
20	1.1342	0	1.1352	1.1317	1.1353	1.1335

Table A.50: Acoustic sharpness (acum) for a heavy vehicle with internal combustion engine at a pass-by recorded at 40 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.241	1.241	1.241	1.241	1.241	1.241
0.0313	1.241	1.241	1.241	1.241	1.241	1.241
0.0625	1.241	1.241	1.241	1.241	1.241	1.241
0.125	1.2411	1.2411	1.2411	1.2411	1.2411	1.2411
0.25	1.2411	1.2411	1.2411	1.2411	1.2411	1.2411
0.5	1.2411	1.2411	1.2411	1.2411	1.2411	1.2411
1	1.2413	1.2413	1.2413	1.2412	1.2413	1.2413
2	1.2414	1.2414	1.2414	1.2414	1.2414	1.2414
4	1.2411	1.2412	1.2411	1.2409	1.2412	1.241
5	1.2407	1.2408	1.2407	1.2404	1.2408	1.2406
10	1.2402	0	1.2405	1.2393	1.2408	1.2399
20	1.2379	0	1.2391	1.2348	1.2392	1.2368

Table A.51: Acoustic sharpness (acum) for a light vehicle with electric motor at a pass-by recorded at 40 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.049	1.049	1.049	1.049	1.049	1.049
0.0313	1.049	1.049	1.049	1.049	1.049	1.049
0.0625	1.049	1.049	1.049	1.049	1.049	1.049
0.125	1.0491	1.0491	1.0491	1.0491	1.0491	1.0491
0.25	1.0491	1.0491	1.0491	1.0491	1.0491	1.0491
0.5	1.0489	1.0489	1.0489	1.0489	1.0489	1.0489
1	1.0489	1.0489	1.0489	1.0489	1.0489	1.049
2	1.0491	1.0491	1.0491	1.049	1.0491	1.0491
4	1.0492	1.0492	1.0492	1.049	1.0492	1.0493
5	1.0491	1.0492	1.0492	1.0489	1.0492	1.0493
10	1.0498	0	1.0499	1.0492	1.05	1.05
20	1.0498	0	1.0502	1.0482	1.0504	1.0501

Table A.52: Acoustic sharpness (acum) for a light vehicle with internal combustion engine at a pass-by recorded at 40 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.0205	1.0205	1.0205	1.0205	1.0205	1.0205
0.0313	1.0205	1.0205	1.0205	1.0205	1.0205	1.0205
0.0625	1.0206	1.0206	1.0206	1.0206	1.0206	1.0206
0.125	1.0206	1.0206	1.0206	1.0206	1.0206	1.0206
0.25	1.0207	1.0207	1.0207	1.0207	1.0207	1.0207
0.5	1.0205	1.0205	1.0206	1.0205	1.0205	1.0206
1	1.0207	1.0207	1.0207	1.0207	1.0207	1.0207
2	1.0209	1.0209	1.0209	1.0208	1.0209	1.021
4	1.0214	1.0214	1.0214	1.0212	1.0214	1.0215
5	1.0214	1.0215	1.0214	1.0211	1.0215	1.0216
10	1.0224	0	1.0225	1.0216	1.0226	1.0226
20	1.023	0	1.0234	1.0212	1.0236	1.0233

Table A.53: Acoustic sharpness (acum) for a heavy vehicle with electric motor at a pass-by recorded at 50 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.1919	1.1919	1.1919	1.1919	1.1919	1.1919
0.0313	1.1919	1.1919	1.1919	1.1919	1.1919	1.1919
0.0625	1.192	1.192	1.192	1.192	1.192	1.192
0.125	1.192	1.192	1.192	1.192	1.192	1.192
0.25	1.1921	1.1921	1.1921	1.1921	1.1921	1.1921
0.5	1.1919	1.1919	1.1919	1.1919	1.1919	1.1919
1.0	1.1919	1.1919	1.1919	1.1919	1.1919	1.1919
2.0	1.192	1.1921	1.192	1.192	1.1921	1.192
4.0	1.1921	1.1922	1.1921	1.192	1.1922	1.1921
5.0	1.1919	1.1921	1.192	1.1918	1.1921	1.1918
10.0	1.1918	0	1.1921	1.1911	1.1922	1.1915
20.0	1.19	0	1.1909	1.1877	1.191	1.1892

Table A.54: Acoustic sharpness (acum) for a heavy vehicle with internal combustion at a pass-by recorded at 50 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.2683	1.2683	1.2683	1.2683	1.2683	1.2683
0.0313	1.2683	1.2683	1.2683	1.2683	1.2683	1.2683
0.0625	1.2683	1.2683	1.2683	1.2683	1.2683	1.2683
0.125	1.2684	1.2684	1.2684	1.2684	1.2684	1.2684
0.25	1.2684	1.2684	1.2684	1.2684	1.2684	1.2684
0.5	1.2683	1.2683	1.2683	1.2683	1.2683	1.2683
1.0	1.2683	1.2684	1.2684	1.2683	1.2684	1.2683
2.0	1.2684	1.2684	1.2684	1.2684	1.2684	1.2684
4.0	1.2682	1.2683	1.2683	1.2681	1.2683	1.2682
5.0	1.2678	1.268	1.2679	1.2676	1.268	1.2677
10.0	1.2675	0	1.2678	1.2667	1.2679	1.2671
20.0	1.2652	0	1.2662	1.2626	1.2663	1.2642

Table A.55: Acoustic sharpness (acum) for a ligth vehicle with electric motor at a pass-by recorded at 50 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.1109	1.1109	1.1109	1.1109	1.1109	1.1109
0.0313	1.1109	1.1109	1.1109	1.1109	1.1109	1.1109
0.0625	1.1109	1.1109	1.1109	1.1109	1.1109	1.1109
0.125	1.111	1.111	1.111	1.111	1.111	1.111
0.25	1.111	1.111	1.111	1.111	1.111	1.111
0.5	1.1109	1.1109	1.1109	1.1109	1.1109	1.1109
1.0	1.111	1.111	1.111	1.111	1.111	1.1111
2.0	1.1111	1.1111	1.1111	1.111	1.1111	1.1111
4.0	1.1113	1.1113	1.1113	1.1111	1.1113	1.1114
5.0	1.1113	1.1113	1.1113	1.1111	1.1113	1.1114
10.0	1.112	0	1.1121	1.1114	1.1121	1.1122
20.0	1.1123	0	1.1126	1.111	1.1128	1.1126

Table A.56: Acoustic sharpness (acum) for a light vehicle with internal combustion engine at a pass-by recorded at 50 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.97447	0.97447	0.97447	0.97447	0.97447	0.97447
0.0313	0.97444	0.97444	0.97444	0.97444	0.97444	0.97445
0.0625	0.9745	0.9745	0.9745	0.97449	0.9745	0.9745
0.125	0.97453	0.97453	0.97453	0.97453	0.97453	0.97454
0.25	0.97462	0.97462	0.97462	0.97461	0.97462	0.97462
0.5	0.97454	0.97454	0.97454	0.97453	0.97454	0.97456
1.0	0.97459	0.97459	0.9746	0.97457	0.97459	0.97462
2.0	0.97464	0.97465	0.97465	0.9746	0.97465	0.9747
4.0	0.97494	0.97498	0.97496	0.97479	0.97498	0.97505
5.0	0.97487	0.97492	0.97489	0.97466	0.97492	0.97498
10.0	0.97536	0	0.97546	0.97481	0.97553	0.97554
20.0	0.97555	0	0.97586	0.97416	0.97601	0.97583

A.2.3 Roughness calculations

Table A.57: Acoustic roughness (aspers) for a heavy vehicle with an electric motor at a pass-by recorded at 40 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.07175	0.07175	0.071749	0.071748	0.07175	0.07175
0.0313	0.068565	0.068565	0.068563	0.068566	0.068565	0.068566
0.0625	0.068623	0.068623	0.06862	0.068621	0.068623	0.068624
0.125	0.068641	0.068641	0.06864	0.068641	0.068641	0.068647
0.25	0.071834	0.071834	0.068681	0.071839	0.071834	0.068691
0.5	0.068916	0.068917	0.068918	0.068912	0.068917	0.068996
1	0.069249	0.06925	0.069247	0.069245	0.06925	0.069257
2	0.069844	0.069843	0.06986	0.069834	0.069842	0.069847
4	0.071368	0.071362	0.071389	0.071389	0.071361	0.071384
5	0.072418	0.072407	0.07242	0.072446	0.072408	0.072448
10	0.061074	0	0.061084	0.061099	0.061028	0.060995
20	0.05211	0	0.052341	0.052031	0.052156	0.06026

Table A.58: Acoustic roughness (aspers) for a heavy vehicle with internal combustion engine at a pass-by recorded at 40 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.062439	0.062439	0.062439	0.06244	0.062439	0.062438
0.0313	0.062439	0.062439	0.062439	0.062441	0.06244	0.062439
0.0625	0.062476	0.062476	0.062476	0.062478	0.062476	0.062475
0.125	0.062502	0.062502	0.062501	0.062503	0.062502	0.062497
0.25	0.062593	0.062593	0.062595	0.062593	0.062593	0.062592
0.5	0.062783	0.062783	0.062785	0.062787	0.062783	0.062778
1	0.063107	0.063107	0.063105	0.063111	0.063107	0.063093
2	0.063794	0.063794	0.06378	0.063792	0.063795	0.063781
4	0.065322	0.065322	0.065288	0.06531	0.065322	0.065279
5	0.066116	0.066121	0.06611	0.066127	0.066121	0.066085
10	0.069766	0	0.069759	0.069792	0.069769	0.06971
20	0.077155	0	0.077254	0.077323	0.077097	0.076859

Table A.59: Acoustic roughness (aspers) for a light vehicle with electric motor at a pass-by recorded at 40 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0759	0.0759	0.0759	0.075899	0.0759	0.0759
0.0313	0.075866	0.075866	0.075865	0.075865	0.075866	0.075865
0.0625	0.075927	0.075927	0.075928	0.075928	0.075927	0.075918
0.125	0.075962	0.075962	0.075962	0.07596	0.075962	0.075957
0.25	0.075998	0.075998	0.075996	0.076002	0.075998	0.075986
0.5	0.076497	0.076496	0.07649	0.076489	0.076497	0.076482
1.0	0.076854	0.076861	0.076853	0.076853	0.076862	0.076854
2.0	0.07767	0.07767	0.077657	0.077666	0.077671	0.077667
4.0	0.079295	0.079304	0.079322	0.079329	0.079313	0.079327
5.0	0.080612	0.080628	0.080624	0.080611	0.080625	0.080643
10.0	0.08239	0	0.08242	0.082414	0.082381	0.082364
20.0	0.079304	0	0.07939	0.079372	0.079281	0.079376

Table A.60: Acoustic roughness (aspers) for a light vehicle with internal combustion engine at a pass-by recorded at 40 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.07519	0.07519	0.07519	0.075188	0.07519	0.075193
0.0313	0.075151	0.075151	0.075151	0.075148	0.075151	0.075156
0.0625	0.075209	0.075209	0.07521	0.075205	0.075209	0.075212
0.125	0.075239	0.075239	0.075236	0.075232	0.075239	0.075241
0.25	0.075275	0.075275	0.075272	0.075265	0.075275	0.075275
0.5	0.075717	0.075717	0.07572	0.075727	0.075717	0.07571
1.0	0.07819	0.07819	0.078185	0.078206	0.07819	0.078192
2.0	0.079051	0.079049	0.079059	0.079054	0.07905	0.079034
4.0	0.07196	0.071968	0.071972	0.07196	0.071967	0.071974
5.0	0.081933	0.081945	0.081927	0.081932	0.081945	0.081929
10.0	0.083851	0	0.083884	0.083824	0.083858	0.083891
20.0	0.086287	0	0.082266	0.086174	0.086282	0.081247

Table A.61: Acoustic roughness (aspers) for a heavy vehicle with electric motor at a pass-by recorded at 50 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.054278	0.054278	0.054279	0.054277	0.054278	0.054278
0.0313	0.054255	0.054255	0.054255	0.054254	0.054255	0.054254
0.0625	0.054317	0.054318	0.054317	0.054316	0.054317	0.054317
0.125	0.054316	0.054316	0.054307	0.054307	0.054316	0.054315
0.25	0.085796	0.085796	0.085795	0.085786	0.085796	0.085801
0.5	0.054509	0.054509	0.060723	0.054506	0.054509	0.060727
1.0	0.061053	0.061052	0.061026	0.061027	0.061052	0.061048
2.0	0.06171	0.061708	0.061705	0.061699	0.061708	0.061723
4.0	0.08967	0.089667	0.089681	0.089647	0.089667	0.089698
5.0	0.063887	0.063885	0.063896	0.06386	0.063884	0.073673
10.0	0.067394	0	0.067412	0.067307	0.067379	0.067436
20.0	0.07448	0	0.074342	0.074296	0.074419	0.074666

Table A.62: Acoustic roughness (aspers) for a heavy vehicle with internal combustion engine at a pass-by recorded at 50 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.10887	0.10887	0.10887	0.10887	0.10887	0.10887
0.0313	0.10887	0.10887	0.10887	0.10887	0.10887	0.10887
0.0625	0.10884	0.10884	0.10884	0.10884	0.10884	0.10884
0.125	0.10883	0.10883	0.10883	0.10884	0.10883	0.10884
0.25	0.1089	0.1089	0.10891	0.10891	0.1089	0.1089
0.5	0.10931	0.10931	0.10931	0.10931	0.10931	0.10931
1.0	0.11005	0.11005	0.11005	0.11005	0.11005	0.11008
2.0	0.11096	0.11096	0.11096	0.11096	0.11096	0.111
4.0	0.11257	0.11257	0.11257	0.11256	0.11257	0.1126
5.0	0.1147	0.1147	0.11472	0.11472	0.1147	0.11474
10.0	0.11922	0	0.11923	0.11922	0.11922	0.11559
20.0	0.13076	0	0.13082	0.13075	0.13078	0.13072

Table A.63: Acoustic roughness (aspers) for a lgt vehicle with electric motor at a pass-by recorded at 50 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.067438	0.067438	0.067439	0.067439	0.067438	0.067441
0.0313	0.067438	0.067438	0.067439	0.067436	0.067438	0.067441
0.0625	0.067472	0.067472	0.067472	0.06747	0.067472	0.067475
0.125	0.067488	0.067488	0.067488	0.067496	0.067488	0.067493
0.25	0.067544	0.067544	0.067575	0.067594	0.067544	0.067571
0.5	0.067757	0.067757	0.067784	0.067798	0.067757	0.067761
1.0	0.068074	0.068076	0.068131	0.068121	0.068074	0.068114
2.0	0.068852	0.068851	0.068904	0.06892	0.068852	0.068903
4.0	0.070342	0.070343	0.070373	0.070364	0.070338	0.07039
5.0	0.071243	0.071248	0.071252	0.071258	0.071243	0.071296
10.0	0.054235	0	0.054266	0.074665	0.054275	0.074711
20.0	0.082427	0	0.08242	0.082343	0.082447	0.082517

Table A.64: Acoustic roughness (aspers) for a lgt vehicle with internal combustion engine at a pass-by recorded at 50 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.066073	0.066073	0.066072	0.066071	0.066073	0.066072
0.0313	0.066074	0.066074	0.066072	0.066073	0.066074	0.066067
0.0625	0.066111	0.066111	0.066108	0.066107	0.066111	0.066107
0.125	0.06613	0.06613	0.066127	0.066129	0.06613	0.066127
0.25	0.066182	0.066182	0.066181	0.06618	0.066182	0.066174
0.5	0.048317	0.048318	0.048318	0.048321	0.048318	0.048318
1.0	0.048534	0.048535	0.048538	0.048543	0.048535	0.048543
2.0	0.049123	0.049125	0.049113	0.049103	0.049123	0.049122
4.0	0.050118	0.050115	0.057729	0.050117	0.050114	0.050127
5.0	0.050737	0.050747	0.050739	0.050734	0.050739	0.050789
10.0	0.053366	0	0.053404	0.053375	0.053374	0.053441
20.0	0.080973	0	0.081056	0.081035	0.081021	0.081011

A.2.4 Fluctuation strength

Table A.65: Fluctuation strength (vacil) presented as average values for a heavy vehicle with an electric motor at a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0076088	0.0076088	0.0076085	0.0076086	0.0076088	0.0076091
0.0313	0.0076201	0.0076201	0.0076201	0.0076199	0.0076201	0.0076203
0.0625	0.0075899	0.00759	0.00759	0.0075897	0.00759	0.0075904
0.125	0.0075696	0.0075696	0.0075696	0.0075695	0.0075696	0.0075695
0.25	0.0075298	0.0075298	0.0075298	0.0075297	0.0075298	0.0075294
0.5	0.0073209	0.0073209	0.0073199	0.0073187	0.0073209	0.00732
1	0.0070503	0.0070504	0.0070507	0.0070491	0.0070504	0.0070489
2	0.0065634	0.0065632	0.0065606	0.0065582	0.0065633	0.0065653
4	0.0057271	0.0057274	0.0057202	0.0057237	0.005728	0.0057334
5	0.005305	0.0053064	0.0052925	0.0053048	0.0053081	0.0053144
10	0.079146	0	0.078992	0.079382	0.079152	0.079567
20	0.0044528	0	0.0042917	0.004326	0.004377	0.0047222

Table A.66: Fluctuation strength (vacil) presented as average values for a heavy vehicle with internal combustion engine at a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.00835	0.00835	0.0083499	0.0083499	0.00835	0.00835
0.0313	0.0083632	0.0083632	0.0083633	0.008363	0.0083632	0.0083632
0.0625	0.0083272	0.0083272	0.0083271	0.0083266	0.0083272	0.0083272
0.125	0.0083061	0.0083061	0.0083059	0.0083055	0.0083061	0.0083059
0.25	0.0082563	0.0082563	0.008256	0.0082555	0.0082563	0.0082561
0.5	0.0079993	0.0079992	0.0079989	0.007998	0.0079992	0.0079997
1	0.0076431	0.0076433	0.0076415	0.0076394	0.0076433	0.0076421
2	0.0069988	0.0069988	0.006994	0.0069938	0.0069987	0.0070004
4	0.0059296	0.0059294	0.00592	0.0059226	0.0059269	0.0059342
5	0.0053941	0.0053939	0.0053811	0.0053911	0.0053879	0.0054024
10	0.08107	0	0.081102	0.081151	0.081072	0.08106
20	0.084402	0	0.084498	0.084691	0.084321	0.084091

Table A.67: Fluctuation strength (vacil) presented as average values for a light vehicle with electric motor at a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0064628	0.0064628	0.0064628	0.0064631	0.0064628	0.006463
0.0313	0.0064698	0.0064698	0.0064701	0.00647	0.0064698	0.0064704
0.0625	0.0064492	0.0064492	0.0064493	0.0064495	0.0064493	0.0064494
0.125	0.0064342	0.0064342	0.006435	0.0064348	0.0064342	0.0064347
0.25	0.0064037	0.0064037	0.0064046	0.0064057	0.0064037	0.006404
0.5	0.0062246	0.0062246	0.0062253	0.0062251	0.0062245	0.0062258
1.0	0.0060044	0.0060044	0.0060043	0.0060038	0.0060044	0.0060059
2.0	0.0055953	0.0055951	0.0055943	0.0055954	0.0055949	0.0056029
4.0	0.0048632	0.0048627	0.0048583	0.0048519	0.004862	0.0048766
5.0	0.0044651	0.0044652	0.0044525	0.0044619	0.0044643	0.0044756
10.0	0.010252	0	0.01003	0.0104	0.01018	0.010437
20.0	0.0041242	0	0.0040302	0.0040485	0.0040798	0.0042604

Table A.68: Fluctuation strength (vacil) presented as average values for a light vehicle with internal combustion engine at a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0073623	0.0073623	0.0073623	0.007362	0.0073623	0.0073621
0.0313	0.00737	0.00737	0.0073701	0.0073703	0.00737	0.0073706
0.0625	0.007348	0.007348	0.0073486	0.0073484	0.007348	0.0073494
0.125	0.0073318	0.0073318	0.0073319	0.0073321	0.0073318	0.0073334
0.25	0.0072995	0.0072995	0.0073	0.007299	0.0072995	0.0073028
0.5	0.007097	0.007097	0.0070973	0.0070969	0.007097	0.0070991
1.0	0.0068542	0.0068544	0.0068556	0.006852	0.0068544	0.0068598
2.0	0.0063912	0.0063911	0.0063921	0.0063871	0.0063911	0.0063991
4.0	0.0055773	0.0055779	0.0055693	0.0055741	0.005577	0.0055897
5.0	0.0051285	0.0051297	0.0051172	0.0051259	0.0051297	0.0051467
10.0	0.009133	0	0.0088588	0.0092988	0.0090455	0.0093074
20.0	0.0043026	0	0.0042119	0.0031344	0.0042591	0.0044465

Table A.69: Fluctuation strength (vacil) presented as average values for a heavy vehicle with an electric motor at a pass-by recorded at 50 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0087758	0.0087758	0.0087758	0.0087756	0.0087758	0.0087756
0.0313	0.0087842	0.0087842	0.008784	0.0087842	0.0087842	0.0087841
0.0625	0.0087534	0.0087535	0.0087535	0.008753	0.0087535	0.0087543
0.125	0.008726	0.008726	0.0087258	0.0087257	0.008726	0.0087279
0.25	0.0086792	0.0086792	0.0086788	0.0086788	0.0086792	0.0086814
0.5	0.0084267	0.0084267	0.0084269	0.0084254	0.0084267	0.0084313
1.0	0.0081061	0.0081066	0.0081068	0.0081011	0.0081066	0.0081146
2.0	0.007513	0.0075137	0.0075153	0.0075053	0.0075138	0.007522
4.0	0.0065037	0.0065047	0.0064982	0.0064916	0.006505	0.0065234
5.0	0.0060015	0.0060026	0.005989	0.0059857	0.0060041	0.0060332
10.0	0.0063144	0	0.0061031	0.0069961	0.0063012	0.0069872
20.0	0.0046027	0	0.0044376	0.0034711	0.0045253	0.0048743

Table A.70: Fluctuation strength (vacil) presented as average values for a heavy vehicle with internal combustion engine at a pass-by recorded at 50 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0088984	0.0088984	0.0088984	0.0088985	0.0088984	0.0088984
0.0313	0.0089122	0.0089122	0.0089122	0.0089121	0.0089122	0.0089122
0.0625	0.0088739	0.0088739	0.0088738	0.0088736	0.0088739	0.008874
0.125	0.0088491	0.0088492	0.0088494	0.0088487	0.0088492	0.0088495
0.25	0.0087965	0.0087965	0.0087963	0.0087957	0.0087965	0.0087965
0.5	0.0085247	0.0085247	0.0085249	0.0085234	0.0085247	0.0085257
1.0	0.0081542	0.0081542	0.0081543	0.0081533	0.0081542	0.0081565
2.0	0.0074685	0.0074683	0.0074679	0.0074651	0.0074683	0.0074734
4.0	0.0063079	0.0063082	0.0063046	0.0063024	0.0063083	0.0063228
5.0	0.005709	0.0057095	0.0057002	0.0057026	0.0057105	0.0057296
10.0	0.086122	0	0.086096	0.086101	0.086126	0.086156
20.0	0.089988	0	0.090067	0.089984	0.089991	0.089928

Table A.71: Fluctuation strength (vacil) presented as average values for a light with electric motor engine at a pass-by recorded at 50 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0070049	0.0070049	0.0070051	0.0070052	0.0070049	0.0070052
0.0313	0.0070125	0.0070125	0.007013	0.007013	0.0070125	0.007013
0.0625	0.0069933	0.0069933	0.0069937	0.0069938	0.0069933	0.0069937
0.125	0.0069772	0.0069772	0.0069781	0.0069774	0.0069772	0.0069778
0.25	0.0069489	0.0069489	0.0069496	0.0069489	0.0069489	0.0069501
0.5	0.0067518	0.0067518	0.0067522	0.0067514	0.0067518	0.006753
1.0	0.0065239	0.006524	0.0065223	0.0065217	0.006524	0.0065271
2.0	0.0060688	0.0060689	0.0060688	0.0060652	0.0060686	0.0060764
4.0	0.0052678	0.0052681	0.0052621	0.0052628	0.0052675	0.0052799
5.0	0.0048408	0.0048421	0.0048327	0.0048352	0.0048405	0.0048536
10.0	0.016646	0	0.016636	0.016704	0.01665	0.016641
20.0	0.0031291	0	0.0030543	0.0030234	0.003087	0.003297

Table A.72: Fluctuation strength (vacil) presented as average values for a light with internal combustion engine at a pass-by recorded at 50 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0084426	0.0084426	0.0084426	0.0084426	0.0084426	0.0084426
0.0313	0.0084505	0.0084505	0.0084502	0.0084501	0.0084505	0.0084503
0.0625	0.0084306	0.0084306	0.0084301	0.0084298	0.0084306	0.0084304
0.125	0.0084137	0.0084137	0.0084138	0.0084127	0.0084137	0.0084141
0.25	0.0083836	0.0083836	0.0083833	0.0083823	0.0083836	0.0083829
0.5	0.0081713	0.0081713	0.0081712	0.0081691	0.0081713	0.0081713
1.0	0.0079068	0.0079069	0.0079072	0.0079023	0.0079069	0.0079084
2.0	0.0074072	0.0074073	0.007405	0.0074026	0.0074074	0.0074101
4.0	0.0065336	0.0065338	0.0065279	0.0065332	0.0065335	0.0065435
5.0	0.0060604	0.0060609	0.0060522	0.0060574	0.0060592	0.006073
10.0	0.015886	0	0.015835	0.015889	0.015876	0.015879
20.0	0.0044496	0	0.0043665	0.0037114	0.0044094	0.0045956

A.2.5 A-weighted values

Table A.73: A-weighted values (dB) presented as single numbers for a heavy vehicle with electric motor at a pass-by recorded at 40 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-30.399	-30.399	-30.399	-30.399	-30.399	-30.399
0.0313	-30.4	-30.4	-30.4	-30.4	-30.4	-30.4
0.0625	-30.399	-30.399	-30.399	-30.399	-30.399	-30.399
0.125	-30.398	-30.398	-30.398	-30.398	-30.398	-30.398
0.25	-30.398	-30.398	-30.398	-30.398	-30.398	-30.398
0.5	-30.394	-30.394	-30.394	-30.394	-30.394	-30.394
1.0	-30.389	-30.389	-30.389	-30.389	-30.389	-30.389
2.0	-30.379	-30.379	-30.379	-30.379	-30.379	-30.379
4.0	-30.359	-30.359	-30.359	-30.36	-30.359	-30.36
5.0	-30.348	-30.348	-30.348	-30.349	-30.348	-30.349
10.0	-30.307	0	-30.306	-30.309	-30.306	-30.308
20.0	-30.242	0	-30.24	-30.248	-30.24	-30.244

Table A.74: A-weighted values (dB) presented as single numbers for a heavy vehicle with an internal combustion engine at a pass-by recorded at 40 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-26.641	-26.641	-26.641	-26.641	-26.641	-26.641
0.0313	-26.641	-26.641	-26.641	-26.641	-26.641	-26.641
0.0625	-26.641	-26.641	-26.641	-26.641	-26.641	-26.641
0.125	-26.64	-26.64	-26.64	-26.64	-26.64	-26.64
0.25	-26.64	-26.64	-26.64	-26.64	-26.64	-26.64
0.5	-26.636	-26.636	-26.636	-26.636	-26.636	-26.636
1.0	-26.631	-26.631	-26.631	-26.631	-26.631	-26.631
2.0	-26.62	-26.62	-26.62	-26.62	-26.62	-26.62
4.0	-26.599	-26.599	-26.599	-26.6	-26.599	-26.599
5.0	-26.588	-26.587	-26.587	-26.588	-26.587	-26.588
10.0	-26.545	0	-26.544	-26.547	-26.544	-26.546
20.0	-26.482	0	-26.479	-26.488	-26.479	-26.484

Table A.75: A-weighted values (dB) presented as single numbers for a light vehicle with electric motor at a pass-by recorded at 40 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-32.082	-32.082	-32.082	-32.082	-32.082	-32.082
0.0313	-32.083	-32.083	-32.083	-32.083	-32.083	-32.083
0.0625	-32.082	-32.082	-32.082	-32.082	-32.082	-32.082
0.125	-32.082	-32.082	-32.082	-32.082	-32.082	-32.082
0.25	-32.08	-32.08	-32.08	-32.08	-32.08	-32.08
0.5	-32.076	-32.076	-32.076	-32.076	-32.076	-32.076
1.0	-32.071	-32.071	-32.071	-32.071	-32.071	-32.071
2.0	-32.06	-32.06	-32.06	-32.06	-32.06	-32.06
4.0	-32.037	-32.037	-32.037	-32.037	-32.037	-32.037
5.0	-32.026	-32.026	-32.026	-32.026	-32.026	-32.026
10.0	-31.982	0	-31.981	-31.984	-31.981	-31.982
20.0	-31.911	0	-31.909	-31.917	-31.909	-31.912

Table A.76: A-weighted values (dB) presented as single numbers for a light vehicle with internal combustion engine at a pass-by recorded at 40 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-31.155	-31.155	-31.155	-31.155	-31.155	-31.155
0.0313	-31.155	-31.155	-31.155	-31.155	-31.155	-31.155
0.0625	-31.155	-31.155	-31.155	-31.155	-31.155	-31.155
0.125	-31.154	-31.154	-31.154	-31.154	-31.154	-31.154
0.25	-31.153	-31.153	-31.153	-31.153	-31.153	-31.153
0.5	-31.149	-31.149	-31.149	-31.149	-31.149	-31.149
1.0	-31.144	-31.144	-31.144	-31.144	-31.144	-31.144
2.0	-31.133	-31.133	-31.133	-31.133	-31.133	-31.133
4.0	-31.11	-31.11	-31.11	-31.11	-31.11	-31.11
5.0	-31.099	-31.098	-31.098	-31.099	-31.098	-31.099
10.0	-31.055	0	-31.054	-31.056	-31.054	-31.055
20.0	-30.984	0	-30.982	-30.99	-30.982	-30.985

Table A.77: A-weighted values (dB) presented as single numbers for a heavy vehicle with electric motor at a pass-by recorded at 50 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-29.246	-29.246	-29.246	-29.246	-29.246	-29.246
0.0313	-29.246	-29.246	-29.246	-29.246	-29.246	-29.246
0.0625	-29.246	-29.246	-29.246	-29.246	-29.246	-29.246
0.125	-29.245	-29.245	-29.245	-29.245	-29.245	-29.245
0.25	-29.244	-29.244	-29.244	-29.244	-29.244	-29.244
0.5	-29.24	-29.24	-29.24	-29.24	-29.24	-29.24
1.0	-29.235	-29.235	-29.235	-29.235	-29.235	-29.235
2.0	-29.224	-29.224	-29.224	-29.224	-29.224	-29.224
4.0	-29.203	-29.203	-29.203	-29.204	-29.203	-29.204
5.0	-29.193	-29.193	-29.193	-29.193	-29.193	-29.193
10.0	-29.152	0	-29.151	-29.154	-29.151	-29.153
20.0	-29.088	0	-29.085	-29.093	-29.085	-29.09

Table A.78: A-weighted values (dB) presented as single numbers for a heavy vehicle with an internal combustion engine at a pass-by recorded at 50 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-26.635	-26.635	-26.635	-26.635	-26.635	-26.635
0.0313	-26.635	-26.635	-26.635	-26.635	-26.635	-26.635
0.0625	-26.634	-26.634	-26.634	-26.634	-26.634	-26.634
0.125	-26.634	-26.634	-26.634	-26.634	-26.634	-26.634
0.25	-26.633	-26.633	-26.633	-26.633	-26.633	-26.633
0.5	-26.629	-26.629	-26.629	-26.629	-26.629	-26.629
1.0	-26.624	-26.624	-26.624	-26.624	-26.624	-26.624
2.0	-26.614	-26.614	-26.614	-26.614	-26.614	-26.614
4.0	-26.593	-26.593	-26.593	-26.594	-26.593	-26.594
5.0	-26.582	-26.582	-26.582	-26.583	-26.582	-26.582
10.0	-26.539	0	-26.538	-26.542	-26.538	-26.54
20.0	-26.478	0	-26.475	-26.485	-26.475	-26.48

Table A.79: A-weighted values (dB) presented as single numbers for a light vehicle with electric motor at a pass-by recorded at 50 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-30.255	-30.255	-30.255	-30.255	-30.255	-30.255
0.0313	-30.255	-30.255	-30.255	-30.255	-30.255	-30.255
0.0625	-30.255	-30.255	-30.255	-30.255	-30.255	-30.255
0.125	-30.254	-30.254	-30.254	-30.254	-30.254	-30.254
0.25	-30.253	-30.253	-30.253	-30.254	-30.253	-30.253
0.5	-30.25	-30.25	-30.25	-30.25	-30.25	-30.25
1.0	-30.245	-30.245	-30.245	-30.245	-30.245	-30.245
2.0	-30.233	-30.233	-30.233	-30.233	-30.233	-30.233
4.0	-30.209	-30.209	-30.209	-30.21	-30.209	-30.209
5.0	-30.198	-30.197	-30.198	-30.198	-30.197	-30.198
10.0	-30.154	0	-30.154	-30.156	-30.154	-30.155
20.0	-30.081	0	-30.079	-30.087	-30.079	-30.082

Table A.80: A-weighted values (dB) presented as single numbers for a light vehicle with internal combustion engine at a pass-by recorded at 50 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-29.749	-29.749	-29.749	-29.749	-29.749	-29.749
0.0313	-29.749	-29.749	-29.749	-29.749	-29.749	-29.749
0.0625	-29.748	-29.748	-29.748	-29.748	-29.748	-29.748
0.125	-29.748	-29.748	-29.748	-29.748	-29.748	-29.748
0.25	-29.747	-29.747	-29.747	-29.747	-29.747	-29.747
0.5	-29.744	-29.744	-29.744	-29.744	-29.744	-29.744
1.0	-29.738	-29.738	-29.738	-29.739	-29.738	-29.738
2.0	-29.727	-29.727	-29.727	-29.727	-29.727	-29.727
4.0	-29.703	-29.703	-29.703	-29.704	-29.703	-29.703
5.0	-29.691	-29.691	-29.691	-29.692	-29.691	-29.691
10.0	-29.648	0	-29.647	-29.65	-29.647	-29.648
20.0	-29.575	0	-29.573	-29.581	-29.573	-29.576

A.3 Barrier with Doppler effect

A.3.1 Loudness calculations

Table A.81: Acoustic loudness (sones) for heavy vehicle with electric motor at a pass-by recorded at 40 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	2.158	2.1581	2.158	2.1585	2.1581	2.1576
0.0313	2.158	2.158	2.1579	2.1589	2.158	2.1572
0.0625	2.1582	2.1582	2.1582	2.16	2.1582	2.1565
0.125	2.1583	2.1583	2.1584	2.1618	2.1583	2.1547
0.25	2.1587	2.1586	2.1573	2.1672	2.1586	2.1528
0.5	2.1608	2.1609	2.159	2.1727	2.1609	2.1461
1.0	2.1624	2.1625	2.16	2.188	2.1623	2.1349
2.0	2.1827	2.1838	2.1782	2.2346	2.1838	2.1261
4.0	2.1989	2.2038	2.1952	2.2918	2.2038	2.0833
5.0	2.1971	2.2037	2.1949	2.3093	2.2037	2.0575
10.0	2.1637	0	2.1721	2.3516	2.1783	1.8774
20.0	2.0244	0	2.0482	2.3104	2.0841	1.4628

Table A.82: Acoustic loudness (sones) for heavy vehicle with internal combustion engine at a pass-by recorded at 40 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	2.158	2.1581	2.158	2.1585	2.1581	2.1576
0.0313	2.158	2.158	2.1579	2.1589	2.158	2.1572
0.0625	2.1582	2.1582	2.1582	2.16	2.1582	2.1565
0.125	2.1583	2.1583	2.1584	2.1618	2.1583	2.1547
0.25	2.1587	2.1586	2.1573	2.1672	2.1586	2.1528
0.5	2.1608	2.1609	2.159	2.1727	2.1609	2.1461
1.0	2.1624	2.1625	2.16	2.188	2.1623	2.1349
2.0	2.1827	2.1838	2.1782	2.2346	2.1838	2.1261
4.0	2.1989	2.2038	2.1952	2.2918	2.2038	2.0833
5.0	2.1971	2.2037	2.1949	2.3093	2.2037	2.0575
10.0	2.1637	0	2.1721	2.3516	2.1783	1.8774
20.0	2.0244	0	2.0482	2.3104	2.0841	1.4628

Table A.83: Acoustic loudness (sones) for a light vehicle with electric motor at a pass-by recorded at 40 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.2166	1.2166	1.2166	1.2169	1.2166	1.2163
0.0313	1.2165	1.2165	1.2166	1.2171	1.2165	1.216
0.0625	1.2167	1.2167	1.2166	1.2179	1.2167	1.2157
0.125	1.2168	1.2168	1.217	1.2187	1.2169	1.2144
0.25	1.2173	1.2171	1.2161	1.2229	1.2171	1.214
0.5	1.2188	1.2186	1.218	1.226	1.2187	1.2093
1.0	1.2194	1.2194	1.2174	1.2379	1.2194	1.2037
2.0	1.2387	1.2392	1.2359	1.2708	1.2392	1.2049
4.0	1.2414	1.2444	1.2391	1.2969	1.2441	1.1763
5.0	1.2385	1.2428	1.2381	1.3064	1.2428	1.1488
10.0	1.2245	0	1.2326	1.3435	1.2347	1.043
20.0	1.1338	0	1.1529	1.311	1.1759	0.78432

Table A.84: Acoustic loudness (sones) for a light vehicle with internal combustion engine at a pass-by recorded at 40 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.5779	1.5779	1.5778	1.5782	1.5779	1.5776
0.0313	1.5778	1.5778	1.5778	1.5785	1.5778	1.577
0.0625	1.578	1.578	1.5779	1.5793	1.578	1.5768
0.125	1.5781	1.5781	1.5784	1.5801	1.5781	1.5752
0.25	1.5785	1.5784	1.5775	1.5852	1.5783	1.5746
0.5	1.5805	1.5804	1.58	1.5888	1.5805	1.5695
1.0	1.5814	1.5814	1.5793	1.6021	1.5815	1.5629
2.0	1.6017	1.6025	1.5988	1.6388	1.6024	1.5598
4.0	1.6093	1.6128	1.6062	1.6767	1.6125	1.5299
5.0	1.6081	1.6132	1.6075	1.688	1.6133	1.5003
10.0	1.5826	0	1.5909	1.7273	1.5948	1.3584
20.0	1.4749	0	1.498	1.6903	1.5266	1.0524

Table A.85: Acoustic loudness (sones) for a heavy vehicle with electric engine at a pass-by recorded at 50 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	2.6835	2.6835	2.6835	2.684	2.6835	2.6829
0.0313	2.6834	2.6834	2.6836	2.6845	2.6834	2.6823
0.0625	2.6836	2.6836	2.6835	2.6858	2.6836	2.6816
0.125	2.6837	2.6838	2.6838	2.6878	2.6838	2.6795
0.25	2.6839	2.6839	2.6816	2.6946	2.6838	2.6768
0.5	2.6863	2.6865	2.6839	2.6998	2.6864	2.669
1.0	2.689	2.6894	2.6858	2.7227	2.6894	2.6528
2.0	2.7094	2.7105	2.7044	2.7738	2.7105	2.6359
4.0	2.7305	2.7365	2.7264	2.8397	2.7365	2.5888
5.0	2.7252	2.7335	2.7228	2.8544	2.7336	2.5478
10.0	2.6794	0	2.6944	2.899	2.698	2.3302
20.0	2.5086	0	2.5412	2.8463	2.5788	1.8437

Table A.86: Acoustic loudness (sones) for a heavy vehicle with internal combustion engine at a pass-by recorded at 50 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	4.4503	4.4503	4.4502	4.4509	4.4503	4.4495
0.0313	4.4502	4.4502	4.4502	4.4516	4.4502	4.4486
0.0625	4.4506	4.4505	4.4504	4.4538	4.4505	4.4478
0.125	4.4507	4.4507	4.4505	4.4568	4.4506	4.4448
0.25	4.4512	4.451	4.4477	4.4664	4.4509	4.4418
0.5	4.4547	4.4547	4.4518	4.4753	4.4548	4.4288
1.0	4.4611	4.4611	4.4587	4.5068	4.4612	4.4122
2.0	4.4881	4.4903	4.4842	4.5784	4.4904	4.3864
4.0	4.5212	4.5291	4.5195	4.6835	4.5292	4.3205
5.0	4.5178	4.53	4.5182	4.7053	4.53	4.2733
10.0	4.4599	0	4.481	4.7736	4.4859	3.9594
20.0	4.2102	0	4.2584	4.6982	4.3132	3.2527

Table A.87: Acoustic loudness (sones) for a light vehicle with electric motor at a pass-by recorded at 50 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.7251	1.7251	1.725	1.7254	1.7251	1.7249
0.0313	1.7251	1.7251	1.7251	1.7256	1.7251	1.7245
0.0625	1.7252	1.7252	1.7252	1.7263	1.7252	1.7242
0.125	1.7253	1.7253	1.7256	1.7272	1.7253	1.7228
0.25	1.7256	1.7256	1.7246	1.7318	1.7256	1.7217
0.5	1.7272	1.7273	1.7258	1.7348	1.7272	1.7174
1.0	1.7277	1.728	1.7261	1.7456	1.728	1.7062
2.0	1.7497	1.7503	1.7462	1.7873	1.7502	1.7119
4.0	1.7541	1.7575	1.751	1.8236	1.7575	1.6712
5.0	1.7471	1.7525	1.7465	1.8281	1.7526	1.6398
10.0	1.7298	0	1.739	1.8678	1.7418	1.5081
20.0	1.6187	0	1.6434	1.8292	1.6722	1.1868

Table A.88: Acoustic loudness (sones) for a light vehicle with electric motor at a pass-by recorded at 50 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	2.1888	2.1888	2.1887	2.1891	2.1888	2.1884
0.0313	2.1887	2.1887	2.1887	2.1894	2.1887	2.1879
0.0625	2.1889	2.1889	2.1888	2.1905	2.1889	2.1874
0.125	2.189	2.189	2.1891	2.1915	2.189	2.1857
0.25	2.1893	2.1892	2.188	2.197	2.1892	2.1837
0.5	2.1911	2.1913	2.1898	2.2013	2.1912	2.1782
1.0	2.1923	2.1926	2.1903	2.2163	2.1926	2.1651
2.0	2.2156	2.2166	2.2111	2.2647	2.2165	2.1649
4.0	2.2267	2.231	2.2207	2.3176	2.2309	2.1209
5.0	2.2233	2.2299	2.2196	2.3286	2.2299	2.087
10.0	2.2068	0	2.2164	2.3834	2.2221	1.9172
20.0	2.0554	0	2.0844	2.3284	2.1234	1.5042

A.3.2 Sharpness calculations

Table A.89: Acoustic sharpness (acum) for a heavy vehicle with electric motor at a pass-by recorded at 40 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.0843	1.0843	1.0843	1.0844	1.0843	1.0843
0.0313	1.0843	1.0843	1.0843	1.0843	1.0843	1.0843
0.0625	1.0843	1.0844	1.0844	1.0844	1.0844	1.0842
0.125	1.0844	1.0844	1.0844	1.0845	1.0844	1.0843
0.25	1.0845	1.0845	1.0847	1.0844	1.0845	1.0843
0.5	1.0842	1.0843	1.0844	1.0848	1.0843	1.0841
1.0	1.0875	1.0877	1.0879	1.0883	1.0876	1.0864
2.0	1.0859	1.086	1.0869	1.0863	1.086	1.0844
4.0	1.0759	1.0761	1.0775	1.08	1.0761	1.0723
5.0	1.077	1.0772	1.0784	1.0827	1.0772	1.072
10.0	1.0802	0	1.082	1.0872	1.0807	1.0696
20.0	1.0709	0	1.0733	1.0815	1.0732	1.0461

Table A.90: Acoustic sharpness (acum) for a heavy vehicle with internal combustion engine at a pass-by recorded at 40 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.2048	1.2048	1.2048	1.2048	1.2048	1.2047
0.0313	1.2048	1.2047	1.2048	1.2049	1.2047	1.2047
0.0625	1.2048	1.2048	1.2047	1.2051	1.2048	1.2046
0.125	1.2049	1.2049	1.2049	1.205	1.2049	1.2045
0.25	1.2052	1.2052	1.2055	1.2056	1.2051	1.2043
0.5	1.2045	1.2045	1.205	1.2062	1.2045	1.203
1.0	1.2103	1.2102	1.2112	1.2128	1.2103	1.208
2.0	1.2064	1.2066	1.2074	1.2095	1.2066	1.2023
4.0	1.1978	1.1983	1.1998	1.2046	1.1983	1.1875
5.0	1.1975	1.1982	1.1999	1.2069	1.1982	1.1844
10.0	1.198	0	1.1996	1.2083	1.1985	1.1795
20.0	1.1858	0	1.1896	1.1968	1.1874	1.1606

Table A.91: Acoustic sharpness (acum) for a light vehicle with electric motor at a pass-by recorded at 40 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.0554	1.0554	1.0554	1.0553	1.0554	1.0554
0.0313	1.0553	1.0553	1.0553	1.0553	1.0553	1.0554
0.0625	1.0554	1.0554	1.0554	1.0553	1.0554	1.0554
0.125	1.0554	1.0554	1.0554	1.0553	1.0554	1.0555
0.25	1.0554	1.0555	1.0558	1.0548	1.0555	1.0555
0.5	1.0558	1.0558	1.0562	1.0557	1.0558	1.0565
1.0	1.0564	1.0564	1.057	1.0549	1.0565	1.057
2.0	1.0574	1.0575	1.0575	1.0553	1.0574	1.0599
4.0	1.0493	1.0493	1.0498	1.0488	1.0493	1.0497
5.0	1.0524	1.0523	1.0526	1.0515	1.0523	1.0539
10.0	1.051	0	1.0511	1.0492	1.0509	1.0511
20.0	1.0502	0	1.0515	1.0478	1.0517	1.0518

Table A.92: Acoustic sharpness (acum) for a light vehicle with internal combustion engine at a pass-by recorded at 40 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.0157	1.0157	1.0157	1.0157	1.0157	1.0157
0.0313	1.0157	1.0157	1.0157	1.0157	1.0157	1.0156
0.0625	1.0158	1.0158	1.0158	1.0157	1.0158	1.0157
0.125	1.0158	1.0158	1.0158	1.0158	1.0158	1.0159
0.25	1.0159	1.0158	1.0161	1.0155	1.0158	1.0159
0.5	1.0162	1.0162	1.0165	1.0164	1.0163	1.0166
1.0	1.0172	1.0172	1.0175	1.0167	1.0172	1.0172
2.0	1.0181	1.0181	1.0182	1.0176	1.018	1.0201
4.0	1.0099	1.0098	1.0104	1.0102	1.0097	1.0094
5.0	1.0123	1.0124	1.0129	1.0134	1.0124	1.0121
10.0	1.014	0	1.0152	1.0125	1.0141	1.014
20.0	1.0103	0	1.0119	1.0097	1.0118	1.0096

Table A.93: Acoustic sharpness (acum) for a heavy vehicle with electric motor at a pass-by recorded at 50 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.1529	1.1529	1.153	1.1529	1.1529	1.1529
0.0313	1.1529	1.1529	1.1529	1.153	1.1529	1.1529
0.0625	1.1529	1.153	1.1529	1.1529	1.1529	1.1528
0.125	1.153	1.153	1.1531	1.153	1.153	1.1528
0.25	1.153	1.153	1.1534	1.1528	1.153	1.1525
0.5	1.1528	1.1528	1.1532	1.1539	1.1528	1.1525
1.0	1.1565	1.1566	1.157	1.1569	1.1565	1.1562
2.0	1.1535	1.1537	1.1541	1.1549	1.1536	1.1522
4.0	1.1439	1.144	1.1454	1.1489	1.144	1.1389
5.0	1.1466	1.1468	1.1485	1.1533	1.1467	1.1412
10.0	1.1498	0	1.1513	1.1581	1.15	1.1369
20.0	1.1397	0	1.1414	1.1535	1.1423	1.1217

Table A.94: Acoustic sharpness (acum) for a heavy vehicle with internal combustion engine at a pass-by recorded at 50 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.2324	1.2324	1.2324	1.2323	1.2324	1.2324
0.0313	1.2323	1.2323	1.2324	1.2323	1.2323	1.2324
0.0625	1.2324	1.2324	1.2324	1.2323	1.2324	1.2323
0.125	1.2324	1.2324	1.2324	1.2325	1.2324	1.2325
0.25	1.2326	1.2326	1.2328	1.2323	1.2326	1.2329
0.5	1.2322	1.2323	1.2324	1.2326	1.2322	1.2329
1.0	1.2363	1.2362	1.236	1.2361	1.2362	1.2367
2.0	1.2324	1.2323	1.2324	1.2333	1.2323	1.2321
4.0	1.2241	1.2241	1.2244	1.2282	1.2242	1.2217
5.0	1.2258	1.2258	1.226	1.2304	1.2258	1.2219
10.0	1.2272	0	1.2273	1.2344	1.2274	1.2185
20.0	1.2194	0	1.2204	1.2286	1.2209	1.2074

Table A.95: Acoustic sharpness (acum) for a light vehicle with electric motor at a pass-by recorded at 50 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.0974	1.0974	1.0974	1.0974	1.0974	1.0974
0.0313	1.0974	1.0974	1.0974	1.0974	1.0974	1.0974
0.0625	1.0974	1.0974	1.0974	1.0973	1.0974	1.0974
0.125	1.0974	1.0974	1.0975	1.0974	1.0974	1.0975
0.25	1.0975	1.0975	1.0977	1.0971	1.0975	1.0974
0.5	1.0978	1.0977	1.098	1.0978	1.0977	1.0981
1.0	1.0987	1.0986	1.0989	1.0986	1.0986	1.0992
2.0	1.0992	1.0992	1.0995	1.0982	1.0992	1.1001
4.0	1.0917	1.0918	1.0924	1.0901	1.0918	1.0936
5.0	1.0954	1.0954	1.0964	1.0938	1.0954	1.0971
10.0	1.0949	0	1.0966	1.0926	1.0953	1.0949
20.0	1.0936	0	1.0952	1.0908	1.0948	1.0907

Table A.96: Acoustic sharpness (acum) for a light vehicle with electric motor at a pass-by recorded at 50 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.97226	0.97226	0.97225	0.97222	0.97226	0.97227
0.0313	0.97225	0.97224	0.97222	0.97218	0.97224	0.97226
0.0625	0.97229	0.97229	0.9723	0.97218	0.97229	0.97223
0.125	0.9723	0.97232	0.97231	0.9722	0.97231	0.97241
0.25	0.97233	0.97233	0.97244	0.97202	0.97233	0.97253
0.5	0.97257	0.97255	0.9727	0.97241	0.97256	0.97304
1.0	0.97335	0.97331	0.97354	0.97272	0.9733	0.97391
2.0	0.97476	0.97476	0.97516	0.97328	0.97475	0.97661
4.0	0.96727	0.96728	0.96865	0.96446	0.96726	0.96973
5.0	0.96881	0.96889	0.97069	0.96617	0.96893	0.9711
10.0	0.96515	0	0.9674	0.96227	0.96539	0.97095
20.0	0.96897	0	0.97104	0.96303	0.96955	0.97783

A.3.3 Roughness calculations

Table A.97: Acoustic roughness (aspers) for a heavy vehicle with an electric motor at a pass-by recorded at 40 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.070348	0.070345	0.070376	0.070363	0.070345	0.040258
0.0313	0.040264	0.070329	0.056688	0.040354	0.070328	0.040254
0.0625	0.070387	0.070381	0.070445	0.070494	0.070382	0.070382
0.125	0.0704	0.070386	0.070501	0.07054	0.070391	0.070479
0.25	0.070433	0.070419	0.040338	0.056951	0.070425	0.040301
0.5	0.040582	0.057099	0.054866	0.054897	0.057091	0.070953
1.0	0.055125	0.055074	0.040805	0.055366	0.055072	0.054798
2.0	0.055957	0.055827	0.062578	0.056569	0.055802	0.051216
4.0	0.043023	0.057419	0.074574	0.043876	0.057337	0.041023
5.0	0.043697	0.043513	0.075526	0.04892	0.043553	0.052453
10.0	0.062739	0	0.07455	0.082194	0.061646	0.074961
20.0	0.080648	0	0.085081	0.055425	0.049009	0.05247

Table A.98: Acoustic roughness (aspers) for a heavy vehicle with internal combustion engine at a pass-by recorded at 40 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.077054	0.077054	0.077041	0.077055	0.077054	0.077072
0.0313	0.077057	0.077056	0.07708	0.077076	0.077056	0.077058
0.0625	0.077061	0.07706	0.077067	0.077096	0.07706	0.07705
0.125	0.077063	0.077068	0.077074	0.077098	0.077065	0.077009
0.25	0.077123	0.07712	0.077054	0.077331	0.077125	0.077062
0.5	0.077655	0.07766	0.077737	0.077912	0.077657	0.077347
1.0	0.078138	0.078113	0.078334	0.078499	0.078111	0.051522
2.0	0.079057	0.052208	0.052204	0.052842	0.052193	0.051118
4.0	0.05383	0.05358	0.081112	0.069102	0.053661	0.065703
5.0	0.054774	0.054711	0.054106	0.083515	0.054571	0.079711
10.0	0.087723	0	0.070726	0.089091	0.087286	0.054056
20.0	0.098106	0	0.079473	0.078467	0.098233	0.057315

Table A.99: Acoustic roughness (aspers) for a light vehicle with electric motor at a pass-by recorded at 40 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.057995	0.057998	0.057971	0.058011	0.057997	0.057956
0.0313	0.05799	0.057991	0.057994	0.05797	0.05799	0.057978
0.0625	0.058025	0.058025	0.058047	0.058049	0.058029	0.058011
0.125	0.058052	0.058034	0.058067	0.058089	0.058037	0.057968
0.25	0.058133	0.058081	0.05814	0.058173	0.058083	0.058013
0.5	0.058775	0.058737	0.05876	0.039108	0.058745	0.045378
1.0	0.039374	0.039344	0.055275	0.055647	0.039317	0.054826
2.0	0.039992	0.039977	0.046548	0.056697	0.040018	0.04548
4.0	0.062257	0.062225	0.047959	0.051204	0.062174	0.054759
5.0	0.049258	0.059122	0.059001	0.04392	0.058946	0.056158
10.0	0.036112	0	0.054465	0.075655	0.068449	0.046538
20.0	0.052901	0	0.0604	0.043939	0.040813	0.061972

Table A.100: Acoustic roughness (aspers) for a light vehicle with internal combustion engine at a pass-by recorded at 40 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.059344	0.059345	0.059341	0.059352	0.059345	0.059343
0.0313	0.059338	0.05934	0.059318	0.059418	0.05934	0.059309
0.0625	0.059374	0.059369	0.059351	0.059464	0.059374	0.059352
0.125	0.059401	0.059388	0.059339	0.059473	0.059371	0.039934
0.25	0.040029	0.040029	0.040039	0.059657	0.040037	0.059349
0.5	0.04015	0.060006	0.060093	0.040332	0.060006	0.047076
1.0	0.04056	0.040518	0.04054	0.041021	0.040484	0.046288
2.0	0.04125	0.041131	0.048752	0.049458	0.041139	0.047766
4.0	0.051776	0.042422	0.049858	0.053511	0.042403	0.057091
5.0	0.051382	0.050738	0.042913	0.045672	0.050757	0.047826
10.0	0.070331	0	0.046385	0.073726	0.069109	0.049544
20.0	0.08278	0	0.042107	0.07215	0.045384	0.050798

Table A.101: Acoustic roughness (aspers) for a heavy vehicle with electric motor at a pass-by recorded at 50 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.040137	0.040135	0.040149	0.040161	0.040136	0.040164
0.0313	0.040124	0.040124	0.04018	0.040122	0.040123	0.040135
0.0625	0.040154	0.040151	0.040196	0.040167	0.040153	0.040173
0.125	0.040161	0.040159	0.040183	0.056087	0.040156	0.055901
0.25	0.056036	0.056027	0.040351	0.040555	0.05603	0.055985
0.5	0.040361	0.040342	0.040527	0.059191	0.040332	0.058608
1.0	0.056672	0.056578	0.056925	0.05725	0.05656	0.040392
2.0	0.05796	0.057534	0.057702	0.058327	0.057524	0.056618
4.0	0.043105	0.047525	0.059351	0.060623	0.047552	0.045857
5.0	0.060823	0.048264	0.060293	0.044842	0.048311	0.046148
10.0	0.065227	0	0.063055	0.053241	0.064389	0.059252
20.0	0.075421	0	0.056775	0.076936	0.074653	0.048838

Table A.102: Acoustic roughness (aspers) for a heavy vehicle with internal combustion engine at a pass-by recorded at 50 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.082885	0.082886	0.08285	0.082861	0.082886	0.082889
0.0313	0.082894	0.082896	0.082875	0.082875	0.082896	0.08291
0.0625	0.082852	0.082857	0.082876	0.082822	0.082857	0.08284
0.125	0.082867	0.082871	0.082868	0.082904	0.082869	0.082844
0.25	0.08291	0.0829	0.082879	0.082933	0.082902	0.082844
0.5	0.083258	0.083262	0.083239	0.083471	0.083267	0.083004
1.0	0.083928	0.083854	0.083946	0.08408	0.08386	0.083347
2.0	0.08469	0.084565	0.084633	0.08523	0.084573	0.083905
4.0	0.087073	0.086904	0.086216	0.087613	0.086865	0.085195
5.0	0.0885	0.088404	0.087316	0.08921	0.088324	0.08625
10.0	0.092668	0	0.090128	0.093728	0.092332	0.087061
20.0	0.10228	0	0.10007	0.10409	0.1031	0.095211

Table A.103: Acoustic roughness (aspers) for a light vehicle with electric motor at a pass-by recorded at 50 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.046604	0.046606	0.046604	0.046531	0.046607	0.04656
0.0313	0.046601	0.046602	0.046551	0.046575	0.046602	0.046554
0.0625	0.04664	0.046641	0.046637	0.046665	0.046627	0.04655
0.125	0.046645	0.046657	0.046641	0.046711	0.046652	0.046633
0.25	0.046651	0.046673	0.046784	0.046907	0.046677	0.063879
0.5	0.046916	0.055381	0.046899	0.055764	0.055395	0.055263
1.0	0.055773	0.055752	0.033788	0.056344	0.05575	0.064018
2.0	0.048089	0.047908	0.047681	0.034986	0.047891	0.046686
4.0	0.058241	0.058302	0.057568	0.060032	0.058172	0.033558
5.0	0.03622	0.036212	0.035184	0.06146	0.036144	0.067073
10.0	0.039925	0	0.038989	0.042166	0.039239	0.058493
20.0	0.087221	0	0.085034	0.090537	0.074417	0.066546

Table A.104: Acoustic roughness (aspers) for a light vehicle with internal combustion engine at a pass-by recorded at 50 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.047492	0.047494	0.04753	0.047497	0.047494	0.047543
0.0313	0.04748	0.047488	0.047522	0.047498	0.047488	0.047578
0.0625	0.047516	0.047529	0.047573	0.047582	0.047525	0.06493
0.125	0.047547	0.047531	0.047568	0.047633	0.047532	0.047536
0.25	0.047598	0.047607	0.047594	0.047663	0.0476	0.047501
0.5	0.065355	0.047812	0.034423	0.05637	0.047854	0.05618
1.0	0.06407	0.064002	0.034596	0.064287	0.064021	0.063497
2.0	0.065188	0.065113	0.068152	0.048838	0.065105	0.067221
4.0	0.059372	0.059143	0.035551	0.060062	0.059205	0.03426
5.0	0.071269	0.071115	0.036302	0.073119	0.071114	0.068035
10.0	0.039689	0	0.03851	0.040332	0.03949	0.058721
20.0	0.086646	0	0.083492	0.064667	0.084982	0.063801

A.3.4 Fluctuation strength

Table A.105: Fluctuation strength (vacil) presented as average values for a heavy vehicle with an electric motor at a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.038106	0.038107	0.0381	0.038127	0.038107	0.038089
0.0313	0.038139	0.038137	0.038143	0.038172	0.038137	0.038142
0.0625	0.03806	0.038063	0.038049	0.038054	0.038061	0.038042
0.125	0.038021	0.038016	0.038032	0.038013	0.038018	0.037983
0.25	0.037952	0.037932	0.03793	0.037931	0.037932	0.037996
0.5	0.037509	0.037503	0.037363	0.037417	0.037508	0.037423
1.0	0.036887	0.037051	0.036562	0.036951	0.037079	0.036771
2.0	0.036062	0.036281	0.035214	0.035682	0.036463	0.035121
4.0	0.032266	0.034336	0.032036	0.033108	0.034385	0.031362
5.0	0.030384	0.033014	0.030475	0.031777	0.032841	0.029663
10.0	0.024264	0	0.03278	0.03426	0.026289	0.035697
20.0	0.029757	0	0.046545	0.056538	0.025196	0.030032

Table A.106: Fluctuation strength (vacil) presented as average values for a heavy vehicle with internal combustion engine at a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.042146	0.042146	0.042143	0.042141	0.042146	0.042175
0.0313	0.042175	0.042174	0.042196	0.042161	0.042174	0.042223
0.0625	0.042096	0.042093	0.0421	0.042108	0.042093	0.042143
0.125	0.042055	0.042051	0.042025	0.042061	0.042051	0.042089
0.25	0.041957	0.041953	0.041871	0.041992	0.041955	0.042028
0.5	0.041424	0.041457	0.041326	0.041283	0.041464	0.041348
1.0	0.040719	0.04088	0.040489	0.040852	0.040946	0.04061
2.0	0.039672	0.039927	0.038837	0.039066	0.040125	0.038523
4.0	0.035194	0.037596	0.034983	0.035531	0.037613	0.034375
5.0	0.032732	0.035936	0.033282	0.033647	0.035798	0.032492
10.0	0.025044	0	0.034196	0.038958	0.027108	0.039182
20.0	0.031274	0	0.0503	0.061022	0.025276	0.031864

Table A.107: Fluctuation strength (vacil) presented as average values for a light vehicle with electric motor at a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.033567	0.033567	0.033559	0.03355	0.033567	0.033557
0.0313	0.033578	0.033581	0.033565	0.033557	0.03358	0.033574
0.0625	0.033535	0.033531	0.033489	0.033581	0.033528	0.033535
0.125	0.033506	0.033502	0.033478	0.033578	0.033502	0.033497
0.25	0.033458	0.033447	0.033407	0.033556	0.033448	0.033463
0.5	0.033105	0.033154	0.033051	0.033187	0.033154	0.032845
1.0	0.032703	0.032782	0.03245	0.032905	0.032826	0.032335
2.0	0.032069	0.032533	0.031586	0.03241	0.032631	0.030922
4.0	0.029546	0.031155	0.028625	0.03075	0.031276	0.027167
5.0	0.028301	0.0304	0.027368	0.029867	0.030391	0.025584
10.0	0.02421	0	0.029519	0.034263	0.025824	0.031127
20.0	0.027538	0	0.043754	0.050978	0.024524	0.02507

Table A.108: Fluctuation strength (vacil) presented as average values for a light vehicle with internal combustion engine at a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.034566	0.034566	0.034595	0.034572	0.034566	0.034554
0.0313	0.034585	0.034584	0.034602	0.034609	0.034585	0.034566
0.0625	0.034532	0.03453	0.03452	0.034528	0.034532	0.034501
0.125	0.034498	0.034488	0.034504	0.034492	0.034489	0.034472
0.25	0.034439	0.034418	0.034333	0.034477	0.034424	0.034426
0.5	0.034042	0.034069	0.033914	0.03406	0.034073	0.033834
1.0	0.033475	0.03364	0.033244	0.033687	0.03369	0.033292
2.0	0.032535	0.033113	0.031931	0.032581	0.033282	0.031679
4.0	0.029473	0.031316	0.028948	0.030286	0.031338	0.028054
5.0	0.028045	0.030346	0.027817	0.029312	0.030239	0.026737
10.0	0.023023	0	0.030074	0.032175	0.024808	0.032476
20.0	0.027332	0	0.043606	0.051441	0.023709	0.027139

Table A.109: Fluctuation strength (vacil) presented as average values for a heavy vehicle with electric motor at a pass-by recorded at 50 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.040343	0.040343	0.040322	0.040336	0.040343	0.040326
0.0313	0.04036	0.040359	0.040363	0.040369	0.040359	0.040351
0.0625	0.040293	0.040292	0.040272	0.040249	0.040292	0.040238
0.125	0.040234	0.040236	0.040177	0.04017	0.040235	0.040158
0.25	0.04012	0.04014	0.039984	0.040076	0.04014	0.040108
0.5	0.039616	0.039657	0.039521	0.039384	0.03966	0.039471
1.0	0.038877	0.039105	0.038552	0.038944	0.039148	0.038728
2.0	0.037836	0.03814	0.036996	0.037531	0.038294	0.036674
4.0	0.033543	0.035809	0.033472	0.034032	0.035901	0.032516
5.0	0.031446	0.03438	0.03204	0.032554	0.034246	0.03054
10.0	0.024525	0	0.033008	0.037812	0.026502	0.035957
20.0	0.029422	0	0.048327	0.056265	0.024913	0.030696

Table A.110: Fluctuation strength (vacil) presented as average values for a heavy vehicle with internal combustion engine at a pass-by recorded at 50 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.042325	0.042324	0.042338	0.042353	0.042324	0.042355
0.0313	0.042354	0.042353	0.042353	0.042352	0.042354	0.042343
0.0625	0.042274	0.042273	0.042273	0.042253	0.042274	0.042288
0.125	0.042221	0.042218	0.042191	0.042197	0.042218	0.042206
0.25	0.042117	0.042114	0.042068	0.042101	0.042113	0.04215
0.5	0.041599	0.041614	0.041471	0.041393	0.041621	0.04152
1.0	0.040864	0.041031	0.040511	0.040969	0.041092	0.040735
2.0	0.039693	0.040035	0.038861	0.039249	0.040234	0.038581
4.0	0.035187	0.037668	0.035197	0.0359	0.037736	0.034312
5.0	0.032808	0.036018	0.033472	0.0341	0.035899	0.032446
10.0	0.024736	0	0.033917	0.037682	0.027149	0.03822
20.0	0.031043	0	0.05051	0.061118	0.025529	0.032395

Table A.111: Fluctuation strength (vacil) presented as average values for a light vehicle with electric motor at a pass-by recorded at 50 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.035194	0.035195	0.035192	0.035191	0.035195	0.035197
0.0313	0.035212	0.035214	0.035206	0.035188	0.035214	0.035204
0.0625	0.03517	0.035169	0.035164	0.035171	0.035172	0.035152
0.125	0.035138	0.035132	0.035178	0.035138	0.03513	0.035085
0.25	0.035119	0.035089	0.035102	0.035198	0.035088	0.035062
0.5	0.034715	0.034728	0.034722	0.034767	0.034737	0.034559
1.0	0.034293	0.034387	0.034162	0.034423	0.034435	0.033847
2.0	0.033452	0.033913	0.032727	0.033838	0.034067	0.032309
4.0	0.030633	0.032471	0.030039	0.031483	0.032513	0.028683
5.0	0.029101	0.031532	0.02878	0.03013	0.031401	0.027061
10.0	0.02383	0	0.030004	0.035099	0.02569	0.031836
20.0	0.026857	0	0.043013	0.05024	0.023207	0.025887

Table A.112: Fluctuation strength (vacil) presented as average values for a light vehicle with internal combustion engine at a pass-by recorded at 50 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.036063	0.036064	0.036061	0.036058	0.036064	0.036062
0.0313	0.036083	0.036086	0.036071	0.036065	0.036085	0.036074
0.0625	0.036031	0.036033	0.03603	0.036087	0.036031	0.036024
0.125	0.035991	0.035992	0.036017	0.03605	0.035993	0.035979
0.25	0.035933	0.035932	0.035888	0.036046	0.035931	0.035907
0.5	0.0355	0.035509	0.035497	0.035476	0.035528	0.035367
1.0	0.034962	0.035047	0.034729	0.035215	0.035104	0.034811
2.0	0.034246	0.034389	0.033594	0.034032	0.034519	0.03323
4.0	0.030572	0.032511	0.030396	0.03128	0.032598	0.029616
5.0	0.028829	0.031323	0.029113	0.029691	0.031245	0.027884
10.0	0.022588	0	0.030548	0.034047	0.024633	0.034286
20.0	0.026482	0	0.044341	0.051721	0.022934	0.028144

A.3.5 A-weighted values

Table A.113: A-weighted values (dB) presented as single numbers for a heavy vehicle with electric motor at a pass-by recorded at 40 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-33.134	-33.134	-33.135	-33.133	-33.134	-33.135
0.0313	-33.135	-33.134	-33.134	-33.132	-33.134	-33.136
0.0625	-33.134	-33.134	-33.134	-33.13	-33.134	-33.138
0.125	-33.134	-33.134	-33.133	-33.126	-33.134	-33.142
0.25	-33.133	-33.133	-33.138	-33.11	-33.133	-33.145
0.5	-33.129	-33.128	-33.134	-33.103	-33.128	-33.165
1.0	-33.133	-33.133	-33.14	-33.074	-33.133	-33.201
2.0	-33.055	-33.052	-33.067	-32.938	-33.052	-33.185
4.0	-33.031	-33.019	-33.04	-32.821	-33.019	-33.314
5.0	-33.067	-33.051	-33.071	-32.81	-33.051	-33.416
10.0	-33.121	0	-33.096	-32.699	-33.086	-33.823
20.0	-33.447	0	-33.382	-32.784	-33.3	-34.953

Table A.114: A-weighted values (dB) presented as single numbers for a heavy vehicle with an internal combustion engine at a pass-by recorded at 40 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-29.389	-29.389	-29.39	-29.388	-29.389	-29.39
0.0313	-29.39	-29.389	-29.389	-29.388	-29.389	-29.391
0.0625	-29.389	-29.389	-29.389	-29.385	-29.389	-29.392
0.125	-29.389	-29.389	-29.39	-29.381	-29.389	-29.397
0.25	-29.388	-29.388	-29.395	-29.365	-29.388	-29.398
0.5	-29.381	-29.381	-29.389	-29.36	-29.381	-29.416
1.0	-29.391	-29.391	-29.396	-29.337	-29.391	-29.455
2.0	-29.313	-29.309	-29.318	-29.204	-29.309	-29.44
4.0	-29.29	-29.279	-29.293	-29.099	-29.28	-29.551
5.0	-29.328	-29.314	-29.328	-29.095	-29.314	-29.648
10.0	-29.379	0	-29.347	-28.967	-29.345	-30.053
20.0	-29.7	0	-29.635	-29.033	-29.551	-31.205

Table A.115: A-weighted values (dB) presented as single numbers for a light vehicle with electric motor at a pass-by recorded at 40 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-34.78	-34.78	-34.78	-34.779	-34.78	-34.781
0.0313	-34.78	-34.78	-34.78	-34.778	-34.78	-34.782
0.0625	-34.779	-34.779	-34.779	-34.776	-34.779	-34.783
0.125	-34.779	-34.779	-34.778	-34.773	-34.779	-34.787
0.25	-34.777	-34.778	-34.782	-34.757	-34.778	-34.786
0.5	-34.774	-34.774	-34.778	-34.75	-34.774	-34.807
1.0	-34.772	-34.773	-34.783	-34.713	-34.773	-34.823
2.0	-34.67	-34.668	-34.685	-34.568	-34.668	-34.78
4.0	-34.729	-34.72	-34.742	-34.544	-34.721	-34.953
5.0	-34.741	-34.727	-34.747	-34.513	-34.726	-35.063
10.0	-34.752	0	-34.73	-34.355	-34.718	-35.425
20.0	-35.08	0	-35.012	-34.455	-34.927	-36.53

Table A.116: A-weighted values (dB) presented as single numbers for a light vehicle with internal combustion engine at a pass-by recorded at 40 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-33.852	-33.852	-33.853	-33.851	-33.852	-33.853
0.0313	-33.853	-33.853	-33.852	-33.851	-33.853	-33.855
0.0625	-33.852	-33.852	-33.852	-33.848	-33.852	-33.856
0.125	-33.852	-33.852	-33.851	-33.846	-33.852	-33.86
0.25	-33.85	-33.85	-33.855	-33.83	-33.851	-33.859
0.5	-33.847	-33.847	-33.85	-33.824	-33.847	-33.88
1.0	-33.845	-33.846	-33.856	-33.786	-33.846	-33.896
2.0	-33.747	-33.746	-33.762	-33.645	-33.746	-33.86
4.0	-33.794	-33.785	-33.808	-33.607	-33.786	-34.02
5.0	-33.805	-33.791	-33.811	-33.577	-33.791	-34.127
10.0	-33.828	0	-33.807	-33.428	-33.794	-34.507
20.0	-34.153	0	-34.087	-33.526	-34.0	-35.607

Table A.117: A-weighted values (dB) presented as single numbers for a heavy vehicle with electric motor at a pass-by recorded at 50 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-31.939	-31.939	-31.939	-31.938	-31.939	-31.94
0.0313	-31.939	-31.939	-31.939	-31.937	-31.939	-31.941
0.0625	-31.939	-31.939	-31.939	-31.934	-31.939	-31.943
0.125	-31.939	-31.938	-31.939	-31.93	-31.938	-31.947
0.25	-31.938	-31.938	-31.946	-31.914	-31.938	-31.95
0.5	-31.934	-31.934	-31.942	-31.911	-31.934	-31.97
1.0	-31.94	-31.938	-31.948	-31.874	-31.939	-32.017
2.0	-31.862	-31.86	-31.878	-31.733	-31.86	-32.001
4.0	-31.841	-31.829	-31.854	-31.626	-31.83	-32.126
5.0	-31.889	-31.874	-31.898	-31.637	-31.874	-32.249
10.0	-31.942	0	-31.911	-31.52	-31.904	-32.68
20.0	-32.288	0	-32.222	-31.601	-32.143	-33.872

Table A.118: A-weighted values (dB) presented as single numbers for a heavy vehicle with an internal combustion engine at a pass-by recorded at 50 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-29.378	-29.379	-29.379	-29.378	-29.379	-29.38
0.0313	-29.379	-29.379	-29.379	-29.377	-29.379	-29.381
0.0625	-29.378	-29.378	-29.378	-29.373	-29.378	-29.382
0.125	-29.378	-29.378	-29.378	-29.369	-29.378	-29.386
0.25	-29.377	-29.378	-29.384	-29.354	-29.378	-29.388
0.5	-29.372	-29.372	-29.378	-29.344	-29.372	-29.41
1.0	-29.376	-29.376	-29.381	-29.313	-29.376	-29.447
2.0	-29.295	-29.292	-29.3	-29.174	-29.292	-29.435
4.0	-29.277	-29.267	-29.281	-29.052	-29.267	-29.55
5.0	-29.311	-29.296	-29.311	-29.053	-29.296	-29.648
10.0	-29.368	0	-29.341	-28.951	-29.333	-30.074
20.0	-29.697	0	-29.632	-29.023	-29.551	-31.216

Table A.119: A-weighted values (dB) presented as single numbers for a light vehicle with electric motor at a pass-by recorded at 50 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-32.936	-32.936	-32.936	-32.935	-32.936	-32.937
0.0313	-32.936	-32.936	-32.936	-32.935	-32.936	-32.938
0.0625	-32.936	-32.936	-32.936	-32.933	-32.936	-32.938
0.125	-32.936	-32.935	-32.934	-32.932	-32.935	-32.942
0.25	-32.934	-32.935	-32.938	-32.917	-32.935	-32.941
0.5	-32.932	-32.932	-32.937	-32.915	-32.932	-32.957
1.0	-32.932	-32.931	-32.938	-32.89	-32.931	-32.993
2.0	-32.835	-32.834	-32.848	-32.736	-32.834	-32.93
4.0	-32.893	-32.885	-32.906	-32.695	-32.885	-33.13
5.0	-32.913	-32.9	-32.92	-32.685	-32.9	-33.225
10.0	-32.914	0	-32.892	-32.527	-32.881	-33.566
20.0	-33.238	0	-33.174	-32.62	-33.083	-34.688

Table A.120: A-weighted values (dB) presented as single numbers for a light vehicle with internal combustion engine at a pass-by recorded at 50 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-32.429	-32.429	-32.429	-32.428	-32.429	-32.43
0.0313	-32.429	-32.429	-32.429	-32.428	-32.429	-32.431
0.0625	-32.429	-32.429	-32.429	-32.426	-32.429	-32.432
0.125	-32.429	-32.429	-32.427	-32.425	-32.428	-32.435
0.25	-32.428	-32.428	-32.432	-32.41	-32.428	-32.435
0.5	-32.425	-32.425	-32.43	-32.407	-32.425	-32.451
1.0	-32.425	-32.424	-32.43	-32.381	-32.424	-32.486
2.0	-32.335	-32.333	-32.347	-32.234	-32.334	-32.434
4.0	-32.374	-32.366	-32.387	-32.176	-32.366	-32.613
5.0	-32.391	-32.377	-32.398	-32.163	-32.377	-32.703
10.0	-32.405	0	-32.383	-32.016	-32.372	-33.068
20.0	-32.733	0	-32.668	-32.111	-32.578	-34.191

A.4 Barrier with no Doppler effect

A.4.1 Loudness calculations

Table A.121: Acoustic loudness (sones) for heavy vehicle with electric motor at a pass-by recorded at 40 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	2.1744	2.1744	2.1744	2.1749	2.1744	2.174
0.0313	2.1743	2.1743	2.1744	2.1753	2.1743	2.1736
0.0625	2.1746	2.1746	2.1746	2.1763	2.1746	2.1729
0.125	2.1746	2.1747	2.1749	2.1782	2.1748	2.171
0.25	2.1751	2.175	2.1738	2.1836	2.175	2.1693
0.5	2.1772	2.1773	2.1755	2.1891	2.1773	2.1625
1.0	2.179	2.179	2.1765	2.2048	2.1789	2.1516
2.0	2.1994	2.2004	2.1947	2.2516	2.2004	2.1426
4.0	2.216	2.2208	2.212	2.3099	2.2208	2.0998
5.0	2.2145	2.2209	2.2118	2.3281	2.221	2.0741
10.0	2.1816	0	2.1892	2.3723	2.1959	1.8947
20.0	2.0426	0	2.0651	2.3302	2.1033	1.4837

Table A.122: Acoustic loudness (sones) for heavy vehicle with internal combustion engine at a pass-by recorded at 40 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	4.4889	4.4889	4.4888	4.4897	4.4889	4.4882
0.0313	4.4888	4.4888	4.4888	4.4903	4.4888	4.4874
0.0625	4.4891	4.4891	4.4888	4.4925	4.4891	4.4866
0.125	4.4894	4.4893	4.4889	4.4946	4.4892	4.4835
0.25	4.4904	4.4902	4.4871	4.5052	4.4901	4.4806
0.5	4.4937	4.4941	4.4909	4.5115	4.494	4.4692
1.0	4.4991	4.4993	4.4964	4.5431	4.499	4.4541
2.0	4.5249	4.5274	4.5219	4.6078	4.5275	4.4284
4.0	4.5557	4.5627	4.5522	4.7062	4.5625	4.3633
5.0	4.5501	4.5604	4.5496	4.7329	4.5605	4.3165
10.0	4.5049	0	4.5239	4.8236	4.529	4.0341
20.0	4.2658	0	4.3069	4.7538	4.3721	3.3192

Table A.123: Acoustic loudness (sones) for light vehicle with electric motor at a pass-by recorded at 40 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.224	1.224	1.2239	1.2243	1.224	1.2237
0.0313	1.2239	1.2239	1.224	1.2245	1.2239	1.2233
0.0625	1.224	1.224	1.224	1.2253	1.2241	1.2231
0.125	1.2242	1.2242	1.2245	1.2261	1.2242	1.2218
0.25	1.2246	1.2244	1.2236	1.2305	1.2245	1.2214
0.5	1.2264	1.2262	1.2256	1.2335	1.2263	1.2167
1.0	1.2271	1.227	1.2249	1.2455	1.227	1.2114
2.0	1.2461	1.2466	1.2433	1.2784	1.2467	1.2123
4.0	1.2493	1.2522	1.2469	1.3053	1.2519	1.1842
5.0	1.2465	1.2508	1.246	1.3151	1.2508	1.1569
10.0	1.2329	0	1.2406	1.3529	1.2431	1.0524
20.0	1.143	0	1.1613	1.3201	1.1856	0.79561

Table A.124: Acoustic loudness (sones) for light vehicle with internal combustion engine at a pass-by recorded at 40 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.5871	1.5871	1.5871	1.5875	1.5871	1.5868
0.0313	1.5871	1.587	1.5871	1.5877	1.5871	1.5864
0.0625	1.5872	1.5872	1.5872	1.5887	1.5872	1.5861
0.125	1.5874	1.5874	1.5877	1.5896	1.5874	1.5845
0.25	1.5878	1.5877	1.5867	1.5945	1.5878	1.5838
0.5	1.5899	1.5898	1.5894	1.5982	1.5899	1.5788
1.0	1.5908	1.5909	1.5886	1.6115	1.5909	1.5723
2.0	1.611	1.6117	1.6079	1.6482	1.6117	1.5691
4.0	1.619	1.6225	1.6158	1.6867	1.6222	1.5397
5.0	1.6182	1.623	1.6171	1.6974	1.6231	1.5103
10.0	1.5931	0	1.6005	1.738	1.605	1.3684
20.0	1.4862	0	1.5084	1.7014	1.5388	1.0676

Table A.125: Acoustic loudness (sones) for heavy vehicle with electric motor at a pass-by recorded at 50 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.1682	1.1682	1.1683	1.1682	1.1682	1.1682
0.0313	1.1682	1.1682	1.1682	1.1682	1.1682	1.1682
0.0625	1.1683	1.1682	1.1682	1.1682	1.1682	1.1682
0.125	1.1683	1.1683	1.1684	1.1683	1.1683	1.1682
0.25	1.1683	1.1684	1.1688	1.1681	1.1683	1.1678
0.5	1.1679	1.1679	1.1683	1.169	1.1679	1.1677
1.0	1.1723	1.1723	1.1727	1.1726	1.1723	1.1721
2.0	1.1689	1.1691	1.1695	1.1702	1.1691	1.1676
4.0	1.1592	1.1593	1.1607	1.1639	1.1594	1.1546
5.0	1.1615	1.1618	1.1635	1.1681	1.1618	1.1566
10.0	1.1649	0	1.167	1.1725	1.1654	1.1531
20.0	1.1539	0	1.1567	1.1658	1.1572	1.1347

Table A.126: Acoustic loudness (sones) for heavy vehicle with internal combustion engine at a pass-by recorded at 50 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	4.4833	4.4833	4.4832	4.484	4.4833	4.4825
0.0313	4.4832	4.4832	4.4832	4.4846	4.4832	4.4816
0.0625	4.4836	4.4836	4.4834	4.4868	4.4836	4.4808
0.125	4.4837	4.4837	4.4835	4.4898	4.4837	4.4779
0.25	4.4843	4.4841	4.4808	4.4994	4.484	4.4749
0.5	4.4878	4.4878	4.485	4.5084	4.4879	4.4619
1.0	4.4944	4.4944	4.4919	4.5402	4.4946	4.4459
2.0	4.5216	4.5237	4.5174	4.6126	4.5237	4.4197
4.0	4.5552	4.5631	4.5529	4.7184	4.5631	4.3544
5.0	4.5526	4.5644	4.5521	4.7405	4.5646	4.3078
10.0	4.4958	0	4.5152	4.8112	4.5215	3.9956
20.0	4.2473	0	4.2934	4.7348	4.3518	3.2946

Table A.127: Acoustic loudness (sones) for light vehicle with electric motor at a pass-by recorded at 50 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.7343	1.7343	1.7342	1.7346	1.7343	1.734
0.0313	1.7342	1.7343	1.7343	1.7348	1.7343	1.7336
0.0625	1.7344	1.7344	1.7344	1.7356	1.7344	1.7333
0.125	1.7345	1.7345	1.7347	1.7364	1.7345	1.732
0.25	1.7349	1.7348	1.7337	1.7409	1.7347	1.7309
0.5	1.7364	1.7365	1.7349	1.7441	1.7364	1.7265
1.0	1.7369	1.7373	1.7354	1.755	1.7372	1.7156
2.0	1.7589	1.7594	1.7552	1.7967	1.7593	1.721
4.0	1.7639	1.7671	1.7605	1.8341	1.7672	1.6808
5.0	1.7571	1.7622	1.7561	1.8388	1.7624	1.6497
10.0	1.7403	0	1.7488	1.8799	1.752	1.5198
20.0	1.6303	0	1.6539	1.8408	1.6845	1.2014

Table A.128: Acoustic loudness (sones) for light vehicle with internal combustion engine at a pass-by recorded at 50 km/h according to ISO 532-1 (Zwicker).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	2.2002	2.2002	2.2001	2.2006	2.2002	2.1998
0.0313	2.2001	2.2001	2.2001	2.2008	2.2001	2.1992
0.0625	2.2003	2.2003	2.2002	2.2018	2.2003	2.1989
0.125	2.2004	2.2004	2.2006	2.2029	2.2004	2.197
0.25	2.2007	2.2007	2.1994	2.2085	2.2007	2.1952
0.5	2.2027	2.2028	2.2013	2.2128	2.2027	2.1898
1.0	2.2038	2.2042	2.2019	2.2279	2.2043	2.1769
2.0	2.2271	2.228	2.2226	2.276	2.228	2.1765
4.0	2.2387	2.2429	2.2325	2.3302	2.2428	2.133
5.0	2.2356	2.242	2.2317	2.3412	2.2421	2.0997
10.0	2.2197	0	2.2285	2.3974	2.2348	1.9312
20.0	2.0696	0	2.0976	2.3415	2.1385	1.5235

A.4.2 Sharpness calculations

Table A.129: Acoustic sharpness (acum) for a heavy vehicle with electric motor at a pass-by recorded at 40 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.0986	1.0986	1.0986	1.0986	1.0986	1.0987
0.0313	1.0986	1.0986	1.0987	1.0986	1.0986	1.0987
0.0625	1.0987	1.0986	1.0987	1.0986	1.0986	1.0986
0.125	1.0986	1.0987	1.0988	1.0988	1.0987	1.0986
0.25	1.0988	1.0988	1.099	1.0987	1.0988	1.0987
0.5	1.0985	1.0985	1.0987	1.0989	1.0985	1.0984
1.0	1.1019	1.102	1.1022	1.1026	1.1021	1.1012
2.0	1.1002	1.1003	1.1013	1.1002	1.1004	1.0989
4.0	1.0902	1.0903	1.0917	1.0937	1.0904	1.0866
5.0	1.091	1.0911	1.0924	1.096	1.0912	1.0858
10.0	1.0944	0	1.0965	1.1003	1.095	1.0834
20.0	1.0834	0	1.087	1.0928	1.0867	1.0617

Table A.130: Acoustic sharpness (acum) for a heavy vehicle with internal combustion engine at a pass-by recorded at 40 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.2226	1.2225	1.2225	1.2227	1.2226	1.2225
0.0313	1.2226	1.2225	1.2226	1.2227	1.2225	1.2225
0.0625	1.2226	1.2226	1.2225	1.2229	1.2226	1.2224
0.125	1.2227	1.2226	1.2227	1.2227	1.2227	1.2224
0.25	1.223	1.223	1.2234	1.2235	1.223	1.2222
0.5	1.2222	1.2221	1.2227	1.224	1.2221	1.2208
1.0	1.2284	1.2284	1.2293	1.2307	1.2284	1.2265
2.0	1.2244	1.2245	1.2254	1.2272	1.2245	1.2204
4.0	1.2155	1.2162	1.2177	1.2218	1.2162	1.2055
5.0	1.2149	1.2158	1.2174	1.2239	1.2157	1.202
10.0	1.2156	0	1.2176	1.2246	1.2164	1.1976
20.0	1.2022	0	1.2071	1.2111	1.2047	1.1788

Table A.131: Acoustic sharpness (acum) for a light vehicle with electric motor at a pass-by recorded at 40 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.0629	1.0629	1.0629	1.0629	1.0629	1.0629
0.0313	1.0629	1.0629	1.0629	1.0629	1.0629	1.0629
0.0625	1.063	1.063	1.0629	1.0629	1.063	1.0631
0.125	1.063	1.063	1.063	1.0629	1.063	1.0632
0.25	1.063	1.063	1.0635	1.0624	1.063	1.063
0.5	1.0634	1.0634	1.0638	1.0632	1.0634	1.0642
1.0	1.0641	1.064	1.0646	1.0622	1.0641	1.0649
2.0	1.0647	1.0648	1.0649	1.0622	1.0648	1.0677
4.0	1.0568	1.0567	1.0573	1.0554	1.0567	1.058
5.0	1.0599	1.0598	1.0603	1.058	1.0599	1.0627
10.0	1.0584	0	1.0588	1.0544	1.0584	1.061
20.0	1.0575	0	1.0598	1.0517	1.0597	1.0632

Table A.132: Acoustic sharpness (acum) for a light vehicle with internal combustion engine at a pass-by recorded at 40 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.0238	1.0238	1.0238	1.0238	1.0238	1.0238
0.0313	1.0238	1.0238	1.0238	1.0238	1.0238	1.0238
0.0625	1.0238	1.0239	1.0239	1.0238	1.0239	1.0239
0.125	1.0239	1.0239	1.0239	1.0239	1.0239	1.024
0.25	1.0239	1.024	1.0241	1.0235	1.024	1.0239
0.5	1.0244	1.0244	1.0246	1.0244	1.0244	1.0248
1.0	1.0254	1.0254	1.0257	1.0247	1.0254	1.0256
2.0	1.0259	1.0259	1.026	1.025	1.0259	1.0285
4.0	1.0179	1.0178	1.0185	1.017	1.0177	1.0183
5.0	1.0205	1.0205	1.0211	1.0192	1.0205	1.0213
10.0	1.0219	0	1.0235	1.017	1.0223	1.0247
20.0	1.018	0	1.0208	1.0139	1.0203	1.0207

Table A.133: Acoustic sharpness (acum) for a heavy vehicle with electric motor at a pass-by recorded at 50 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.1682	1.1682	1.1683	1.1682	1.1682	1.1682
0.0313	1.1682	1.1682	1.1682	1.1682	1.1682	1.1682
0.0625	1.1683	1.1682	1.1682	1.1682	1.1682	1.1682
0.125	1.1683	1.1683	1.1684	1.1683	1.1683	1.1682
0.25	1.1683	1.1684	1.1688	1.1681	1.1683	1.1678
0.5	1.1679	1.1679	1.1683	1.169	1.1679	1.1677
1.0	1.1723	1.1723	1.1727	1.1726	1.1723	1.1721
2.0	1.1689	1.1691	1.1695	1.1702	1.1691	1.1676
4.0	1.1592	1.1593	1.1607	1.1639	1.1594	1.1546
5.0	1.1615	1.1618	1.1635	1.1681	1.1618	1.1566
10.0	1.1649	0	1.167	1.1725	1.1654	1.1531
20.0	1.1539	0	1.1567	1.1658	1.1572	1.1347

Table A.134: Acoustic sharpness (acum) for a heavy vehicle with internal combustion engine at a pass-by recorded at 50 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.2496	1.2496	1.2496	1.2496	1.2496	1.2496
0.0313	1.2496	1.2496	1.2497	1.2496	1.2496	1.2497
0.0625	1.2497	1.2497	1.2497	1.2495	1.2497	1.2496
0.125	1.2497	1.2497	1.2496	1.2497	1.2496	1.2498
0.25	1.2499	1.2499	1.2501	1.2495	1.25	1.2503
0.5	1.2495	1.2495	1.2496	1.2496	1.2495	1.2503
1.0	1.2537	1.2536	1.2533	1.2532	1.2536	1.2546
2.0	1.2497	1.2496	1.2497	1.2502	1.2496	1.2498
4.0	1.2412	1.2413	1.2415	1.244	1.2413	1.2395
5.0	1.2428	1.2429	1.2431	1.2455	1.2428	1.2398
10.0	1.2442	0	1.2449	1.2483	1.2447	1.2367
20.0	1.2354	0	1.2377	1.2407	1.2379	1.2258

Table A.135: Acoustic sharpness (acum) for a light vehicle with electric motor at a pass-by recorded at 50 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	1.1048	1.1048	1.1048	1.1047	1.1048	1.1048
0.0313	1.1047	1.1047	1.1047	1.1047	1.1047	1.1048
0.0625	1.1048	1.1048	1.1048	1.1047	1.1048	1.1048
0.125	1.1048	1.1048	1.1048	1.1048	1.1048	1.1049
0.25	1.1048	1.1049	1.1051	1.1044	1.1049	1.1049
0.5	1.1051	1.1051	1.1054	1.105	1.1051	1.1056
1.0	1.1061	1.106	1.1064	1.1058	1.106	1.1069
2.0	1.1065	1.1064	1.1068	1.1049	1.1064	1.1077
4.0	1.099	1.0991	1.0998	1.0964	1.0991	1.1016
5.0	1.1027	1.1028	1.104	1.1	1.1028	1.1055
10.0	1.1021	0	1.1043	1.0975	1.1027	1.1051
20.0	1.1007	0	1.1033	1.0945	1.1026	1.1027

Table A.136: Acoustic sharpness (acum) for a light vehicle with internal combustion engine at a pass-by recorded at 50 km/h according to DIN45692 and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.97915	0.97916	0.97916	0.97915	0.97915	0.97916
0.0313	0.97914	0.97913	0.97915	0.97911	0.97913	0.97912
0.0625	0.97918	0.97918	0.97919	0.97904	0.97917	0.97917
0.125	0.9792	0.97919	0.97926	0.9791	0.97919	0.97931
0.25	0.97925	0.9793	0.97937	0.97894	0.97929	0.97947
0.5	0.97957	0.97951	0.97968	0.97928	0.97953	0.98012
1.0	0.98036	0.98036	0.98058	0.97956	0.98038	0.98117
2.0	0.9815	0.98151	0.98192	0.97964	0.98154	0.98364
4.0	0.9741	0.97417	0.9756	0.97059	0.97417	0.97713
5.0	0.97583	0.97585	0.9778	0.97212	0.97594	0.97885
10.0	0.97204	0	0.97465	0.96709	0.97245	0.9793
20.0	0.97562	0	0.97858	0.9669	0.97679	0.98852

A.4.3 Roughness calculations

Table A.137: Acoustic roughness (aspers) for a heavy vehicle with an electric motor at a pass-by recorded at 40 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.04499	0.044988	0.044989	0.044978	0.044988	0.04493
0.0313	0.044982	0.044987	0.04496	0.044982	0.04498	0.044915
0.0625	0.045044	0.045039	0.045049	0.045026	0.045035	0.044997
0.125	0.045038	0.045047	0.044967	0.04497	0.045048	0.04494
0.25	0.045086	0.045084	0.045084	0.045101	0.045087	0.045002
0.5	0.045255	0.045278	0.045309	0.045397	0.045301	0.045262
1.0	0.045573	0.04554	0.045639	0.045799	0.045547	0.045362
2.0	0.0463	0.046252	0.046052	0.046626	0.046184	0.045299
4.0	0.05017	0.047604	0.049854	0.048777	0.047517	0.048115
5.0	0.051197	0.050958	0.050333	0.04651	0.051018	0.043635
10.0	0.055752	0	0.04998	0.056005	0.054703	0.046421
20.0	0.063851	0	0.056877	0.066464	0.06354	0.068465

Table A.138: Acoustic roughness (aspers) for a heavy vehicle with internal combustion engine at a pass-by recorded at 40 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.073254	0.073254	0.073228	0.073225	0.073254	0.073232
0.0313	0.073239	0.07324	0.073226	0.073212	0.073241	0.073204
0.0625	0.073262	0.073264	0.073257	0.073295	0.073265	0.073247
0.125	0.073252	0.073256	0.073248	0.07329	0.073255	0.073199
0.25	0.073321	0.073321	0.073288	0.073478	0.073318	0.073204
0.5	0.073842	0.073838	0.073938	0.074049	0.073853	0.073568
1.0	0.07429	0.074273	0.074584	0.074617	0.07428	0.073952
2.0	0.075173	0.075024	0.05216	0.075878	0.075027	0.074217
4.0	0.077403	0.077207	0.08941	0.068679	0.077218	0.075375
5.0	0.078182	0.078056	0.077804	0.069619	0.078014	0.0756
10.0	0.083012	0	0.081072	0.084496	0.082569	0.078256
20.0	0.076075	0	0.090484	0.085808	0.067427	0.077698

Table A.139: Acoustic roughness (aspers) for a light vehicle with electric motor at a pass-by recorded at 40 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.053427	0.053427	0.05342	0.053423	0.053428	0.053429
0.0313	0.053403	0.053404	0.053386	0.053402	0.053403	0.053375
0.0625	0.053446	0.053447	0.053445	0.053416	0.053452	0.053416
0.125	0.053477	0.053474	0.053458	0.053503	0.053478	0.053467
0.25	0.053522	0.053494	0.053486	0.053533	0.053482	0.053481
0.5	0.054108	0.054066	0.053973	0.054011	0.054042	0.05368
1.0	0.054353	0.054386	0.054458	0.054729	0.05438	0.053909
2.0	0.055238	0.05523	0.055028	0.055657	0.05524	0.053898
4.0	0.056903	0.056901	0.05646	0.058613	0.056913	0.053686
5.0	0.058008	0.058052	0.057944	0.060499	0.057789	0.055043
10.0	0.064041	0	0.062518	0.069354	0.062797	0.055313
20.0	0.075099	0	0.07173	0.077527	0.073328	0.035353

Table A.140: Acoustic roughness (aspers) for a light vehicle with internal combustion engine at a pass-by recorded at 40 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.053427	0.053427	0.05342	0.053423	0.053428	0.053429
0.0313	0.053403	0.053404	0.053386	0.053402	0.053403	0.053375
0.0625	0.053446	0.053447	0.053445	0.053416	0.053452	0.053416
0.125	0.053477	0.053474	0.053458	0.053503	0.053478	0.053467
0.25	0.053522	0.053494	0.053486	0.053533	0.053482	0.053481
0.5	0.054108	0.054066	0.053973	0.054011	0.054042	0.05368
1.0	0.054353	0.054386	0.054458	0.054729	0.05438	0.053909
2.0	0.055238	0.05523	0.055028	0.055657	0.05524	0.053898
4.0	0.056903	0.056901	0.05646	0.058613	0.056913	0.053686
5.0	0.058008	0.058052	0.057944	0.060499	0.057789	0.055043
10.0	0.064041	0	0.062518	0.069354	0.062797	0.055313
20.0	0.075099	0	0.07173	0.077527	0.073328	0.035353

Table A.141: Acoustic roughness (aspers) for a heavy vehicle with an electric motor at a pass-by recorded at 50 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.084367	0.084366	0.084376	0.084387	0.084366	0.084378
0.0313	0.084371	0.084369	0.084395	0.084396	0.084371	0.084391
0.0625	0.084341	0.084343	0.084468	0.084401	0.084342	0.084344
0.125	0.08435	0.084353	0.084413	0.084421	0.084352	0.084335
0.25	0.084408	0.084396	0.084439	0.084559	0.084392	0.084376
0.5	0.084775	0.084749	0.084825	0.085012	0.084748	0.084661
1.0	0.085428	0.085372	0.08559	0.085734	0.085368	0.085062
2.0	0.086231	0.086094	0.086247	0.087071	0.086081	0.085751
4.0	0.088642	0.088396	0.088131	0.089527	0.088372	0.086856
5.0	0.090161	0.089907	0.089145	0.090967	0.089878	0.088022
10.0	0.094506	0	0.091921	0.095822	0.094229	0.088957
20.0	0.10405	0	0.10164	0.10609	0.10473	0.096365

Table A.142: Acoustic roughness (aspers) for a heavy vehicle with internal combustion engine at a pass-by recorded at 50 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.084367	0.084366	0.084376	0.084387	0.084366	0.084378
0.0313	0.084371	0.084369	0.084395	0.084396	0.084371	0.084391
0.0625	0.084341	0.084343	0.084468	0.084401	0.084342	0.084344
0.125	0.08435	0.084353	0.084413	0.084421	0.084352	0.084335
0.25	0.084408	0.084396	0.084439	0.084559	0.084392	0.084376
0.5	0.084775	0.084749	0.084825	0.085012	0.084748	0.084661
1.0	0.085428	0.085372	0.08559	0.085734	0.085368	0.085062
2.0	0.086231	0.086094	0.086247	0.087071	0.086081	0.085751
4.0	0.088642	0.088396	0.088131	0.089527	0.088372	0.086856
5.0	0.090161	0.089907	0.089145	0.090967	0.089878	0.088022
10.0	0.094506	0	0.091921	0.095822	0.094229	0.088957
20.0	0.10405	0	0.10164	0.10609	0.10473	0.096365

Table A.143: Acoustic roughness (aspers) for a light vehicle with electric motor at a pass-by recorded at 50 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.059544	0.059544	0.059542	0.059531	0.059545	0.059493
0.0313	0.05954	0.05954	0.059505	0.059531	0.059542	0.059503
0.0625	0.059546	0.05955	0.059536	0.0596	0.059537	0.059452
0.125	0.059536	0.059571	0.059593	0.059681	0.059566	0.059492
0.25	0.059693	0.059621	0.059681	0.059924	0.059632	0.059555
0.5	0.060006	0.059964	0.059771	0.06034	0.059956	0.059571
1.0	0.060374	0.060306	0.060334	0.061039	0.06027	0.05956
2.0	0.061486	0.061401	0.061204	0.062364	0.061373	0.059979
4.0	0.063065	0.063093	0.062443	0.064706	0.062972	0.06019
5.0	0.064456	0.064309	0.063592	0.066446	0.064262	0.055352
10.0	0.070541	0	0.06969	0.074514	0.069457	0.063067
20.0	0.081425	0	0.078915	0.084359	0.080336	0.035728

Table A.144: Acoustic roughness (aspers) for a light vehicle with internal combustion engine at a pass-by recorded at 50 km/h according to Zwicker's method and ISO 532-1:2017(E).

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.060358	0.06036	0.060354	0.060411	0.06036	0.060388
0.0313	0.060351	0.06035	0.060377	0.060393	0.060355	0.060367
0.0625	0.060371	0.060369	0.060379	0.060481	0.060376	0.060356
0.125	0.060398	0.060393	0.06045	0.060555	0.060401	0.060377
0.25	0.060503	0.060491	0.060567	0.060703	0.060489	0.060458
0.5	0.060839	0.060814	0.060908	0.061176	0.060828	0.060832
1.0	0.061282	0.061201	0.061198	0.061627	0.061215	0.060666
2.0	0.062438	0.062239	0.062044	0.06319	0.062204	0.058518
4.0	0.064201	0.063857	0.063329	0.065045	0.063929	0.061032
5.0	0.065428	0.065019	0.06456	0.064603	0.064988	0.056005
10.0	0.070203	0	0.068886	0.07219	0.069485	0.06351
20.0	0.08127	0	0.07695	0.083055	0.0799	0.033014

A.4.4 Fluctuation strength

Table A.145: Fluctuation strength (vacil) presented as average values for a heavy vehicle with an electric motor at a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.055315	0.055313	0.055284	0.055292	0.055314	0.05529
0.0313	0.055285	0.055288	0.05525	0.055248	0.055287	0.055236
0.0625	0.05533	0.055336	0.055275	0.055321	0.055334	0.055278
0.125	0.055346	0.055338	0.055352	0.05552	0.055344	0.055359
0.25	0.05537	0.055402	0.055392	0.055666	0.055388	0.055229
0.5	0.055842	0.055821	0.055939	0.056228	0.055842	0.055571
1.0	0.056153	0.056067	0.056167	0.056742	0.056077	0.055849
2.0	0.057213	0.057111	0.057389	0.058232	0.056954	0.056328
4.0	0.059274	0.058556	0.058739	0.061152	0.058588	0.056486
5.0	0.060419	0.059913	0.059946	0.062687	0.059911	0.057039
10.0	0.06552	0	0.064213	0.068857	0.064643	0.058814
20.0	0.077508	0	0.042939	0.081821	0.075841	0.032195

Table A.146: Fluctuation strength (vacil) presented as average values for a heavy vehicle with an internal combustion engine at a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.042392	0.042393	0.042388	0.042405	0.042392	0.042369
0.0313	0.042421	0.04242	0.042406	0.042422	0.04242	0.042415
0.0625	0.042341	0.042343	0.04234	0.042339	0.042343	0.042323
0.125	0.042305	0.0423	0.042297	0.042315	0.042302	0.042298
0.25	0.042222	0.042209	0.042084	0.042151	0.042207	0.042204
0.5	0.04171	0.041721	0.041625	0.041564	0.041728	0.041503
1.0	0.041013	0.041179	0.040716	0.040768	0.041232	0.04085
2.0	0.039523	0.040261	0.038884	0.039424	0.040469	0.038684
4.0	0.035411	0.037875	0.035171	0.035752	0.037885	0.034341
5.0	0.032983	0.036171	0.03351	0.03389	0.036009	0.032467
10.0	0.024763	0	0.034816	0.037943	0.027232	0.040644
20.0	0.031135	0	0.050362	0.061039	0.025029	0.031436

Table A.147: Fluctuation strength (vacil) presented as average values for a light vehicle with electric motor at a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.03375	0.033749	0.033761	0.033813	0.03375	0.033756
0.0313	0.033765	0.033764	0.0338	0.033848	0.033765	0.033793
0.0625	0.033723	0.03372	0.033762	0.033841	0.033722	0.033728
0.125	0.033689	0.033688	0.033723	0.033802	0.03369	0.03364
0.25	0.033661	0.033642	0.033577	0.03382	0.033648	0.033557
0.5	0.033387	0.033361	0.033299	0.033398	0.033366	0.033015
1.0	0.032967	0.033013	0.032668	0.033032	0.033045	0.032475
2.0	0.032352	0.03263	0.031663	0.032585	0.032752	0.030997
4.0	0.029732	0.031428	0.028784	0.030828	0.031473	0.027242
5.0	0.028382	0.030589	0.027635	0.02985	0.030551	0.025607
10.0	0.024298	0	0.029979	0.033758	0.025849	0.03207
20.0	0.027461	0	0.043734	0.050827	0.023593	0.025041

Table A.148: Fluctuation strength (vacil) presented as average values for a light vehicle with internal combustion engine at a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.034704	0.034703	0.034696	0.0347	0.034703	0.034679
0.0313	0.03472	0.034722	0.034684	0.034704	0.034722	0.034672
0.0625	0.034666	0.034669	0.034651	0.034605	0.034671	0.034684
0.125	0.034625	0.034628	0.034596	0.034608	0.034632	0.034592
0.25	0.034558	0.034578	0.034525	0.034562	0.034578	0.034557
0.5	0.03418	0.034227	0.034067	0.034165	0.034234	0.033994
1.0	0.03365	0.033787	0.033384	0.033739	0.033848	0.033456
2.0	0.032676	0.033283	0.032047	0.032784	0.033481	0.031829
4.0	0.029585	0.031529	0.029205	0.030406	0.031496	0.028011
5.0	0.028153	0.030478	0.02795	0.029317	0.030336	0.026816
10.0	0.023128	0	0.030621	0.031712	0.024881	0.033402
20.0	0.027213	0	0.043717	0.051477	0.023559	0.026938

Table A.149: Fluctuation strength (vacil) presented as average values for a heavy vehicle with an electric motor at a pass-by recorded at 50 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.04031	0.04031	0.040314	0.040319	0.04031	0.040315
0.0313	0.040326	0.040325	0.040317	0.040348	0.040325	0.040337
0.0625	0.04026	0.040262	0.040268	0.040341	0.040262	0.040293
0.125	0.040203	0.040208	0.040202	0.040238	0.040207	0.040192
0.25	0.040116	0.04011	0.040032	0.040207	0.040111	0.040191
0.5	0.039622	0.039645	0.039578	0.039547	0.039652	0.039606
1.0	0.039004	0.03913	0.03871	0.03914	0.039178	0.038856
2.0	0.037574	0.038236	0.037124	0.037696	0.038401	0.03654
4.0	0.033774	0.036045	0.033597	0.034149	0.036034	0.032309
5.0	0.031586	0.034523	0.032034	0.032611	0.034418	0.03037
10.0	0.024301	0	0.033396	0.037264	0.026544	0.037322
20.0	0.029306	0	0.048358	0.056456	0.024764	0.030366

Table A.150: Fluctuation strength (vacil) presented as average values for a heavy vehicle with an internal combustion engine at a pass-by recorded at 50 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0424	0.0424	0.042405	0.0424	0.0424	0.042401
0.0313	0.042428	0.042427	0.042427	0.042419	0.042427	0.042469
0.0625	0.042352	0.04235	0.042344	0.042362	0.04235	0.04235
0.125	0.0423	0.042298	0.042343	0.042347	0.042299	0.042282
0.25	0.042202	0.042199	0.042106	0.042274	0.042197	0.042191
0.5	0.041687	0.041712	0.041597	0.041589	0.041724	0.041583
1.0	0.041049	0.041161	0.040692	0.040936	0.041228	0.040865
2.0	0.03952	0.040266	0.038793	0.039573	0.040425	0.038648
4.0	0.035439	0.037889	0.035351	0.036215	0.037915	0.034249
5.0	0.033056	0.036267	0.033644	0.034313	0.036058	0.032335
10.0	0.024932	0	0.034525	0.037297	0.027295	0.03967
20.0	0.0309	0	0.050615	0.061147	0.025253	0.032012

Table A.151: Fluctuation strength (vacil) presented as average values for a light vehicle with electric motor at a pass-by recorded at 50 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.035384	0.035384	0.035384	0.035374	0.035384	0.035417
0.0313	0.035403	0.035402	0.035413	0.035397	0.035403	0.035444
0.0625	0.03536	0.035361	0.035346	0.035352	0.03536	0.035406
0.125	0.035328	0.035328	0.035344	0.035276	0.035328	0.035307
0.25	0.035275	0.035272	0.035186	0.035312	0.035274	0.035218
0.5	0.03489	0.034914	0.034845	0.034937	0.034927	0.034672
1.0	0.034488	0.034591	0.034263	0.034622	0.034635	0.033987
2.0	0.033598	0.034096	0.032875	0.034006	0.034295	0.032349
4.0	0.03071	0.032528	0.030106	0.031569	0.032623	0.028644
5.0	0.029143	0.031605	0.028887	0.030068	0.031553	0.027098
10.0	0.024005	0	0.030515	0.034827	0.025781	0.032797
20.0	0.026742	0	0.043148	0.050173	0.023065	0.025772

Table A.152: Fluctuation strength (vacil) presented as average values for a light vehicle with internal combustion engine at a pass-by recorded at 50 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.036246	0.036245	0.036211	0.036248	0.036245	0.036225
0.0313	0.036266	0.036265	0.036272	0.036261	0.036265	0.036232
0.0625	0.036215	0.036216	0.036224	0.036195	0.036215	0.03618
0.125	0.036176	0.036177	0.036198	0.036185	0.036175	0.036154
0.25	0.036144	0.036131	0.036123	0.036155	0.036135	0.036107
0.5	0.035732	0.035728	0.035693	0.035666	0.035732	0.035551
1.0	0.035124	0.03531	0.034906	0.035402	0.035339	0.034978
2.0	0.033981	0.034654	0.033826	0.034296	0.034818	0.033434
4.0	0.030767	0.032817	0.030654	0.031449	0.032866	0.029685
5.0	0.028995	0.031569	0.029286	0.029844	0.031441	0.027965
10.0	0.022805	0	0.031089	0.033681	0.02476	0.03558
20.0	0.026307	0	0.044337	0.051663	0.022757	0.027948

A.4.5 A-weighted values

Table A.153: A-weighted values (dB) presented as single numbers for a heavy vehicle with electric motor at a pass-by recorded at 40 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-33.117	-33.117	-33.117	-33.116	-33.117	-33.118
0.0313	-33.117	-33.117	-33.117	-33.115	-33.117	-33.119
0.0625	-33.117	-33.117	-33.116	-33.112	-33.117	-33.12
0.125	-33.116	-33.116	-33.115	-33.108	-33.116	-33.125
0.25	-33.115	-33.115	-33.12	-33.093	-33.116	-33.127
0.5	-33.111	-33.111	-33.117	-33.085	-33.111	-33.147
1.0	-33.115	-33.115	-33.122	-33.056	-33.115	-33.183
2.0	-33.037	-33.034	-33.049	-32.92	-33.034	-33.167
4.0	-33.013	-33.001	-33.023	-32.802	-33.001	-33.295
5.0	-33.049	-33.033	-33.053	-32.79	-33.033	-33.396
10.0	-33.1	0	-33.078	-32.675	-33.067	-33.798
20.0	-33.421	0	-33.36	-32.76	-33.274	-34.909

Table A.154: A-weighted values (dB) presented as single numbers for a heavy vehicle with an internal combustion engine at a pass-by recorded at 40 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-29.368	-29.368	-29.369	-29.367	-29.368	-29.369
0.0313	-29.369	-29.369	-29.369	-29.367	-29.369	-29.371
0.0625	-29.368	-29.368	-29.369	-29.364	-29.368	-29.371
0.125	-29.368	-29.368	-29.369	-29.36	-29.368	-29.376
0.25	-29.367	-29.367	-29.374	-29.344	-29.367	-29.378
0.5	-29.36	-29.36	-29.368	-29.339	-29.36	-29.394
1.0	-29.37	-29.37	-29.375	-29.316	-29.37	-29.433
2.0	-29.291	-29.288	-29.297	-29.182	-29.287	-29.418
4.0	-29.268	-29.258	-29.273	-29.077	-29.259	-29.529
5.0	-29.306	-29.292	-29.306	-29.072	-29.292	-29.625
10.0	-29.355	0	-29.325	-28.939	-29.322	-30.025
20.0	-29.671	0	-29.61	-29.004	-29.522	-31.158

Table A.155: A-weighted values (dB) presented as single numbers for a light vehicle with electric motor at a pass-by recorded at 40 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-34.767	-34.767	-34.767	-34.766	-34.767	-34.768
0.0313	-34.767	-34.767	-34.767	-34.766	-34.767	-34.769
0.0625	-34.767	-34.767	-34.766	-34.763	-34.767	-34.77
0.125	-34.766	-34.766	-34.765	-34.76	-34.766	-34.774
0.25	-34.764	-34.765	-34.769	-34.744	-34.765	-34.773
0.5	-34.76	-34.761	-34.764	-34.737	-34.761	-34.794
1.0	-34.759	-34.76	-34.77	-34.7	-34.76	-34.809
2.0	-34.656	-34.655	-34.671	-34.554	-34.655	-34.767
4.0	-34.715	-34.706	-34.728	-34.529	-34.707	-34.939
5.0	-34.726	-34.713	-34.733	-34.497	-34.712	-35.047
10.0	-34.736	0	-34.716	-34.335	-34.702	-35.405
20.0	-35.058	0	-34.995	-34.433	-34.905	-36.491

Table A.156: A-weighted values (dB) presented as single numbers for a light vehicle with internal combustion engine at a pass-by recorded at 40 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-33.84	-33.84	-33.84	-33.838	-33.84	-33.84
0.0313	-33.84	-33.84	-33.84	-33.838	-33.84	-33.842
0.0625	-33.839	-33.839	-33.839	-33.836	-33.839	-33.843
0.125	-33.839	-33.839	-33.838	-33.833	-33.839	-33.847
0.25	-33.837	-33.837	-33.842	-33.817	-33.837	-33.846
0.5	-33.833	-33.834	-33.837	-33.81	-33.834	-33.867
1.0	-33.832	-33.833	-33.843	-33.773	-33.833	-33.882
2.0	-33.734	-33.732	-33.749	-33.632	-33.732	-33.846
4.0	-33.78	-33.771	-33.794	-33.592	-33.773	-34.005
5.0	-33.79	-33.777	-33.798	-33.561	-33.777	-34.111
10.0	-33.811	0	-33.793	-33.408	-33.778	-34.486
20.0	-34.132	0	-34.069	-33.505	-33.978	-35.568

Table A.157: A-weighted values (dB) presented as single numbers for a heavy vehicle with electric motor at a pass-by recorded at 50 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-31.921	-31.921	-31.922	-31.92	-31.921	-31.922
0.0313	-31.921	-31.921	-31.921	-31.919	-31.921	-31.924
0.0625	-31.921	-31.921	-31.921	-31.917	-31.921	-31.925
0.125	-31.921	-31.921	-31.921	-31.912	-31.921	-31.929
0.25	-31.92	-31.92	-31.928	-31.897	-31.921	-31.932
0.5	-31.916	-31.916	-31.924	-31.893	-31.916	-31.952
1.0	-31.921	-31.921	-31.93	-31.856	-31.92	-31.999
2.0	-31.844	-31.842	-31.86	-31.714	-31.842	-31.982
4.0	-31.823	-31.811	-31.836	-31.606	-31.811	-32.107
5.0	-31.87	-31.855	-31.88	-31.616	-31.855	-32.229
10.0	-31.921	0	-31.892	-31.495	-31.884	-32.655
20.0	-32.262	0	-32.2	-31.576	-32.116	-33.827

Table A.158: A-weighted values (dB) presented as single numbers for a heavy vehicle with an internal combustion engine at a pass-by recorded at 50 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-29.356	-29.356	-29.356	-29.355	-29.356	-29.357
0.0313	-29.356	-29.356	-29.356	-29.354	-29.356	-29.359
0.0625	-29.356	-29.356	-29.356	-29.351	-29.356	-29.36
0.125	-29.356	-29.356	-29.355	-29.347	-29.356	-29.364
0.25	-29.355	-29.355	-29.361	-29.331	-29.355	-29.366
0.5	-29.349	-29.349	-29.355	-29.321	-29.349	-29.388
1.0	-29.354	-29.353	-29.358	-29.29	-29.353	-29.424
2.0	-29.272	-29.269	-29.278	-29.151	-29.269	-29.412
4.0	-29.254	-29.245	-29.259	-29.028	-29.245	-29.527
5.0	-29.287	-29.273	-29.288	-29.027	-29.272	-29.624
10.0	-29.342	0	-29.317	-28.922	-29.309	-30.044
20.0	-29.666	0	-29.606	-28.992	-29.52	-31.169

Table A.159: A-weighted values (dB) presented as single numbers for a light vehicle with electric motor at a pass-by recorded at 50 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-32.923	-32.923	-32.924	-32.923	-32.923	-32.924
0.0313	-32.924	-32.924	-32.923	-32.922	-32.924	-32.925
0.0625	-32.923	-32.923	-32.923	-32.92	-32.923	-32.926
0.125	-32.923	-32.923	-32.921	-32.919	-32.923	-32.929
0.25	-32.922	-32.922	-32.926	-32.905	-32.922	-32.928
0.5	-32.919	-32.919	-32.925	-32.903	-32.919	-32.944
1.0	-32.92	-32.919	-32.925	-32.877	-32.919	-32.98
2.0	-32.822	-32.821	-32.835	-32.722	-32.821	-32.918
4.0	-32.88	-32.872	-32.893	-32.68	-32.872	-33.116
5.0	-32.899	-32.886	-32.907	-32.669	-32.886	-33.21
10.0	-32.898	0	-32.879	-32.507	-32.866	-33.546
20.0	-33.217	0	-33.157	-32.598	-33.062	-34.65

Table A.160: A-weighted values (dB) presented as single numbers for a light vehicle with internal combustion engine at a pass-by recorded at 50 km/h. Calculated according to ANSI standard [9]

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	-32.416	-32.416	-32.417	-32.416	-32.416	-32.417
0.0313	-32.416	-32.416	-32.416	-32.415	-32.416	-32.418
0.0625	-32.416	-32.416	-32.416	-32.413	-32.416	-32.419
0.125	-32.416	-32.416	-32.414	-32.412	-32.416	-32.423
0.25	-32.415	-32.415	-32.419	-32.398	-32.415	-32.422
0.5	-32.412	-32.412	-32.417	-32.395	-32.412	-32.438
1.0	-32.412	-32.411	-32.417	-32.368	-32.411	-32.473
2.0	-32.322	-32.32	-32.334	-32.221	-32.32	-32.421
4.0	-32.36	-32.352	-32.373	-32.161	-32.352	-32.598
5.0	-32.377	-32.363	-32.384	-32.147	-32.363	-32.688
10.0	-32.389	0	-32.369	-31.996	-32.357	-33.048
20.0	-32.712	0	-32.65	-32.09	-32.556	-34.151

B

Appendix 2

B.0.0.1 No barrier and no Doppler

Table B.1: Psychoacoustic annoyance for a heavy vehicle with an with an electric motor at a pass-by recorded at 40 km/h according to method by Zwicker and Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	6.7521	6.7521	6.7521	6.7521	6.7521	6.7521
0.0313	6.7521	6.7521	6.7521	6.7521	6.7521	6.7521
0.0625	6.7523	6.7523	6.7523	6.7523	6.7523	6.7523
0.125	6.7523	6.7523	6.7523	6.7523	6.7523	6.7523
0.25	6.7523	6.7523	6.7524	6.7524	6.7523	6.7523
0.5	6.7527	6.7527	6.7528	6.7527	6.7527	6.7528
1	6.7534	6.7534	6.7535	6.7534	6.7534	6.7535
2	6.7544	6.7543	6.7544	6.7543	6.7543	6.7542
4	6.7571	6.7571	6.7571	6.7571	6.7571	6.7572
5	6.7594	6.7594	6.7592	6.7594	6.7593	6.7595
10	6.9706	*	6.9702	6.9713	6.9705	6.9716
20	6.7515	*	6.7514	6.7514	6.7514	6.7519

Table B.2: Psychoacoustic annoyance for a heavy vehicle with an with an internal combustion engine at a pass-by recorded at 40 km/h according to method by Zwicker and Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	12.107	12.107	12.107	12.107	12.107	12.107
0.0313	12.107	12.107	12.107	12.107	12.107	12.107
0.0625	12.107	12.107	12.107	12.107	12.107	12.107
0.125	12.107	12.107	12.107	12.107	12.107	12.107
0.25	12.107	12.107	12.107	12.107	12.107	12.107
0.5	12.11	12.11	12.11	12.11	12.11	12.11
1	12.111	12.111	12.111	12.111	12.111	12.111
2	12.113	12.113	12.113	12.113	12.113	12.113
4	12.118	12.118	12.118	12.118	12.118	12.118
5	12.123	12.123	12.123	12.123	12.123	12.123
10	12.432	*	12.433	12.433	12.432	12.432
20	12.474	*	12.475	12.476	12.474	12.473

Table B.3: Psychoacoustic annoyance for light vehicle with an with an electric motor at a pass-by recorded at 40 km/h according to method by Zwicker and Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	4.5119	4.5119	4.5119	4.5119	4.5119	4.5119
0.0313	4.5118	4.5118	4.5118	4.5118	4.5118	4.5118
0.0625	4.5119	4.5119	4.5119	4.5119	4.5119	4.5119
0.1256	4.512	4.512	4.512	4.512	4.512	4.512
0.25	4.512	4.512	4.512	4.512	4.512	4.512
0.5	4.5131	4.5131	4.5131	4.5131	4.5131	4.5131
1	4.5137	4.5137	4.5137	4.5137	4.5137	4.5137
2	4.5153	4.5153	4.5153	4.5153	4.5153	4.5153
4	4.5187	4.5187	4.5187	4.5187	4.5187	4.5186
5	4.5214	4.5214	4.5213	4.5214	4.5214	4.5213
10	4.5442	*	4.5436	4.5445	4.544	4.5445
20	4.4328	*	4.4324	4.5528	4.4325	4.433

Table B.4: Psychoacoustic annoyance for light vehicle with an internal combustion engine at a pass-by recorded at 40 km/h according to method by Zwicker Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	5.4418	5.4418	5.4418	5.4417	5.4418	5.4418
0.0313	5.4417	5.4417	5.4417	5.4417	5.4417	5.4417
0.0625	5.4418	5.4418	5.4418	5.4418	5.4418	5.4418
0.125	5.4419	5.4419	5.4419	5.4419	5.4419	5.4419
0.25	5.4419	5.4419	5.4419	5.4418	5.4419	5.4419
0.5	5.4431	5.4431	5.4431	5.4431	5.4431	5.4431
1	5.4434	5.4434	5.4434	5.4434	5.4434	5.4434
2	5.4452	5.4452	5.4452	5.4452	5.4452	5.4452
4	5.4485	5.4485	5.4485	5.4485	5.4485	5.3401
5	5.451	5.451	5.4511	5.4509	5.451	5.4511
10	5.476	*	5.4759	5.4759	5.4761	5.4761
20	5.3538	*	5.3538	5.3514	5.3536	5.3541

Table B.5: Psychoacoustic annoyance for a heavy vehicle with an electric motor at a pass-by recorded at 50 km/h according to method by Zwicker Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	8.0076	8.0076	8.0076	8.0076	8.0076	8.0076
0.0313	8.0075	8.0075	8.0075	8.0075	8.0075	8.0075
0.0625	8.0076	8.0076	8.0076	8.0076	8.0076	8.0076
0.125	8.0078	8.0078	8.0078	8.0078	8.0078	8.0078
0.25	8.0078	8.0078	8.0078	8.0078	8.0078	8.0078
0.5	8.0085	8.0085	8.0085	8.0085	8.0085	8.0085
1	8.0091	8.0091	7.9822	8.0091	8.0091	8.0092
2	7.9844	7.9844	7.9844	7.9844	7.9844	7.9845
4	7.9895	7.9895	7.9895	7.9894	7.9895	7.9896
5	7.9919	7.9919	7.9918	7.9919	7.9919	7.9921
10	8.0377	*	8.0368	8.0108	8.0076	8.041
20	8.0547	*	8.0537	8.0546	8.0543	8.0568

Table B.6: Psychoacoustic annoyance for a heavy vehicle with an internal combustion engine at a pass-by recorded at 50 km/h according to method by Zwicker Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	12.17	12.17	12.17	12.17	12.17	12.17
0.0313	12.17	12.17	12.17	12.17	12.17	12.17
0.0625	12.17	12.17	12.17	12.17	12.17	12.17
0.125	12.17	12.17	12.17	12.17	12.17	12.17
0.25	12.17	12.17	12.17	12.17	12.17	12.17
0.5	12.171	12.171	12.171	12.171	12.171	12.171
1	12.174	12.174	12.174	12.174	12.174	12.174
2	12.176	12.176	12.176	12.176	12.176	12.176
4	12.178	12.178	12.178	12.178	12.178	12.179
5	12.241	12.241	12.241	12.241	12.241	12.241
10	12.263	*	12.263	12.263	12.263	12.263
20	12.303	*	12.304	12.303	12.304	12.303

Table B.7: Psychoacoustic annoyance for a light vehicle with an electric motor at a pass-by recorded at 50 km/h according to method by Zwicker Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	5.5273	5.5273	5.5273	5.5273	5.5273	5.5273
0.0313	5.5273	5.5273	5.5273	5.5273	5.5273	5.5273
0.0625	5.5273	5.5273	5.5273	5.5273	5.5273	5.5273
0.125	5.5273	5.5273	5.5273	5.5273	5.5273	5.5273
0.25	5.5276	5.5276	5.5276	5.5276	5.5276	5.5275
0.5	5.5281	5.5281	5.5281	5.5282	5.5281	5.528
1	5.529	5.529	5.529	5.529	5.529	5.5289
2	5.5316	5.5316	5.5315	5.5315	5.5316	5.5314
4	5.5356	5.5356	5.5355	5.5355	5.5356	5.5354
5	5.5382	5.5383	5.5382	5.5382	5.5383	5.5381
10	5.6984	*	5.6983	5.6983	5.6983	5.6982
20	5.5734	*	5.5732	5.5707	5.5733	5.5718

Table B.8: Psychoacoustic annoyance for a light vehicle with an internal combustion engine at a pass-by recorded at 50 km/h according to method by Zwicker Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	6.9113	6.9113	6.9113	6.9113	6.9113	6.9113
0.0313	6.9113	6.9113	6.9113	6.9113	6.9113	6.9113
0.0625	6.9113	6.9113	6.9113	6.9113	6.9113	6.9113
0.125	6.9114	6.9114	6.9114	6.9114	6.9114	6.9114
0.25	6.9117	6.9117	6.9117	6.9117	6.9117	6.9117
0.5	6.9124	6.9124	6.9124	6.9124	6.9124	6.9124
1	6.9132	6.9132	6.9131	6.9132	6.9132	6.9132
2	6.916	6.9159	6.9159	6.9159	6.9159	6.9159
4	6.9202	6.9202	6.9202	6.9202	6.9202	6.9202
5	6.9228	6.9228	6.9228	6.9228	6.9228	6.9229
10	7.0913	*	7.0915	7.0914	7.0914	7.0916
20	6.9603	*	6.9601	6.9583	6.9602	6.9606

B.0.0.2 No barrier with Doppler effect

Table B.9: Psychoacoustic annoyance for a heavy vehicle with an with an electric motor at a pass-by recorded at 40 km/h according to method by Zwicker and Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	6.7442	6.7442	6.7442	6.7442	6.7442	6.7442
0.0313	6.7315	6.7315	6.7315	6.7315	6.7315	6.7315
0.0625	6.7317	6.7317	6.7317	6.7317	6.7317	6.7317
0.125	6.7317	6.7317	6.7317	6.7317	6.7317	6.7318
0.25	6.7444	6.7444	6.7318	6.7447	6.7444	6.7319
0.5	6.7321	6.7321	6.7324	6.732	6.7322	6.7326
1.0	6.7327	6.7328	6.7332	6.7332	6.7328	6.733
2.0	6.7336	6.7338	6.7345	6.7343	6.7339	6.7328
4.0	6.7373	6.7376	6.7379	6.7386	6.738	6.7345
5.0	6.7399	6.7406	6.741	6.7415	6.741	6.7368
10.0	6.8883	*	6.8887	6.8898	6.8889	6.8882
20.0	6.638	*	6.6385	6.6374	6.638	6.6713

Table B.10: Psychoacoustic annoyance for a heavy vehicle with an with an internal combustion engine at a pass-by recorded at 40 km/h according to method by Zwicker and Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	11.85	11.85	11.85	11.85	11.85	11.85
0.0313	11.85	11.85	11.85	11.85	11.85	11.85
0.0625	11.85	11.85	11.85	11.85	11.85	11.85
0.125	11.85	11.85	11.85	11.85	11.85	11.85
0.25	11.851	11.851	11.851	11.851	11.851	11.851
0.5	11.851	11.851	11.851	11.851	11.851	11.851
1.0	11.851	11.851	11.851	11.851	11.851	11.85
2.0	11.852	11.853	11.852	11.853	11.852	11.852
4.0	11.856	11.857	11.857	11.857	11.856	11.853
5.0	11.857	11.859	11.859	11.86	11.858	11.854
10.0	12.159	*	12.159	12.159	12.159	12.155
20.0	12.185	*	12.186	12.188	12.185	12.183

Table B.11: Psychoacoustic annoyance for light vehicle with an with an electric motor at a pass-by recorded at 40 km/h according to method by Zwicker and Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	4.4939	4.4939	4.4939	4.4939	4.4939	4.4939
0.0313	4.4938	4.4938	4.4938	4.4938	4.4938	4.4938
0.0625	4.494	4.494	4.494	4.494	4.494	4.4939
0.125	4.494	4.494	4.494	4.4939	4.494	4.494
0.25	4.4941	4.4941	4.4941	4.494	4.4941	4.494
0.5	4.4953	4.4953	4.4953	4.4952	4.4953	4.4952
1.0	4.4958	4.4959	4.4957	4.4957	4.496	4.496
2.0	4.4974	4.4976	4.4973	4.4973	4.4976	4.4972
4.0	4.5008	4.5012	4.5011	4.5009	4.5011	4.5002
5.0	4.5038	4.5043	4.5039	4.5034	4.5039	4.5028
10.0	4.5199	*	4.52	4.5208	4.5201	4.5196
20.0	4.4897	*	4.4898	4.4898	4.4896	4.4902

Table B.12: Psychoacoustic annoyance for light vehicle with an internal combustion engine at a pass-by recorded at 40 km/h according to method by Zwicker Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	5.4159	5.4159	5.4159	5.4158	5.4159	5.4159
0.0313	5.4157	5.4157	5.4157	5.4157	5.4157	5.4158
0.0625	5.4159	5.4159	5.4159	5.4159	5.4159	5.4159
0.125	5.416	5.416	5.4159	5.4158	5.416	5.416
0.25	5.416	5.416	5.416	5.4158	5.416	5.416
0.5	5.4171	5.4171	5.417	5.417	5.4171	5.417
1.0	5.4251	5.4251	5.4251	5.4249	5.4251	5.425
2.0	5.4269	5.4271	5.4268	5.4269	5.4271	5.427
4.0	5.4003	5.4005	5.4005	5.3993	5.4006	5.3997
5.0	5.4339	5.4342	5.434	5.4324	5.4341	5.4332
10.0	5.4477	*	5.4471	5.448	5.4475	5.4482
20.0	5.4357	*	5.4214	5.4325	5.4355	5.4184

Table B.13: Psychoacoustic annoyance for a heavy vehicle with an electric motor at a pass-by recorded at 50 km/h according to method by Zwicker Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	7.8189	7.8189	7.8189	7.8189	7.8189	7.8189
0.0313	7.8188	7.8188	7.8188	7.8188	7.8188	7.8188
0.0625	7.819	7.819	7.819	7.819	7.819	7.819
0.125	7.8189	7.8189	7.8189	7.8188	7.8189	7.819
0.25	7.9573	7.9573	7.9573	7.9572	7.9573	7.9575
0.5	7.8189	7.8189	7.8463	7.8192	7.8189	7.8463
1.0	7.8467	7.8468	7.8469	7.8471	7.8468	7.8471
2.0	7.8478	7.8479	7.848	7.8494	7.8479	7.8482
4.0	7.9673	7.9679	7.9691	7.9702	7.9683	7.9672
5.0	7.8522	7.8531	7.8547	7.8545	7.8537	7.8963
10.0	7.8678	*	7.8675	7.8697	7.8679	7.8669
20.0	7.8765	*	7.8755	7.8724	7.8761	7.8782

Table B.14: Psychoacoustic annoyance for a heavy vehicle with an internal combustion engine at a pass-by recorded at 50 km/h according to method by Zwicker Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	12.099	12.099	12.099	12.099	12.099	12.099
0.0313	12.099	12.099	12.099	12.099	12.099	12.099
0.0625	12.099	12.099	12.099	12.099	12.099	12.099
0.125	12.099	12.099	12.099	12.099	12.099	12.099
0.25	12.099	12.099	12.099	12.099	12.099	12.099
0.5	12.1	12.1	12.1	12.1	12.1	12.101
1.0	12.103	12.103	12.103	12.103	12.103	12.104
2.0	12.106	12.106	12.105	12.105	12.106	12.106
4.0	12.11	12.11	12.11	12.109	12.11	12.11
5.0	12.119	12.12	12.119	12.119	12.119	12.118
10.0	12.439	*	12.439	12.439	12.439	12.419
20.0	12.49	*	12.491	12.49	12.49	12.49

Table B.15: Psychoacoustic annoyance for a light vehicle with an electric motor at a pass-by recorded at 50 km/h according to method by Zwicker Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	5.4462	5.4462	5.4462	5.4462	5.4462	5.4462
0.0313	5.4463	5.4463	5.4463	5.4463	5.4463	5.4463
0.0625	5.4463	5.4463	5.4463	5.4464	5.4463	5.4463
0.125	5.4463	5.4463	5.4463	5.4465	5.4463	5.4463
0.25	5.4465	5.4465	5.4465	5.4467	5.4465	5.4465
0.5	5.4468	5.4468	5.4469	5.447	5.4468	5.4466
1.0	5.4473	5.4474	5.4475	5.4476	5.4473	5.4473
2.0	5.4489	5.449	5.4496	5.4491	5.449	5.4484
4.0	5.4522	5.4524	5.4531	5.4521	5.4524	5.4509
5.0	5.4542	5.4546	5.4548	5.4539	5.4544	5.4531
10.0	5.4194	*	5.4195	5.4907	5.4196	5.4913
20.0	5.4768	*	5.4766	5.4763	5.4768	5.4775

Table B.16: Psychoacoustic annoyance for a light vehicle with an internal combustion engine at a pass-by recorded at 50 km/h according to method by Zwicker Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	6.8213	6.8213	6.8212	6.8212	6.8213	6.8212
0.0313	6.8213	6.8213	6.8213	6.8213	6.8213	6.8212
0.0625	6.8214	6.8214	6.8213	6.8214	6.8214	6.8213
0.125	6.8214	6.8214	6.8213	6.8215	6.8214	6.8213
0.25	6.8215	6.8215	6.8214	6.8216	6.8215	6.8214
0.5	6.7489	6.7489	6.7487	6.749	6.7489	6.7488
1.0	6.7491	6.7491	6.7489	6.749	6.7491	6.7487
2.0	6.75	6.75	6.7498	6.7498	6.7502	6.7493
4.0	6.7514	6.7516	6.7822	6.7514	6.7515	6.7514
5.0	6.7524	6.7528	6.7529	6.7519	6.7528	6.7525
10.0	6.7872	*	6.7872	6.7872	6.7872	6.7874
20.0	6.8573	*	6.8574	6.8555	6.8573	6.8578

B.0.0.3 Barrier with Doppler effect

Table B.17: Psychoacoustic annoyance for a heavy vehicle with an with an electric motor at a pass-by recorded at 40 km/h according to method by Zwicker and Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	5.9551	5.9551	5.9545	5.9548	5.9551	5.8423
0.0313	5.8444	5.9551	5.9041	5.8473	5.9551	5.8428
0.0625	5.9553	5.9552	5.955	5.9576	5.9549	5.9511
0.125	5.9565	5.9567	5.9619	5.9615	5.9566	5.9508
0.25	5.956	5.9569	5.8468	5.9299	5.9567	5.8482
0.5	5.8483	5.9138	5.8973	5.9175	5.9138	5.9459
1.0	5.8742	5.8821	5.8276	5.9202	5.8818	5.8541
2.0	5.8893	5.9135	5.9451	5.9947	5.9156	5.8054
4.0	5.7987	5.9178	6.0587	6.0644	5.913	5.7926
5.0	5.7606	5.8488	6.0779	6.1189	5.8543	5.7804
10.0	5.4652	*	5.8361	6.0608	5.5832	5.3702
20.0	4.6746	*	5.2663	5.3708	4.7158	4.1342

Table B.18: Psychoacoustic annoyance for a heavy vehicle with an with an internal combustion engine at a pass-by recorded at 40 km/h according to method by Zwicker and Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	10.598	10.598	10.598	10.599	10.598	10.6
0.0313	10.598	10.598	10.599	10.6	10.598	10.602
0.0625	10.598	10.598	10.598	10.601	10.598	10.601
0.125	10.598	10.598	10.611	10.6	10.597	10.59
0.25	10.601	10.603	10.6	10.627	10.601	10.592
0.5	10.602	10.604	10.61	10.618	10.604	10.603
1.0	10.565	10.573	10.576	10.644	10.579	10.39
2.0	10.582	10.48	10.48	10.582	10.477	10.339
4.0	10.375	10.49	10.775	10.839	10.478	10.402
5.0	10.297	10.461	10.641	11.025	10.465	10.457
10.0	9.9112	*	10.361	10.785	10.141	9.6074
20.0	8.6227	*	9.4311	9.7439	8.8439	7.63

Table B.19: Psychoacoustic annoyance for light vehicle with an with an electric motor at a pass-by recorded at 40 km/h according to method by Zwicker and Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	3.8974	3.8973	3.8958	3.8989	3.8973	3.8949
0.0313	3.8973	3.8974	3.8969	3.9023	3.8974	3.8943
0.0625	3.8966	3.8973	3.8977	3.9034	3.8972	3.8925
0.125	3.8972	3.8972	3.8975	3.9048	3.8973	3.8865
0.25	3.8977	3.8976	3.8945	3.9274	3.8971	3.8861
0.5	3.8964	3.8979	3.8966	3.8756	3.8972	3.8307
1.0	3.8296	3.8389	3.887	3.9282	3.8382	3.7944
2.0	3.8432	3.868	3.8772	3.9557	3.8659	3.7849
4.0	3.8167	3.901	3.9179	3.9604	3.8954	3.7903
5.0	3.7266	3.8392	3.9578	3.9587	3.8387	3.7537
10.0	3.5169	*	3.8025	3.975	3.6847	3.4302
20.0	2.9531	*	3.387	3.4546	3.0189	2.6537

Table B.20: Psychoacoustic annoyance for light vehicle with an internal combustion engine at a pass-by recorded at 40 km/h according to method by Zwicker Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	4.711	4.711	4.7108	4.7118	4.711	4.7092
0.0313	4.7111	4.711	4.7112	4.7141	4.7111	4.7086
0.0625	4.7108	4.7108	4.7121	4.714	4.7109	4.7083
0.125	4.7105	4.7112	4.7117	4.7132	4.7111	4.643
0.25	4.6509	4.6492	4.6504	4.7245	4.6497	4.7061
0.5	4.6517	4.7175	4.7126	4.6662	4.7168	4.6326
1.0	4.6337	4.6463	4.6465	4.6781	4.6454	4.6142
2.0	4.6306	4.6523	4.6628	4.712	4.6512	4.5954
4.0	4.5996	4.6528	4.7267	4.7451	4.6533	4.6153
5.0	4.5436	4.6353	4.7168	4.754	4.6356	4.5444
10.0	4.3779	*	4.5529	4.7791	4.4719	4.1523
20.0	3.683	*	4.0558	4.2783	3.6965	3.2389

Table B.21: Psychoacoustic annoyance for a heavy vehicle with an electric motor at a pass-by recorded at 50 km/h according to method by Zwicker Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	6.9558	6.9558	6.9556	6.9594	6.9558	6.9547
0.0313	6.956	6.9558	6.9566	6.9588	6.9559	6.9531
0.0625	6.9568	6.9558	6.9577	6.9571	6.956	6.956
0.125	6.9592	6.9579	6.9627	7.0243	6.9579	7.0113
0.25	7.026	7.0264	6.958	6.9747	7.0257	7.0092
0.5	6.9534	6.9565	6.9396	7.0444	6.9561	6.955
1.0	6.9865	6.998	6.9739	7.0473	6.998	6.8019
2.0	6.9909	7.0142	7.0171	7.0873	7.0118	6.8435
4.0	6.8525	6.9991	7.1464	7.2123	6.9938	6.7971
5.0	6.8293	6.9103	7.129	7.1677	6.9124	6.7151
10.0	6.4351	*	6.8595	7.0041	6.5867	6.2321
20.0	5.5189	*	6.1579	6.42	5.6682	4.8575

Table B.22: Psychoacoustic annoyance for a heavy vehicle with an internal combustion engine at a pass-by recorded at 50 km/h according to method by Zwicker Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	10.675	10.675	10.674	10.676	10.675	10.674
0.0313	10.675	10.675	10.675	10.677	10.675	10.674
0.0625	10.674	10.675	10.675	10.674	10.675	10.674
0.125	10.676	10.676	10.679	10.68	10.676	10.673
0.25	10.682	10.681	10.677	10.695	10.68	10.685
0.5	10.693	10.694	10.688	10.691	10.694	10.676
1.0	10.646	10.658	10.655	10.699	10.659	10.6
2.0	10.65	10.681	10.694	10.805	10.677	10.558
4.0	10.61	10.727	10.831	11.028	10.727	10.593
5.0	10.574	10.709	10.873	11.121	10.719	10.512
10.0	9.9617	*	10.506	10.819	10.185	9.6147
20.0	8.5679	*	9.5706	9.8817	8.8096	7.6703

Table B.23: Psychoacoustic annoyance for a light vehicle with an electric motor at a pass-by recorded at 50 km/h according to method by Zwicker Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	4.7635	4.7635	4.7638	4.7638	4.7635	4.7631
0.0313	4.7635	4.7635	4.7633	4.7633	4.7633	4.7629
0.0625	4.7637	4.7635	4.7633	4.762	4.7634	4.7624
0.125	4.7634	4.7636	4.7644	4.7589	4.7635	4.7612
0.25	4.7603	4.7613	4.7593	4.7704	4.7608	4.82
0.5	4.7653	4.7956	4.7664	4.7954	4.7958	4.7993
1.0	4.7753	4.7774	4.7081	4.7872	4.7787	4.8069
2.0	4.7576	4.7714	4.7777	4.7937	4.7703	4.7471
4.0	4.7624	4.8152	4.8367	4.9408	4.8054	4.6808
5.0	4.6558	4.7221	4.7885	4.9577	4.7261	4.7249
10.0	4.3701	*	4.6283	4.7639	4.4892	4.3402
20.0	3.8248	*	4.2865	4.429	3.8994	3.3901

Table B.24: Psychoacoustic annoyance for a light vehicle with an internal combustion engine at a pass-by recorded at 50 km/h according to method by Zwicker Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	5.9706	5.9706	5.97	5.9701	5.9706	5.9705
0.0313	5.9705	5.9706	5.9711	5.9694	5.9706	5.9714
0.0625	5.9705	5.9708	5.97	5.9688	5.9705	6.0361
0.125	5.9707	5.9704	5.9709	5.9679	5.9707	5.9734
0.25	5.9696	5.9697	5.9674	5.972	5.9693	5.9782
0.5	6.0429	5.9793	5.9278	6.005	5.9804	6.008
1.0	6.0169	6.0218	5.9112	6.0194	6.0217	6.005
2.0	6.0128	6.0274	6.0339	6.0044	6.0249	5.9769
4.0	5.9677	6.0347	5.925	6.1125	6.0234	5.862
5.0	5.9692	6.0616	5.9975	6.2228	6.0615	5.9205
10.0	5.5201	*	5.8518	6.0035	5.6679	5.4631
20.0	4.8175	*	5.401	5.4814	4.9639	4.2308

B.0.0.4 Barrier with no Doppler effect

Table B.25: Psychoacoustic annoyance for a heavy vehicle with an with an electric motor at a pass-by recorded at 40 km/h according to method by Zwicker and Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	5.905	5.9051	5.9054	5.9043	5.9051	5.9049
0.0313	5.9052	5.9051	5.905	5.9038	5.9052	5.9044
0.0625	5.9051	5.9051	5.9057	5.9022	5.9048	5.9007
0.125	5.905	5.9056	5.9061	5.9044	5.9055	5.9021
0.25	5.9036	5.9027	5.9006	5.9251	5.9029	5.908
0.5	5.9085	5.9079	5.906	5.9135	5.908	5.8966
1.0	5.8781	5.8896	5.8875	5.9249	5.8879	5.8611
2.0	5.8885	5.9212	5.9269	5.9956	5.92	5.8295
4.0	5.8682	5.9272	6.0024	6.1259	5.9184	5.8625
5.0	5.8234	5.9218	6.0294	6.1557	5.9219	5.7949
10.0	5.4812	*	5.7901	6.0005	5.6012	5.3204
20.0	4.6597	*	5.2153	5.4434	4.7995	4.2356

Table B.26: Psychoacoustic annoyance for a heavy vehicle with an with an internal combustion engine at a pass-by recorded at 40 km/h according to method by Zwicker and Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	10.655	10.655	10.655	10.656	10.655	10.659
0.0313	10.655	10.655	10.655	10.66	10.655	10.659
0.0625	10.655	10.656	10.658	10.659	10.656	10.657
0.125	10.659	10.658	10.665	10.659	10.658	10.657
0.25	10.66	10.658	10.654	10.692	10.659	10.652
0.5	10.663	10.667	10.67	10.679	10.664	10.661
1.0	10.63	10.633	10.635	10.698	10.634	10.587
2.0	10.633	10.677	10.559	10.773	10.672	10.537
4.0	10.57	10.699	10.893	10.914	10.685	10.536
5.0	10.489	10.663	10.84	11.026	10.666	10.526
10.0	9.9681	*	10.49	10.826	10.189	9.8357
20.0	8.6025	*	9.551	9.8394	8.7715	7.8198

Table B.27: Psychoacoustic annoyance for light vehicle with an with an electric motor at a pass-by recorded at 40 km/h according to method by Zwicker and Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	3.9028	3.9026	3.9032	3.9051	3.9026	3.9015
0.0313	3.9027	3.9026	3.9039	3.9066	3.9026	3.9031
0.0625	3.9032	3.9027	3.9044	3.908	3.9027	3.9003
0.125	3.9047	3.9041	3.9054	3.9091	3.9039	3.8936
0.25	3.9066	3.9072	3.9062	3.9342	3.9073	3.8893
0.5	3.9035	3.9075	3.9035	3.9357	3.9054	3.874
1.0	3.8877	3.9061	3.9023	3.9441	3.906	3.8175
2.0	3.9058	3.9288	3.9186	3.9708	3.9276	3.827
4.0	3.8192	3.8994	3.9653	4.003	3.8869	3.8094
5.0	3.7695	3.8563	3.9741	4.0239	3.8553	3.7756
10.0	3.6153	*	3.8469	3.9729	3.6943	3.4853
20.0	3.0268	*	3.4329	3.556	3.1184	2.625

Table B.28: Psychoacoustic annoyance for light vehicle with an internal combustion engine at a pass-by recorded at 40 km/h according to method by Zwicker & Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	4.72	4.7198	4.7182	4.7208	4.7199	4.7183
0.0313	4.7199	4.7199	4.7196	4.722	4.7199	4.7172
0.0625	4.7196	4.7196	4.7206	4.7216	4.7195	4.7155
0.125	4.719	4.7196	4.7208	4.7244	4.72	4.7127
0.25	4.7208	4.7213	4.7202	4.7319	4.7217	4.7108
0.5	4.7221	4.73	4.7162	4.7394	4.7285	4.6869
1.0	4.7025	4.7188	4.7171	4.7532	4.7187	4.6662
2.0	4.6931	4.7223	4.7108	4.766	4.7227	4.6449
4.0	4.6469	4.7222	4.774	4.7903	4.7193	4.6382
5.0	4.5944	4.6879	4.7902	4.8298	4.6867	4.5974
10.0	4.3855	*	4.6305	4.7829	4.4803	4.2109
20.0	3.6905	*	4.0748	4.3265	3.8043	3.225

Table B.29: Psychoacoustic annoyance for a heavy vehicle with an electric motor at a pass-by recorded at 50 km/h according to method by Zwicker & Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	7.1131	7.1129	7.1118	7.1153	7.1129	7.1098
0.0313	7.1131	7.1129	7.1128	7.119	7.1126	7.1088
0.0625	7.1137	7.1132	7.1151	7.1182	7.1128	7.1121
0.125	7.1132	7.113	7.1177	7.1175	7.1135	7.1021
0.25	7.116	7.1182	7.1135	7.1361	7.1171	7.1028
0.5	7.1076	7.1108	7.1014	7.1296	7.1092	7.0466
1.0	7.0772	7.0941	7.0773	7.1493	7.0952	6.8701
2.0	7.0559	7.0886	7.0839	7.15	7.0876	6.9463
4.0	7.0215	7.0742	7.2084	7.2837	7.0711	6.9409
5.0	6.9329	7.0615	7.1975	7.3349	7.0594	6.8634
10.0	6.5327	*	6.8826	7.1599	6.61	6.3382
20.0	5.5436	*	6.2315	6.4835	5.6617	4.9545

Table B.30: Psychoacoustic annoyance for a heavy vehicle with an internal combustion engine at a pass-by recorded at 50 km/h according to method by Zwicker & Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	10.755	10.755	10.754	10.756	10.755	10.755
0.0313	10.755	10.755	10.754	10.756	10.755	10.754
0.0625	10.755	10.754	10.756	10.755	10.755	10.755
0.125	10.756	10.754	10.755	10.76	10.754	10.757
0.25	10.764	10.765	10.757	10.773	10.764	10.762
0.5	10.769	10.77	10.767	10.762	10.771	10.743
1.0	10.725	10.728	10.729	10.776	10.732	10.688
2.0	10.722	10.755	10.769	10.878	10.754	10.64
4.0	10.688	10.806	10.913	11.113	10.789	10.672
5.0	10.647	10.79	10.954	11.192	10.796	10.591
10.0	10.039	*	10.592	10.891	10.266	9.7077
20.0	8.6393	*	9.6453	9.9513	8.8813	7.7706

Table B.31: Psychoacoustic annoyance for a light vehicle with an electric motor at a pass-by recorded at 50 km/h according to method by Zwicker & Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	4.8313	4.8314	4.8304	4.8315	4.8314	4.8312
0.0313	4.8311	4.8314	4.8317	4.8333	4.8314	4.8319
0.0625	4.8306	4.8308	4.8309	4.8326	4.8311	4.8312
0.125	4.8299	4.8305	4.8322	4.8316	4.8306	4.8266
0.25	4.8279	4.8281	4.8287	4.8385	4.8283	4.8325
0.5	4.8375	4.8381	4.8356	4.8409	4.8382	4.8396
1.0	4.8157	4.818	4.8214	4.8289	4.818	4.8107
2.0	4.8257	4.8415	4.8467	4.9074	4.8402	4.8144
4.0	4.8056	4.8566	4.8766	4.9732	4.8438	4.7921
5.0	4.7681	4.839	4.908	4.9963	4.8414	4.7142
10.0	4.4883	*	4.7574	4.8953	4.61	4.3859
20.0	3.8333	*	4.289	4.4327	3.9381	3.3456

Table B.32: Psychoacoustic annoyance for a light vehicle with an internal combustion engine at a pass-by recorded at 50 km/h according to method by Zwicker & Fastl.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	6.0508	6.0508	6.0508	6.0506	6.0508	6.0505
0.0313	6.0509	6.0508	6.051	6.0507	6.0507	6.051
0.0625	6.0515	6.0509	6.0506	6.0497	6.051	6.0521
0.125	6.0512	6.0505	6.0524	6.0511	6.051	6.0549
0.25	6.0526	6.053	6.0496	6.0507	6.053	6.0561
0.5	6.0602	6.0596	6.0597	6.0543	6.0596	6.0562
1.0	6.0451	6.0473	6.0422	6.0375	6.0471	6.0226
2.0	6.034	6.052	6.0391	6.088	6.05	5.9761
4.0	6.0198	6.0866	6.056	6.1594	6.0775	5.9929
5.0	5.979	6.0688	6.1427	6.2178	6.0677	5.9113
10.0	5.6553	*	5.9919	6.1505	5.799	5.5185
20.0	4.8305	*	5.4025	5.5702	4.9725	4.1831

Table B.33: Difference in acoustic (sones) loudness, calculated according to ISO 532-1 (Zwicker), between a scenario without a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a heavy vehicle with electric motor during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.023334	0.023334	0.02333	0.023334	0.023334	0.023331
0.0313	0.02333	0.02333	0.023326	0.023327	0.02333	0.023328
0.0625	0.023345	0.023345	0.023341	0.023345	0.023345	0.023342
0.125	0.023355	0.023355	0.023348	0.023343	0.023355	0.023346
0.25	0.023377	0.023376	0.023375	0.023371	0.023376	0.023362
0.5	0.023448	0.023447	0.023448	0.023428	0.023447	0.023417
1.0	0.02357	0.023569	0.023555	0.023563	0.02357	0.023557
2.0	0.023742	0.023755	0.023751	0.023723	0.023753	0.023723
4.0	0.024117	0.024149	0.024083	0.024027	0.02414	0.024114
5.0	0.024344	0.024363	0.024395	0.02427	0.024347	0.024339
10.0	0.025218	0	0.025225	0.025044	0.025271	0.025294
20.0	0.026689	0	0.026684	0.026334	0.026763	0.026815

Table B.34: Difference in acoustic (sones) loudness, calculated according to ISO 532-1 (Zwicker), between a scenario without a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a heavy vehicle with internal combustion engine during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.043667	0.043667	0.043671	0.043666	0.043667	0.043666
0.0313	0.043659	0.043659	0.043658	0.043659	0.043659	0.043657
0.0625	0.043679	0.043679	0.043674	0.043672	0.043679	0.043683
0.125	0.04369	0.043689	0.043688	0.043678	0.043689	0.043707
0.25	0.043712	0.043711	0.043714	0.043707	0.043711	0.043745
0.5	0.04384	0.04384	0.043859	0.043805	0.04384	0.0439
1.0	0.044082	0.044083	0.044098	0.044091	0.044082	0.044144
2.0	0.044523	0.044525	0.044468	0.044471	0.044526	0.044554
4.0	0.04529	0.045306	0.045305	0.045184	0.045322	0.04542
5.0	0.045777	0.045801	0.045815	0.045668	0.04582	0.045931
10.0	0.04748	0	0.04754	0.047125	0.047545	0.047732
20.0	0.049971	0	0.050062	0.049211	0.050146	0.050477

Table B.35: Difference in acoustic (sones) loudness, calculated according to ISO 532-1 (Zwicker), between a scenario without a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a light vehicle with electric motor during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.010891	0.010891	0.010889	0.010887	0.010891	0.010894
0.0313	0.010888	0.010887	0.010886	0.010883	0.010888	0.010891
0.0625	0.010901	0.010901	0.0109	0.0109	0.0109	0.010902
0.125	0.01091	0.01091	0.010908	0.010904	0.010909	0.010903
0.25	0.010932	0.010933	0.010921	0.010927	0.010933	0.010915
0.5	0.010974	0.010974	0.010963	0.010968	0.010975	0.010934
1.0	0.011054	0.011055	0.011031	0.011044	0.011054	0.011015
2.0	0.011214	0.011213	0.011164	0.011164	0.011215	0.011163
4.0	0.011547	0.011548	0.011552	0.011489	0.011547	0.011516
5.0	0.011708	0.011718	0.011645	0.011644	0.011705	0.011688
10.0	0.012427	0	0.012407	0.012355	0.012427	0.012477
20.0	0.013624	0	0.013638	0.013378	0.013662	0.013823

Table B.36: Difference in acoustic (sones) loudness, calculated according to ISO 532-1 (Zwicker), between a scenario without a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a light vehicle with internal combustion engine during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.013544	0.013544	0.013546	0.013543	0.013545	0.013545
0.0313	0.01354	0.01354	0.01354	0.013533	0.01354	0.013538
0.0625	0.013557	0.013557	0.013557	0.01355	0.013557	0.013557
0.125	0.013567	0.013567	0.013562	0.013567	0.013567	0.013564
0.25	0.013593	0.013594	0.013587	0.013579	0.013594	0.013591
0.5	0.013637	0.013638	0.013625	0.01362	0.013638	0.013625
1.0	0.013726	0.013729	0.013725	0.013703	0.013728	0.013737
2.0	0.013929	0.013935	0.013928	0.013902	0.013934	0.013966
4.0	0.014323	0.014328	0.014342	0.014286	0.014325	0.014352
5.0	0.014527	0.014549	0.014519	0.014462	0.014546	0.014577
10.0	0.015476	0	0.015454	0.015317	0.015518	0.015587
20.0	0.016874	0	0.016889	0.016556	0.016965	0.01716

Table B.37: Difference in acoustic sharpness (acum), according to DIN45692 and ISO 532-1:2017(E),between a scenario without a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a heavy vehicle with electric motor during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.011658	0.011658	0.011656	0.01166	0.011658	0.011655
0.0313	0.011657	0.011657	0.011654	0.011656	0.011657	0.011652
0.0625	0.011662	0.011661	0.011659	0.011661	0.011661	0.01166
0.125	0.011666	0.011666	0.011659	0.011662	0.011666	0.011657
0.25	0.011675	0.011674	0.011674	0.011678	0.011674	0.011666
0.5	0.011686	0.011685	0.011682	0.011689	0.011686	0.011666
1.0	0.011709	0.011709	0.011705	0.011708	0.01171	0.011705
2.0	0.011744	0.011752	0.011754	0.011743	0.01175	0.011738
4.0	0.01182	0.011834	0.011803	0.011762	0.011831	0.011814
5.0	0.011847	0.01186	0.011873	0.011815	0.011851	0.011844
10.0	0.011965	0	0.011975	0.011844	0.011998	0.012
20.0	0.012081	0	0.012084	0.011849	0.012124	0.012154

Table B.38: Difference in acoustic sharpness (acum), according to DIN45692 and ISO 532-1:2017(E),between a scenario without a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a heavy vehicle with internal combustion engine during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.015103	0.015103	0.015104	0.015103	0.015103	0.015104
0.0313	0.015101	0.015101	0.0151	0.015101	0.015101	0.0151
0.0625	0.015106	0.015106	0.015105	0.015102	0.015106	0.015108
0.125	0.01511	0.01511	0.01511	0.015105	0.01511	0.015117
0.25	0.015116	0.015115	0.01512	0.015115	0.015116	0.015129
0.5	0.015128	0.015129	0.015133	0.015112	0.015129	0.015153
1.0	0.015165	0.015165	0.015169	0.015154	0.015165	0.015188
2.0	0.015227	0.015227	0.015203	0.015196	0.015228	0.015253
4.0	0.015299	0.015306	0.015301	0.015235	0.015312	0.015366
5.0	0.015309	0.015315	0.015326	0.015233	0.015326	0.015396
10.0	0.015424	0	0.01544	0.015263	0.01544	0.015597
20.0	0.015621	0	0.015606	0.015248	0.015664	0.015928

Table B.39: Difference in acoustic sharpness (acum), according to DIN45692 and ISO 532-1:2017(E),between a scenario without a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a light vehicle with electric motor during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0053768	0.0053768	0.0053751	0.0053744	0.0053771	0.0053774
0.0313	0.0053751	0.0053748	0.0053731	0.0053718	0.0053751	0.0053758
0.0625	0.0053813	0.0053813	0.0053811	0.005379	0.005381	0.0053806
0.125	0.0053844	0.0053845	0.0053827	0.0053826	0.0053842	0.0053793
0.25	0.0053933	0.0053928	0.00539	0.0053917	0.0053928	0.0053787
0.5	0.0054011	0.0054004	0.0053952	0.0053991	0.0054005	0.0053777
1.0	0.0054174	0.0054182	0.0054081	0.0054158	0.005418	0.0054031
2.0	0.0054736	0.0054744	0.0054535	0.0054601	0.0054756	0.0054598
4.0	0.0055694	0.0055677	0.0055764	0.0055428	0.005572	0.005569
5.0	0.0056176	0.0056222	0.0055915	0.0055865	0.0056166	0.0056159
10.0	0.0058447	0	0.0058594	0.0058148	0.0058523	0.0058841
20.0	0.0062149	0	0.0062279	0.0060737	0.006252	0.0063341

Table B.40: Difference in acoustic sharpness (acum), according to DIN45692 and ISO 532-1:2017(E),between a scenario without a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a light vehicle with internal combustion engine during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0062021	0.0062021	0.0062023	0.0062018	0.0062022	0.0062014
0.0313	0.0062005	0.0062005	0.0062002	0.006199	0.0062005	0.0062
0.0625	0.0062089	0.0062089	0.0062092	0.0062065	0.0062089	0.0062086
0.125	0.0062135	0.0062134	0.0062099	0.0062145	0.0062135	0.0062123
0.25	0.0062238	0.0062241	0.00622	0.0062155	0.0062241	0.0062273
0.5	0.0062412	0.0062417	0.0062321	0.0062289	0.0062416	0.0062312
1.0	0.0062745	0.0062759	0.0062786	0.0062488	0.0062758	0.0062801
2.0	0.0063573	0.0063587	0.0063574	0.0063294	0.0063575	0.006385
4.0	0.0064959	0.0064926	0.0065099	0.0064678	0.0064917	0.0065045
5.0	0.006572	0.0065772	0.006564	0.0065371	0.0065764	0.0065879
10.0	0.0068881	0	0.0068796	0.0067676	0.0069139	0.0069659
20.0	0.0072934	0	0.0073069	0.0070745	0.0073392	0.0074542

Table B.41: Difference in acoustic roughness (asper), according to Zwicker's method and ISO 532-1:2017(E) ,between a scenario without a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a heavy vehicle with electric motor during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0074626	0.0074626	0.0074623	0.0074602	0.0074626	0.0074626
0.0313	0.0042834	0.0042834	0.0042803	0.0042821	0.0042834	0.0042847
0.0625	0.0042828	0.0042827	0.0042804	0.0042809	0.0042827	0.0042857
0.125	0.0042909	0.0042909	0.0042863	0.0042895	0.0042909	0.0042956
0.25	0.0074367	0.0074369	0.0042778	0.0074403	0.0074369	0.0042951
0.5	0.0042827	0.0042841	0.0042801	0.0042804	0.0042839	0.004359
1.0	0.0042503	0.0042514	0.0042394	0.0042526	0.0042516	0.0042536
2.0	0.0042643	0.0042657	0.0042774	0.004263	0.0042652	0.0043096
4.0	0.0043787	0.0043781	0.0044053	0.0043895	0.0043776	0.0043761
5.0	0.0044756	0.0044711	0.0044982	0.0044969	0.0044734	0.0045036
10.0	0.010552	0	0.010548	0.010513	0.010578	0.010597
20.0	0.018747	0	0.018589	0.018877	0.018728	0.010492

Table B.42: Difference in acoustic roughness (asper), according to Zwicker's method and ISO 532-1:2017(E) ,between a scenario without a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a heavy vehicle with internal combustion engine during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.032329	0.032329	0.032332	0.032331	0.032329	0.03233
0.0313	0.032322	0.032322	0.032325	0.032323	0.032322	0.032322
0.0625	0.032308	0.032309	0.032311	0.032309	0.032308	0.032309
0.125	0.032281	0.032281	0.032285	0.032283	0.032281	0.032286
0.25	0.032255	0.032255	0.032254	0.032257	0.032255	0.032255
0.5	0.032674	0.032674	0.032673	0.032669	0.032674	0.032682
1.0	0.032891	0.032891	0.032897	0.032894	0.032891	0.032914
2.0	0.032954	0.032955	0.032974	0.03296	0.032954	0.033004
4.0	0.033173	0.033174	0.033245	0.033232	0.033176	0.033248
5.0	0.033707	0.033703	0.033759	0.033741	0.033704	0.033771
10.0	0.035163	0	0.035176	0.035145	0.035157	0.035238
20.0	0.037874	0	0.037849	0.037794	0.037932	0.038083

Table B.43: Difference in acoustic roughness (asper), according to Zwicker's method and ISO 532-1:2017(E) ,between a scenario without a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a light vehicle with an electric motor during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.00047807	0.00047807	0.00047736	0.00047684	0.00047815	0.00047805
0.0313	0.0004726	0.00047254	0.00047172	0.00047111	0.0004726	0.00046901
0.0625	0.00047815	0.00047815	0.00047854	0.000476	0.00047809	0.00047082
0.125	0.00048477	0.00048485	0.00048672	0.00048636	0.0004847	0.00048792
0.25	0.00049452	0.00049494	0.00050072	0.00050148	0.00049494	0.00048621
0.5	0.00051724	0.00051662	0.00051095	0.00051279	0.00051688	0.0005077
1.0	0.00052579	0.00053445	0.00053873	0.00053983	0.00053476	0.00052465
2.0	0.00054243	0.00054415	0.00054493	0.00054776	0.00054461	0.00053853
4.0	0.00055407	0.00055885	0.00058441	0.0005858	0.00056935	0.00062154
5.0	0.00068227	0.00069671	0.00069698	0.00069105	0.00069821	0.00074147
10.0	0.0015592	0	0.0015192	0.0015371	0.0015715	0.0015271
20.0	0.024324	0	0.024452	0.014162	0.024353	0.024427

Table B.44: Difference in acoustic roughness (asper), according to Zwicker's method and ISO 532-1:2017(E) ,between a scenario without a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a light vehicle with internal combustion engine during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0017538	0.0017538	0.0017542	0.0017539	0.0017538	0.0017521
0.0313	0.0017615	0.0017615	0.0017609	0.0017627	0.0017615	0.0017581
0.0625	0.00176	0.0017601	0.0017603	0.0017639	0.00176	0.001761
0.125	0.0017598	0.0017599	0.0017658	0.0017672	0.0017598	0.0017583
0.25	0.0017407	0.001741	0.0017479	0.0017471	0.001741	0.0017411
0.5	0.0017834	0.0017836	0.0017728	0.0017677	0.0017836	0.0017877
1.0	0.00038342	0.00038294	0.00038953	0.0004128	0.00038231	0.0003823
2.0	0.0004086	0.00040513	0.00041822	0.00041022	0.00040549	0.00040235
4.0	0.0082304	0.0082359	0.0082456	0.0082366	0.0082344	0.022783
5.0	0.00059757	0.00058924	0.00055042	0.00060573	0.00059846	0.00058793
10.0	0.031589	0	0.031657	0.031545	0.031573	0.031612
20.0	0.028985	0	0.02491	0.0288	0.029008	0.023973

Table B.45: Difference in fluctuation (vacil), according to Zwicker and ISO 532-1 (E) ,between a scenario without a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a heavy vehicle with electric motor during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.000042787	0.000042796	0.000043235	0.000043061	0.000042787	0.000042668
0.0313	0.000042642	0.000042642	0.000042953	0.000043319	0.000042642	0.000042571
0.0625	0.000043293	0.000043268	0.000043336	0.000043565	0.000043268	0.000042844
0.125	0.000043517	0.000043517	0.000043558	0.000043964	0.000043517	0.000043032
0.25	0.000043665	0.00004362	0.000043387	0.000044324	0.00004362	0.00004317
0.5	0.00004372	0.000043774	0.000044318	0.000047467	0.00004378	0.00004365
1.0	0.000045798	0.000045564	0.000043937	0.000047452	0.000045546	0.000046509
2.0	0.000044754	0.000045173	0.000047387	0.000048663	0.000045092	0.000046637
4.0	0.000043196	0.00004453	0.00004342	0.000047802	0.000044484	0.000053504
5.0	0.000034406	0.000035601	0.000038346	0.000035683	0.00003553	0.000038089
10.0	0.00039618	0	0.00039619	0.00043169	0.00038255	0.00040296
20.0	2.6159e-8	0	0.000011345	0.000013821	6.7439e-6	0.0001788

Table B.46: Difference in fluctuation (vacil), according to Zwicker and ISO 532-1 (E) ,between a scenario without a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a heavy vehicle with internal combustion engine during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.000084685	0.000084663	0.000085179	0.000084966	0.000084671	0.000084557
0.0313	0.000084753	0.000084759	0.000084942	0.000085297	0.000084776	0.000084703
0.0625	0.000085441	0.000085434	0.000086024	0.000086277	0.000085441	0.000085182
0.125	0.000085906	0.000085901	0.000086105	0.000086343	0.000085901	0.000086268
0.25	0.000086537	0.000086483	0.000086575	0.000086017	0.000086525	0.000087726
0.5	0.000086696	0.000086772	0.000086701	0.000085916	0.000086761	0.000087909
1.0	0.000086165	0.000085918	0.000085852	0.000085475	0.000085843	0.000090167
2.0	0.000088625	0.000088504	0.000089189	0.000088481	0.000088473	0.000091018
4.0	0.000078481	0.000078568	0.00007735	0.000079513	0.000078562	0.000080072
5.0	0.000070335	0.00007114	0.000064687	0.000073697	0.000070174	0.000073197
10.0	0.00060144	0	0.00062257	0.00058073	0.00060868	0.00051382
20.0	0.00071713	0	0.00079806	0.0007342	0.00074809	0.00075605

Table B.47: Difference in fluctuation (vacil), according to Zwicker and ISO 532-1 (E) ,between a scenario without a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a light vehicle with electric motor during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.00012458	0.00012458	0.00012455	0.00012469	0.00012456	0.00012478
0.0313	0.00012477	0.00012473	0.00012443	0.00012553	0.00012477	0.00012403
0.0625	0.0001246	0.0001246	0.00012527	0.00012583	0.00012456	0.000125
0.125	0.00012455	0.00012455	0.00012411	0.00012511	0.00012451	0.00012548
0.25	0.00012501	0.0001249	0.0001259	0.00012541	0.0001249	0.00012578
0.5	0.00012411	0.00012395	0.00012304	0.00012457	0.00012401	0.00012499
1.0	0.00012127	0.00012134	0.00012312	0.00012333	0.00012132	0.00012449
2.0	0.00011513	0.00011494	0.00011544	0.00011199	0.00011492	0.00011005
4.0	0.000097973	0.000098816	0.000098599	0.00011123	0.000099366	0.000093073
5.0	0.000079846	0.000081536	0.000079939	0.000087193	0.000081574	0.000076533
10.0	0.00013253	0	0.00011057	0.00012084	0.00013437	0.00017456
20.0	0.000032621	0	0.000035703	0.000042053	0.000033141	0.000045227

Table B.48: Difference in fluctuation (vacil), according to Zwicker and ISO 532-1 (E) ,between a scenario without a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a light vehicle with internal combustion engine during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.00013741	0.00013741	0.0001372	0.00013779	0.00013731	0.0001377
0.0313	0.00013795	0.00013795	0.00013839	0.00013793	0.00013795	0.00013759
0.0625	0.00013722	0.00013713	0.00013675	0.0001373	0.00013722	0.00013601
0.125	0.00013753	0.00013753	0.00013834	0.00013791	0.00013743	0.00013694
0.25	0.00013838	0.00013838	0.00013887	0.00013836	0.00013838	0.000137
0.5	0.00013834	0.00013836	0.00013894	0.00013938	0.00013836	0.00013976
1.0	0.00013813	0.00013834	0.00013715	0.00014023	0.00013827	0.00013449
2.0	0.00013661	0.00013704	0.00013548	0.00013887	0.00013697	0.00013956
4.0	0.00013076	0.00013079	0.00013391	0.00013019	0.00013112	0.00014105
5.0	0.00011954	0.00011824	0.00011446	0.0001201	0.00011718	0.00012412
10.0	0.051073	0	0.051368	0.050857	0.05118	0.050925
20.0	0.000021809	0	0.000022388	0.000033529	0.000022697	0.00002662

B.0.1 Loudness

Table B.49: Difference in acoustic (sones) loudness, calculated according to ISO 532-1 (Zwicker), between a scenario with a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a heavy vehicle with electric motor during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.016358	0.016351	0.016384	0.016392	0.016351	0.016444
0.0313	0.016355	0.016353	0.016455	0.016417	0.016353	0.016462
0.0625	0.016393	0.016368	0.016337	0.016394	0.016377	0.016418
0.125	0.016356	0.016428	0.016502	0.016385	0.016437	0.016347
0.25	0.016403	0.016351	0.016496	0.016456	0.016382	0.01643
0.5	0.016476	0.016412	0.016473	0.016343	0.016367	0.016368
1.0	0.016614	0.01647	0.016482	0.016778	0.016558	0.016708
2.0	0.016631	0.016628	0.016533	0.017008	0.016662	0.016517
4.0	0.017056	0.01692	0.016767	0.01814	0.016972	0.01645
5.0	0.017393	0.017169	0.016915	0.018837	0.017221	0.016596
10.0	0.017944	0	0.017088	0.020693	0.017682	0.017284
20.0	0.018166	0	0.016996	0.019796	0.019174	0.020841

Table B.50: Difference in acoustic (sones) loudness, calculated according to ISO 532-1 (Zwicker), between a scenario with a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a heavy vehicle with internal combustion engine during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.036602	0.036581	0.036605	0.036634	0.036585	0.036629
0.0313	0.036609	0.036597	0.036636	0.036561	0.036604	0.036618
0.0625	0.036601	0.036621	0.036649	0.036594	0.036639	0.0366
0.125	0.036558	0.036552	0.036559	0.036549	0.036559	0.036618
0.25	0.036655	0.036693	0.03663	0.036618	0.036711	0.036652
0.5	0.036568	0.036599	0.036658	0.036555	0.036559	0.036656
1.0	0.037071	0.037058	0.036949	0.037035	0.037032	0.037442
2.0	0.037018	0.036936	0.036829	0.037293	0.036992	0.037144
4.0	0.037567	0.03751	0.037138	0.038393	0.037503	0.037475
5.0	0.037872	0.037721	0.037299	0.039018	0.037709	0.037639
10.0	0.039304	0	0.038261	0.040705	0.039079	0.04097
20.0	0.039568	0	0.038707	0.03749	0.042055	0.048036

Table B.51: Difference in acoustic (sones) loudness, calculated according to ISO 532-1 (Zwicker), between a scenario with a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a light vehicle with electric motor during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0073691	0.0073689	0.0073814	0.0073864	0.0073704	0.0074063
0.0313	0.0073536	0.0073629	0.0073903	0.0073618	0.0073724	0.0073593
0.0625	0.0073483	0.0073488	0.0073928	0.007469	0.007354	0.0074167
0.125	0.0073835	0.0073551	0.0074327	0.0074914	0.007366	0.0073893
0.25	0.0073766	0.0073328	0.0075165	0.0075614	0.0073813	0.0073889
0.5	0.0075737	0.0075932	0.0075451	0.0074623	0.0075617	0.0074637
1.0	0.0077035	0.0076409	0.0075076	0.0075489	0.0075885	0.0076446
2.0	0.0074519	0.0073991	0.0074392	0.0076324	0.0074844	0.0074139
4.0	0.0079238	0.0078534	0.0078278	0.0084273	0.007787	0.0078374
5.0	0.0080425	0.0080196	0.0078425	0.0086635	0.0080238	0.0081436
10.0	0.0084402	0	0.007958	0.0094429	0.0084036	0.0093825
20.0	0.0092324	0	0.0084034	0.0091276	0.0096941	0.011288

Table B.52: Difference in acoustic (sones) loudness, calculated according to ISO 532-1 (Zwicker), between a scenario with a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a light vehicle with internal combustion engine during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0092512	0.0092448	0.0092653	0.0092895	0.0092466	0.0092426
0.0313	0.0092583	0.0092417	0.0092738	0.0092801	0.0092544	0.0093374
0.0625	0.0092597	0.0092559	0.0092364	0.0093166	0.0092754	0.0093272
0.125	0.0092186	0.0093157	0.0093418	0.0094137	0.0092956	0.009287
0.25	0.0092608	0.0093306	0.009194	0.0093396	0.0094131	0.0092166
0.5	0.009359	0.0094063	0.0093816	0.0093343	0.0093484	0.0093237
1.0	0.0093791	0.0094815	0.0093536	0.0094219	0.0094357	0.0093665
2.0	0.0092337	0.009171	0.0090628	0.0093364	0.0092769	0.0092851
4.0	0.0097609	0.0097055	0.0096287	0.010008	0.0097298	0.009815
5.0	0.010047	0.009797	0.0095266	0.0094605	0.0098285	0.0099615
10.0	0.01047	0	0.0096159	0.010614	0.010224	0.010028
20.0	0.011342	0	0.010471	0.011033	0.012159	0.015198

Table B.53: Difference in acoustic sharpness (acum), according to DIN45692 and ISO 532-1:2017(E),between a scenario with a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a heavy vehicle with electric motor during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0143	0.0143	0.014295	0.014273	0.014296	0.014352
0.0313	0.014293	0.014295	0.014389	0.014285	0.014288	0.014393
0.0625	0.014323	0.014275	0.014262	0.014259	0.014279	0.014389
0.125	0.014236	0.014304	0.014371	0.014283	0.014272	0.014313
0.25	0.014288	0.014276	0.014363	0.014303	0.014287	0.014389
0.5	0.014289	0.014206	0.014277	0.014062	0.014178	0.014372
1.0	0.014444	0.014347	0.014393	0.014288	0.01441	0.014823
2.0	0.014325	0.014325	0.014366	0.013933	0.014341	0.014596
4.0	0.014252	0.014198	0.014241	0.013627	0.014218	0.014295
5.0	0.013994	0.013867	0.014003	0.013251	0.014024	0.013812
10.0	0.0142	0	0.014502	0.013021	0.014295	0.013859
20.0	0.012487	0	0.013639	0.01133	0.013548	0.015568

Table B.54: Difference in acoustic sharpness (acum), according to DIN45692 and ISO 532-1:2017(E),between a scenario with a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a heavy vehicle with internal combustion engine during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.017797	0.01779	0.017788	0.017834	0.017791	0.017812
0.0313	0.017804	0.017799	0.017805	0.017802	0.0178	0.017807
0.0625	0.017795	0.017815	0.017815	0.017813	0.017811	0.017775
0.125	0.017789	0.017775	0.017786	0.017734	0.017781	0.017849
0.25	0.01782	0.017857	0.017872	0.017848	0.017862	0.017892
0.5	0.017678	0.017686	0.017728	0.017736	0.017676	0.01776
1.0	0.018077	0.01811	0.018069	0.017908	0.01807	0.018444
2.0	0.017937	0.017912	0.017946	0.017665	0.017917	0.018114
4.0	0.017741	0.017848	0.017846	0.017192	0.017813	0.017923
5.0	0.017457	0.017535	0.017559	0.017007	0.017529	0.017554
10.0	0.01768	0	0.018004	0.016246	0.017906	0.018146
20.0	0.016439	0	0.017489	0.014264	0.017321	0.018181

Table B.55: Difference in acoustic sharpness (acum), according to DIN45692 and ISO 532-1:2017(E),between a scenario with a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a light vehicle with electric motor during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0075766	0.007578	0.0075764	0.0076151	0.0075793	0.0075545
0.0313	0.0075706	0.0075755	0.0075583	0.0075567	0.0075821	0.0075362
0.0625	0.0075744	0.0075586	0.0075524	0.0076124	0.0075611	0.0076081
0.125	0.0075788	0.0075732	0.0075816	0.0075487	0.0075776	0.0076511
0.25	0.0075605	0.0075478	0.0076162	0.0076002	0.007552	0.007547
0.5	0.00761	0.0076117	0.0075929	0.0074298	0.0076189	0.0077104
1.0	0.0076889	0.0076123	0.0076108	0.007313	0.0076202	0.0078956
2.0	0.0073131	0.0073501	0.0073737	0.006875	0.0074158	0.0077994
4.0	0.0075199	0.0074399	0.0075139	0.0065316	0.0074003	0.0082753
5.0	0.0075659	0.0075688	0.007689	0.0064845	0.0076293	0.0087937
10.0	0.0073761	0	0.0076914	0.0052153	0.0075567	0.0099411
20.0	0.0073008	0	0.0082546	0.0038344	0.0079686	0.011416

Table B.56: Difference in acoustic sharpness (acum), according to DIN45692 and ISO 532-1:2017(E),between a scenario with a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a light vehicle with internal combustion engine during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0080867	0.0080855	0.0081208	0.0081231	0.008087	0.008086
0.0313	0.0080912	0.0080829	0.0081118	0.0080969	0.0080906	0.0081471
0.0625	0.0080717	0.008091	0.0080845	0.0080641	0.0080979	0.0081634
0.125	0.0080488	0.0081261	0.0081577	0.0081177	0.0081201	0.0081401
0.25	0.0080668	0.0081472	0.0079997	0.0080158	0.0082002	0.0080439
0.5	0.0081333	0.008182	0.0080955	0.0079776	0.0081367	0.0082452
1.0	0.0081725	0.0082393	0.0081703	0.0079136	0.0082144	0.0083556
2.0	0.0078119	0.0078511	0.0078462	0.007346	0.0079197	0.0083966
4.0	0.0079788	0.008013	0.0080841	0.0067615	0.0080098	0.0089093
5.0	0.0082281	0.0081044	0.0081449	0.0058058	0.0081363	0.0091741
10.0	0.0079326	0	0.0083235	0.0045746	0.0081253	0.010695
20.0	0.0077092	0	0.0088293	0.0042172	0.0085356	0.0111

Table B.57: Difference in acoustic roughness (asper), according to Zwicker's method and ISO 532-1:2017(E) ,between a scenario with a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a heavy vehicle with electric motor during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.025358	0.025358	0.025387	0.025385	0.025358	0.0046719
0.0313	0.0047188	0.025341	0.011728	0.0046279	0.025348	0.0046608
0.0625	0.025343	0.025342	0.025395	0.025468	0.025348	0.025385
0.125	0.025362	0.025339	0.025534	0.02557	0.025342	0.025538
0.25	0.025347	0.025335	0.0047468	0.01185	0.025339	0.0047005
0.5	0.0046739	0.011821	0.0095568	0.0094999	0.01179	0.025691
1.0	0.0095516	0.0095338	0.0048341	0.0095676	0.0095251	0.009436
2.0	0.0096567	0.0095748	0.016526	0.0099436	0.0096174	0.005917
4.0	0.0071476	0.0098155	0.024719	0.0049004	0.0098199	0.0070917
5.0	0.0074996	0.0074454	0.025193	0.0024101	0.0074648	0.0088181
10.0	0.0069876	0	0.02457	0.02619	0.0069432	0.02854
20.0	0.016797	0	0.028204	0.011039	0.014531	0.015995

Table B.58: Difference in acoustic roughness (asper), according to Zwicker's method and ISO 532-1:2017(E) ,between a scenario with a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a heavy vehicle with internal combustion engine during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0038001	0.0038007	0.0038132	0.00383	0.0038007	0.0038396
0.0313	0.0038181	0.0038164	0.0038541	0.0038637	0.0038148	0.0038542
0.0625	0.0037987	0.0037963	0.00381	0.0038007	0.0037955	0.0038035
0.125	0.003811	0.0038121	0.0038263	0.0038081	0.0038093	0.00381
0.25	0.0038016	0.0037994	0.0037663	0.0038533	0.0038072	0.0038579
0.5	0.003813	0.0038217	0.0037995	0.003863	0.0038044	0.0037786
1.0	0.0038479	0.0038398	0.0037508	0.0038823	0.003831	0.02243
2.0	0.0038838	0.022816	0.000044463	0.023036	0.022834	0.023099
4.0	0.023572	0.023627	0.0082979	0.00042354	0.023557	0.0096714
5.0	0.023408	0.023345	0.023699	0.013896	0.023443	0.0041112
10.0	0.0047106	0	0.010346	0.0045948	0.0047173	0.024199
20.0	0.022031	0	0.011012	0.0073414	0.030806	0.020382

Table B.59: Difference in acoustic roughness (asper), according to Zwicker's method and ISO 532-1:2017(E) ,between a scenario with a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a light vehicle with electric motor engine during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0045681	0.0045713	0.0045514	0.0045872	0.0045691	0.0045276
0.0313	0.0045867	0.0045875	0.0046081	0.0045678	0.0045863	0.0046033
0.0625	0.0045789	0.0045786	0.0046015	0.0046336	0.0045766	0.0045951
0.125	0.0045751	0.0045594	0.0046089	0.0045862	0.0045598	0.0045013
0.25	0.004611	0.0045869	0.0046545	0.00464	0.0046009	0.0045315
0.5	0.0046673	0.004671	0.0047878	0.014902	0.0047035	0.0083023
1.0	0.014979	0.015042	0.00081695	0.00091832	0.015062	0.00091661
2.0	0.015245	0.015253	0.0084795	0.0010402	0.015222	0.008418
4.0	0.005354	0.005324	0.0085008	0.0074088	0.0052618	0.0010729
5.0	0.0087499	0.0010701	0.0010564	0.016579	0.0011569	0.0011157
10.0	0.02793	0	0.0080525	0.0063013	0.0056517	0.0087755
20.0	0.022198	0	0.01133	0.033588	0.032514	0.026618

Table B.60: Difference in acoustic roughness (asper), according to Zwicker's method and ISO 532-1:2017(E) ,between a scenario with a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a light vehicle with internal combustion engine during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.0040294	0.0040324	0.0040566	0.0040607	0.0040308	0.0040537
0.0313	0.004053	0.0040524	0.0040676	0.0041705	0.0040529	0.0040728
0.0625	0.0040443	0.004033	0.0040758	0.0041431	0.0040396	0.0040732
0.125	0.0040552	0.00405	0.0039876	0.0039538	0.0040274	0.015425
0.25	0.015342	0.015373	0.015353	0.0039916	0.015351	0.0041195
0.5	0.015692	0.0041848	0.0041532	0.015896	0.0041644	0.0084949
1.0	0.015593	0.015549	0.015628	0.015722	0.015593	0.009561
2.0	0.015963	0.01598	0.0086372	0.0087739	0.015814	0.0085626
4.0	0.0074978	0.016134	0.0088804	0.0076415	0.016185	0.00060472
5.0	0.0090367	0.009175	0.017033	0.017015	0.0091535	0.0092134
10.0	0.0048119	0	0.017828	0.0048686	0.0044664	0.0092706
20.0	0.0052713	0	0.00083216	0.0096714	0.030457	0.018603

Table B.61: Difference in fluctuation (vacil), according to Zwicker and ISO 532-1 (E) ,between a scenario with a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a heavy vehicle with electric motor during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.00016481	0.0001644	0.00016837	0.00013641	0.00016383	0.00014832
0.0313	0.00016174	0.00016273	0.00013714	0.0001457	0.00016295	0.00014213
0.0625	0.00016699	0.00016194	0.00015584	0.00015183	0.00016438	0.0001301
0.125	0.00015427	0.00016455	0.00015569	0.00012584	0.00016309	0.00018268
0.25	0.0001461	0.00016654	0.000074352	0.00015151	0.00016613	0.000094831
0.5	0.00013565	0.00018828	0.00016456	0.0000216	0.00018338	0.00011968
1.0	0.00015805	0.00016258	0.00017895	0.00016814	0.00018466	0.00021204
2.0	0.00029094	0.00020193	0.00021068	0.00026984	0.00021504	0.00012478
4.0	0.000060015	0.00015368	0.00019503	0.00017477	0.00014222	0.00011116
5.0	0.00006264	0.00006755	0.00020503	0.00020853	0.00012643	0.00029141
10.0	0.00016334	0	0.0006114	0.00063054	0.00013062	0.0013502
20.0	0.000081293	0	0.00015119	0.00029084	0.000099039	0.00028596

Table B.62: Difference in fluctuation (vacil), according to Zwicker and ISO 532-1 (E) ,between a scenario with a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a heavy vehicle with internal combustion engine during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.00024584	0.00024639	0.0002446	0.0002632	0.000246	0.00019403
0.0313	0.00024525	0.00024572	0.00021044	0.00026112	0.00024603	0.00019151
0.0625	0.00024544	0.00024957	0.00023979	0.00023075	0.00024915	0.00018031
0.125	0.0002496	0.00024934	0.00027202	0.00025379	0.0002505	0.00020869
0.25	0.00026501	0.00025591	0.00021339	0.0001594	0.00025172	0.00017583
0.5	0.00028595	0.00026352	0.00029868	0.00028084	0.00026462	0.00015495
1.0	0.00029426	0.00029873	0.00022629	0.000084104	0.00028641	0.00023986
2.0	0.00014955	0.00033465	0.000047513	0.0003586	0.00034428	0.0001615
4.0	0.0002166	0.00027899	0.00018772	0.00022118	0.00027263	0.000033849
5.0	0.00025058	0.00023469	0.00022721	0.0002427	0.00021052	0.000025321
10.0	0.00028155	0	0.00061959	0.0010151	0.00012489	0.0014621
20.0	0.0001384	0	0.000062128	0.000017089	0.00024697	0.00042797

Table B.63: Difference in fluctuation (vacil), according to Zwicker and ISO 532-1 (E) ,between a scenario with a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a light vehicle with electric motor during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.00018229	0.00018274	0.00020195	0.00026341	0.00018309	0.00019975
0.0313	0.0001878	0.00018369	0.00023449	0.00029049	0.00018457	0.00021897
0.0625	0.00018793	0.00018958	0.00027316	0.00026026	0.00019408	0.00019336
0.125	0.00018266	0.00018622	0.00024574	0.0002241	0.00018801	0.00014284
0.25	0.000203	0.00019448	0.00016957	0.00026364	0.00020031	0.000094482
0.5	0.00028219	0.00020617	0.00024799	0.00021069	0.00021185	0.00017004
1.0	0.00026484	0.00023111	0.00021763	0.00012712	0.00021846	0.00014019
2.0	0.00028241	0.000096685	0.000076305	0.00017504	0.00012061	0.000074982
4.0	0.00018552	0.00027291	0.00015888	0.000078437	0.00019699	0.000075042
5.0	0.000080718	0.00018919	0.00026765	0.000017187	0.0001601	0.000022355
10.0	0.00008772	0	0.00046021	0.00050475	0.000025214	0.00094319
20.0	0.000076181	0	0.000020228	0.00015076	0.00093063	0.000028526

Table B.64: Difference in fluctuation (vacil), according to Zwicker and ISO 532-1 (E) ,between a scenario with a screen where Doppler effect was not considered and a scenario were Doppler effect was considered for a light vehicle with internal combustion engine during a pass-by recorded at 40 km/h.

Δx	Linear	Makima	Nearest	Next	Pchip	Previous
0.0156	0.00013777	0.00013748	0.00010067	0.00012775	0.00013742	0.0001252
0.0313	0.00013431	0.00013779	0.000082489	0.000095127	0.00013714	0.00010597
0.0625	0.00013373	0.00013869	0.00013097	0.000076555	0.00013858	0.00018296
0.125	0.00012709	0.00014069	0.000091966	0.00011599	0.0001434	0.00011961
0.25	0.00011918	0.00015939	0.00019211	0.000084516	0.000154	0.00013016
0.5	0.00013778	0.0001574	0.00015253	0.00010481	0.00016077	0.00015978
1.0	0.00017482	0.00014699	0.00013984	0.000052143	0.0001584	0.0001642
2.0	0.00014024	0.00017043	0.00011559	0.00020283	0.00019813	0.00015
4.0	0.0001117	0.0002132	0.00025672	0.00012047	0.00015831	0.000042877
5.0	0.00010804	0.00013203	0.00013243	4.7595e-6	0.000096911	0.000078848
10.0	0.00010507	0	0.00054733	0.00046354	0.000072878	0.00092556
20.0	0.00011931	0	0.00011087	0.000036709	0.0001495	0.00020037

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