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The failure of traditional traffic noise control for quiet areas

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Abstract [629] One can consider the acoustic soundscape as consisting of two parts the direct acoustic soundscape and the diffuse acoustic soundscape. This fact has important consequences when attempting to change the acoustic soundscapes. The traditional approach to control traffic noise by means of noise barriers or change of traffic distribution is only valid for the areas directly exposed from sources (direct acoustic soundscape). These areas will experience a certain decrease of sound pressure levels when applying these noise control measures. However there will be a lower limit for reduction due to the presence of a diffuse acoustic soundscape. To control/modify such a diffuse acoustic soundscape has been shown very difficult by traditional means of noise control. Main characteristic of diffuse acoustic soundscapes is the presence of a multitude of sources, distributed over a wide area contributing evenly to the acoustic soundscape in a certain areas. Screening will only lead to a redistribution of sound, however consequences of such a redistribution will not be recognised in a diffuse sound field. Absorption has been identified as a main parameter to control diffuse acoustic soundscapes. Reducing sound pressure levels in shielded areas such as inner-yards can only be achieved by adding acoustically absorbing areas along the transfer path between source and receiver, but especially inside the inner-yard. Redistribution of traffic flow has been shown to have a tremendous effect on the directly exposed side, but only a small effect in shielded areas.

1 INTRODUCTION

This paper deals with the effectiveness of traditional noise control measures for road traffic noise in urban areas with a relatively dense building structure. Traditional noise control measures are typically shielding of traffic sources by screens, buildings, etc. and the change of traffic composition or amount of traffic work in certain areas. The work presented in the following summarisse results from a national Swedish project “Soundscape support to health”. In this project a series of field measurements were carried out to document the noise exposure (Leq,24h) for people living in areas that belong to the application examples in the project. Five different sites were considered. The activity of the description for each individual site was as follows:

- Long time measurements (at least one complete week) in representative points both in directly exposed and shielded areas during a representative time period (not during holidays or other period where traffic might have deviated from normal).
- Short time measurements (at least 30 minutes or 500 vehicles) in a number of complementary positions.

- Measurements of traffic data (number of vehicles, percentage heavy vehicles, and motorbikes). In cases where sufficiently exact data were available from authorities, these data were used.
- Calculation of traffic noise levels for each dwelling based on traffic input data and geometrical data of the field site.

All acoustic measurements were carried out by acoustic consultancies during a period close to the timeslot where the field studies (questionnaires, etc.) were carried out. The calculations of sound pressure levels were carried out by acoustic consultancies and the Department of Applied Acoustics, Chalmers. For all application examples digital information of the building structure were collected. Based on this material together with traffic data the sound exposure for all dwellings included in the field study were calculated. At the beginning it was planned that all calculations should be carried out by acoustic consultancies. However, the first results showed that the calculation methods available for such purposes fail in most of the cases involving shielded areas. Models as described in national or international standards for calculating road traffic noise underestimate substantially (up to 10 dB) levels in such areas. Therefore a very simple but efficient model (the flat city model) was developed which is described in detail in [1]. The model was used to calculate the sound pressure levels in such cases where the existing standard methods fail. Additionally a model for the more exact description of sound propagation between street canyons was developed by Ögren [2] in order to investigate the influence of absorption and diffusion on the sound levels inside inner yards. Both models are used in the following discussions.

2 THE PROPERTIES OF ACOUSTIC SOUNDSCAPES IN SHIELDED AREAS

When dealing with the characterisation of acoustic soundscapes the idea was suggested that two extreme cases of soundscapes could be identified and that "reality" is expected always to be a mixture of both cases.
In Case 1 the acoustic soundscape is determined by individual sources of traffic noise, i.e. each car passing by. The resulting traffic noise will vary substantially both on a short-time and long-time scale. This type of acoustic soundscapes will mainly be found in directly exposed areas situated in close vicinity to the main source of traffic noise or in shielded areas where one main road nearby is determining the sound field. It will hardly be influenced by meteorological parameters such as wind or temperature gradient. This type of acoustic soundscape might be named "*direct acoustic soundscape*". A typical example of the time variation of sound pressure levels measured in an area characterised by such an acoustic soundscape is shown in Figure 1, left. One observes the sudden changes in the time record when individual vehicles are passing by. The statistical distribution of noise levels in a long-time measurement is expected to be spread over a wider range (see Figure 2, left). At the same time it is typical for such situations that the distribution of sound pressure levels is unsymmetrical with a maximum at higher levels.

In Case 2 individual sources of traffic noise (i.e. individual vehicles passing by) cannot be identified. Traffic noise will vary mainly in a long-time scale. This type of acoustic soundscapes will be found at a substantial distance from a main source of traffic noise (e.g. a motorway with high traffic density) and in areas, which are influenced by a multitude of sources. The variations on a short-time scale are relatively small. On a long-time scale substantial variations can take place due to the meteorology, especially when considering long distance propagation. This type of acoustic soundscapes might be named "diffuse acoustic soundscape".
The distribution of noise levels in a long-time measurement is expected to be in a relatively narrow range with a maximum on the lower level side. A typical example of the time variation of sound

pressure levels measured in an area characterised by such an acoustic soundscape is also shown in Figure 1. The statistical distribution of noise levels is shown in Figure 2 on the right.

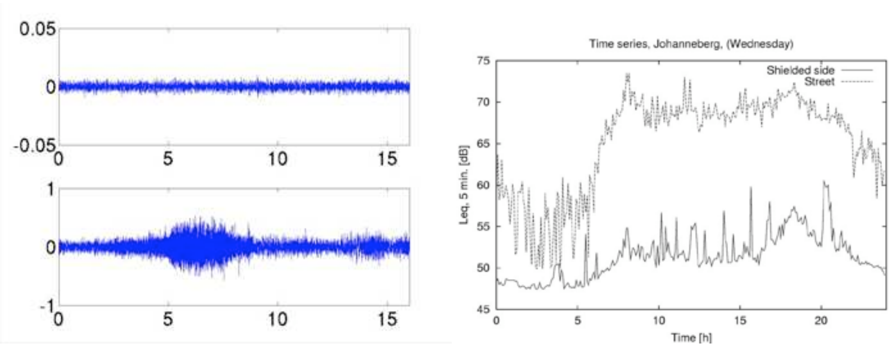

Figure 1. Time record of sound pressure levels measured in a directly exposed position (lower curve, left) and a shielded position (upper curve left). 5 minutes Leq (right) for a directly exposed (upper curve) and a shielded position (lower curve) for the application example in Johanneberg, Göteborg.

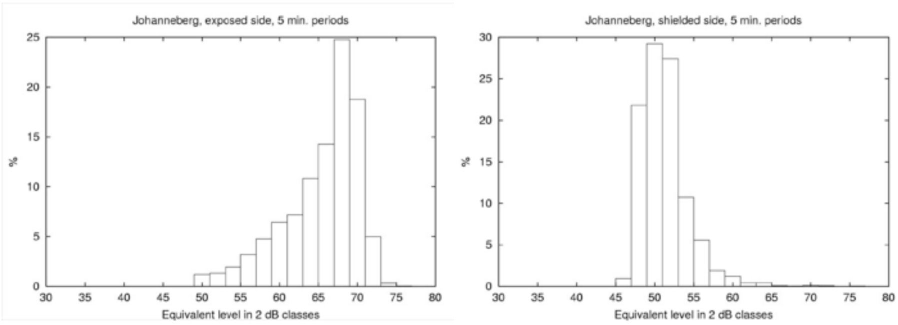

Figure 2. Statistical distribution of sound pressure levels (Leq for 5 min) in a directly exposed position (left) and a shielded area (right) for the application example in Johanneberg, Göteborg (2 dB classes).

Investigations of many of the application examples showed that the acoustic soundscapes in shielded areas are influenced by all roads in the wider neighbourhood. Söder in Stockholm is a typical example fitting well to the description above. Figure 3 shows the Leq,24h for the area, calculated with the flat city model.

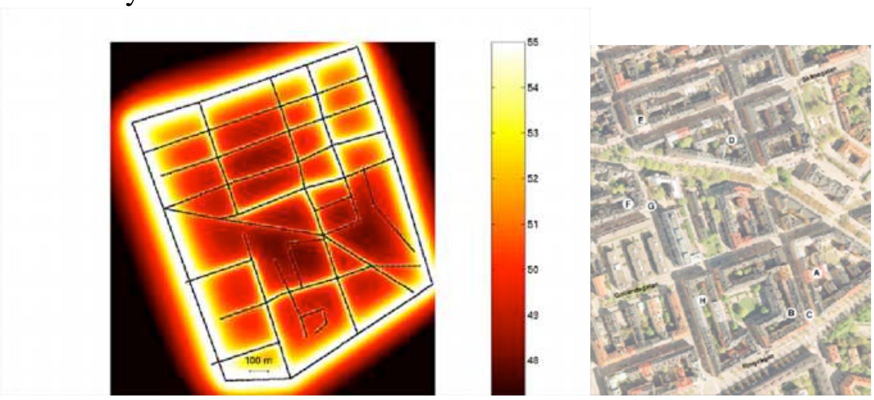

Figure 3. 24 h equivalent levels for the area Söder, Stockholm (left), picture of the field site (right).

There might also be strong contributions by major roads at longer distance. The soundscape in the shielded areas can be considered as a diffuse acoustic soundscape, while the directly exposed areas along the streets are rather influenced by individual vehicles passing by and can therefore be considered as a direct acoustic soundscape. Although one can find areas, which can be characterised as direct or diffuse acoustic soundscapes, one has to be aware that both types will always be present, either as a mixture or one masked by the contribution of the other. Which type of acoustic soundscape is dominating, however, will determine whether traditional noise control measures will be efficient in a certain situation or not. In the following section some case studies will be presented.

3 MEASURES TO REDUCE ROAD TRAFFIC NOISE

In general all today's activities concerning traffic noise control focus on modification of the direct acoustic soundscapes. Typical instruments are noise barriers in the form of screens or high buildings, façade design (e.g. balconies), speed limits and traffic regulations. A measure, very little applied, is the addition of absorption, which however might be a dominating design parameter, as shown below. The different measures for the modification of soundscapes (i.e. in the first hand a reduction of the road traffic noise levels) and their potential in the cases of direct and diffuse acoustic soundscapes is discussed in the following.

3.1 Noise screens

Noise barriers are one of the most applied measures to modify acoustic soundscapes. These barriers can be berms, high buildings, screens, etc. The main idea is to interrupt the propagation path between source and receiver. It is definitely applicable in the cases of direct acoustic soundscapes. Height and length and placement in relation to source and receiver will be the main design parameters. For a barrier in a flat geometry, mainly changes to the barrier top gives improved performance. Optimising the shape and acoustic properties of the top can lead to substantial noise reductions. A flat geometry here means in general that the barrier is low in comparison to its distance from both the source and the receiver. However, for situations where the sound is multiply reflected, as inbetween high, hard façades or double screens, the sound path to the receiver can be relatively flat, and it approaches a flat geometry.

For non-flat geometries, addition of absorbing materials to the faces of a screen can have strong positive effects. Especially for double screen situations where the absorption forces down the strength of the multiple reflections.

Thick barriers do in general result in better performance than thin ones. This can be seen as being due to the longer path around a thick barrier than around a thin one with the same height. Also earth berms or combinations of berms and screens have been tested and used, but so far there are no clear conclusions as to which shapes and materials do result in better performance than a thin screen. There can be very strong effects of refraction, i.e. the curved sound paths due to wind speed and temperature variations with height. The refraction is especially important for flat geometries, and can cause strong long-time fluctuations of the noise if one propagation direction is dominating. The effect of the barrier on the wind is also of importance. When the wind blows from the source toward the receiver, the increased wind speed above the barrier leads to stronger refraction and impaired performance.

The efficiency of a noise barrier will also depend strongly on how dominant the shielded source (e.g. road) is for the area of interest. The reduction will be limited to the "background sound" due to all remaining sources influencing the acoustic soundscape in the now shielded area. One might also point out the fact (trivial but often forgotten) that barriers do not reduce sound but redistribute it.

For areas characterised as diffuse acoustic soundscape additional noise barriers will have minor or no influence.

3.2 Balconies

Balconies as a part of the façade design can be applied to modify the direct acoustic soundscape. A theoretical model was developed to take into account absorbing areas inside cavity of balconies [3]. The model was tested against scale model measurements and shows a good agreement. It can be

concluded that treating the back and the ceiling of the balcony gives the highest insertion loss in front of the window at the back of the balcony: about 3 dB at frequencies above 100 Hz are obtained for an absorber consisting of 15 cm thick mineral wool.
Although these improvements are rather moderate the importance of the balcony increases when considering the sound field inside a room with and without a balcony. Figure 4 shows the reduction of the sound field inside a room achieved due to inserting a balcony with rigid walls and a balcony with absorbing walls. The main assumption was that the room and the balcony are separated by an open window. With absorbing back and ceiling, the insertion loss increases by up to 7 dB above 200 Hz inside the room.

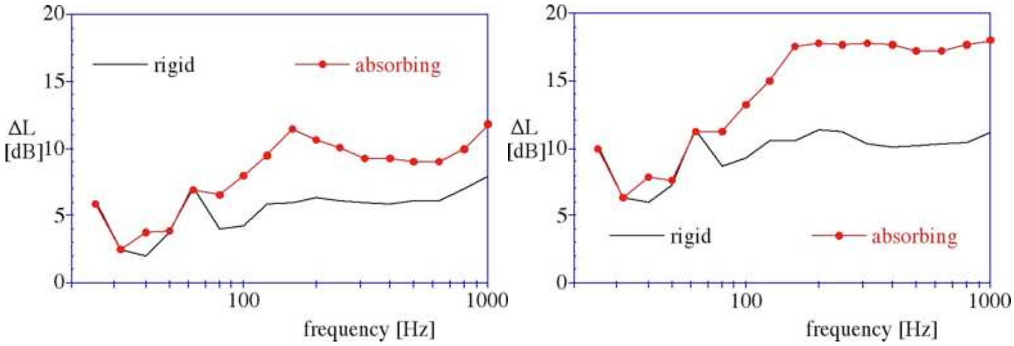

Figure 4. Insertion loss for an open window for traffic noise from road. (left: balcony at 4 m and right: balcony at 25 m above ground).

The total insertion loss reaches between 10 and 20 dB for the case of a room without balcony and compared with a room with balcony and absorber inside the balcony. However, one should be aware, that the efficiency of the treatment depends on the balcony position: the higher the balcony is above the ground, the bigger the attenuation. This difference is the result of a better shielding against the direct sound at high elevation. The use of balconies as studied in this work could therefore lead to a substantial reduction of the indoor levels assuming that absorbing surfaces are placed in the balcony cavity as shown in [3]. The insertion loss of balconies for the diffuse acoustic soundscape has not yet been investigated. It is expected that the efficiency will be somewhat lower due to the fact that there is no or very little shielding to be expected.

3.3 Absorption

Absorbing surfaces play a crucial role when intending to modify the direct but also the diffuse acoustic soundscapes. Two aspects are important:

- Close to the sources, on façades and roofs, absorption can be preferable to screening since it does not redistribute sound energy but changes it into heat. However such a concept has to be used over a wide area in order to have a sufficient effect.
- At the receiving side (i.e. shielded areas such as backyards) absorption can lead to a reduction of the overall sound levels. Measurements show that typical backyards have a substantial reverberation time of 1 to 2 seconds, which is surprisingly long and indicates that very little absorption is normally applied in such situations.

The influence of absorption can be studied by applying the street canyon model as described in [2]. The model can be used to calculate the sound pressure inside street canyons when applying different amounts of damping to the canyon. A typical situation is shown in Figure 5 (left) where a source simulates the sound coming from another street canyon or a major road. The insertion loss describing the effect of different absorption inside the canyon is shown in Figure 5 (right).

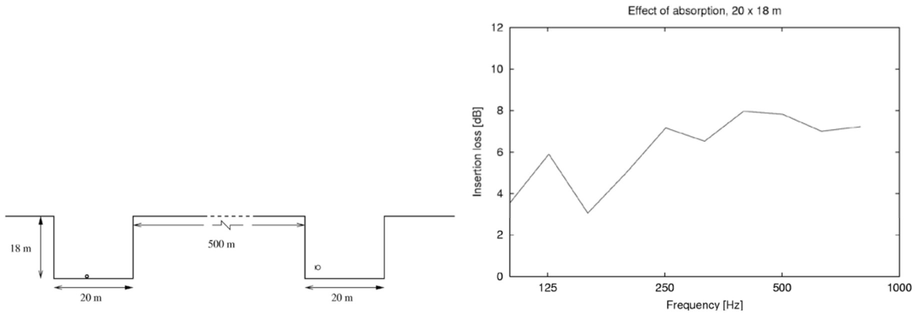

Figure 5. Influence of absorption on the sound pressure levels in the street canyon where the source is placed.

The result shows that even with moderate damping a substantial insertion loss can be achieved. The most realistic damping is applied in the form of 10 cm absorber over all façades. These preliminary results show that absorption contrary to shielding could be a much more effective tool to achieve a reduction of noise in shielded areas.

3.4 Traffic distribution

An obvious method to abate noise in urban environments is redistribution of traffic, i.e., to move the noise sources away from the receivers and/or to reduce their strengths through reducing the vehicle flow. To study the influence of these parameters the area Söder in Stockholm was chosen due to its regular street structure. Almost all streets are directed along two directions, one direction is close to north-south (N-S) and one direction is close to east-west (E-W). The traffic distribution in this area has then been modified and its impact on the noise levels has been studied using the flat city model described earlier in this report. Screening by houses has been taken into account by using the city canyon model also described earlier. The flat city model gives the 24 h equivalent level on the back of the houses, i.e., on the shielded side. It is also possible to calculate the levels on the exposed side with the flat city model, but in the present context it is more important to study the levels on the shielded side. The starting point here was the existing traffic distribution in Söder. The equivalent levels in the courtyards can be seen in Figure 6.

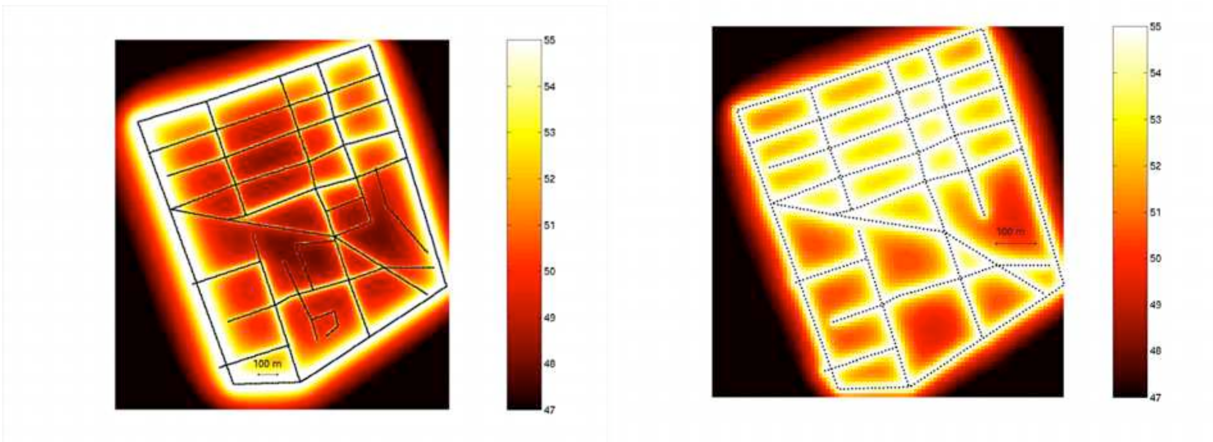

Figure 6. Equivalent levels in the area Söder with existing traffic (left). (Equal to Figure 3, but with different colour scale.) Equivalent levels in Söder with equal traffic on all streets (right).

The traffic flows in the area vary between 500 and 22,000 vehicles/24 h. The traffic has now been redistributed based on two extreme cases:

- A homogeneous traffic distribution, i. e., equal traffic flows.
- All traffic concentrated on two streets; one in each main direction of the street grid.

Two examples of even distributions have been studied: equal traffic on the streets in N-S direction and equal traffic on the streets in E-W direction, and equal traffic on all streets. A result from calculations for these examples can be seen in Figure (right). Only one figure is shown, since the difference is negligible. A few very small streets have been removed from the model, since they were not significant for the noise levels. In the calculations shown in Figure 6 (right) the traffic flows on all streets are equal with a value of 7,300 vehicles /24 h. It is clear when comparing Figure 6 (left and right) that the original traffic distribution gives lower levels in a large part of the area. Very close to the surrounding roads the levels are however lower in the even case than in the original case. Thus, an even traffic distribution is not desirable when considering the noise levels in the whole area. The second extreme case was to concentrate all traffic to two streets: one in N-S direction and one in E-W direction. The traffic on these streets was then 46,000 and 48,900 vehicles/24 h respectively. The equivalent level distribution for this case is shown in Figure 8.

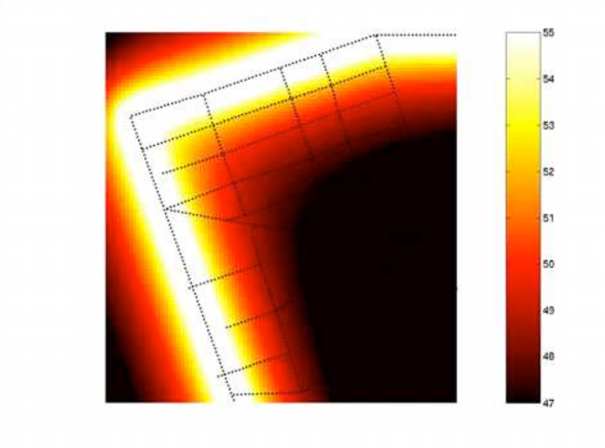

Figure 7. Equivalent levels in Söder if all traffic in the area is concentrated to two streets.

It is evident that in this case a larger area has access to a quiet side with lower levels than in either the even case or the original case. By concentrating the traffic to a few streets noise reducing measures, such as barriers or absorption, can be more cost-effective since they need only to be applied to a small range of locations.

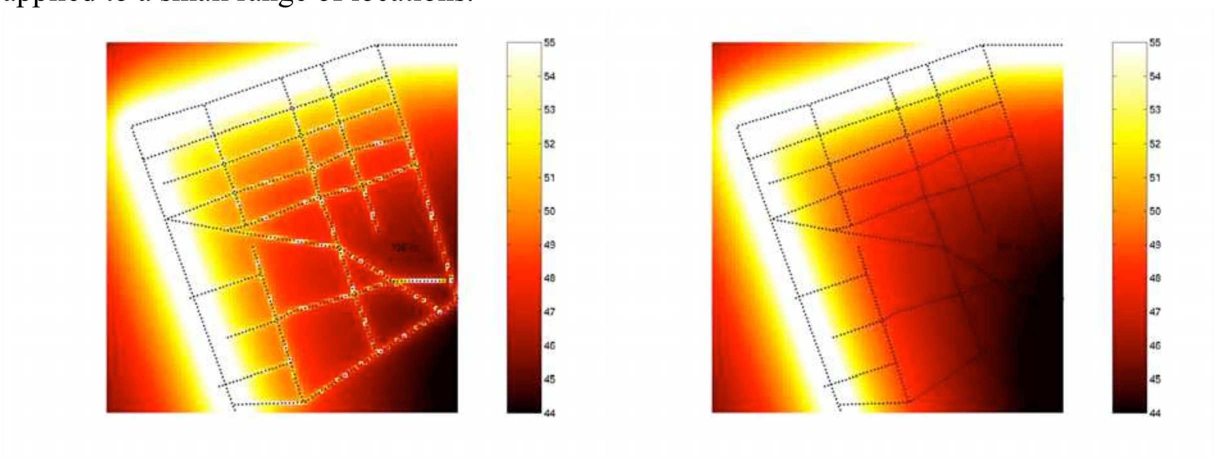

Figure 8. Equivalent levels in Söder with 500 vehicles/24 h on all streets but the two with heavy traffic (left). Equivalent levels in Söder with no traffic on other streets (right).

However, Figure 7 represents an ideal case with no traffic on any other street. Some traffic is always needed, so if a minimal traffic of 500 vehicles/24 h is given to all streets (but the two strong streets) the levels are increased in the regions with lowest levels (see Figure 8). Note that the colour scale is different for the figures in Figure 3 than for Figures 7-8. This was chosen to show the lower levels in larger detail. From this figure it is clear that even a small vehicle flow affect the equivalent levels, but the improvement gained by the traffic concentration is not entirely lost.

4 SUMMARY

The fact that the acoustic soundscape consists of two parts the direct acoustic soundscape and the diffuse acoustic soundscape has important consequences when attempting to changes the acoustic soundscapes. The traditional approach to control traffic noise by means of noise barriers or change of traffic distribution is only valid for the areas directly exposed from sources (direct acoustic soundscape). These areas will experience a certain decrease of sound pressure levels when applying these noise control measures. However there will be a lower limit for reduction due to the presence of a diffuse acoustic soundscape. To control/modify such a diffuse acoustic soundscape has been shown very difficult by traditional means of noise control. Main characteristic of diffuse acoustic soundscapes is the presence of a multitude of sources, distributed over a wide area contributing evenly to the acoustic soundscape in a certain areas. Screening will only lead to a redistribution of sound, however consequences of such redistribution will not be recognised in a diffuse sound field. Absorption has been identified as a main parameter to control diffuse acoustic soundscapes. Reducing sound pressure levels in shielded areas such as inner-yards can only be achieved by adding acoustically absorbing areas along the transfer path between source and receiver, but especially inside the inner-yard. Redistribution of traffic flow has been shown to have a tremendous effect on the directly exposed side, but only a small effect in shielded areas.

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