

Modelling road traffic noise annoyance by listening tests

Mine AŞCIGİL DİNCER¹, Sevtap YILMAZ²

¹ mineascigil@gmail.com • Department of Architecture, Faculty of Architecture, Istanbul Technical University, Istanbul, Turkey

² demirkale@itu.edu.tr • Department of Architecture, Faculty of Architecture, Istanbul Technical University, Istanbul, Turkey

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Abstract

Noise annoyance studies evaluate people's responses to noise exposure, questioning how much they are annoyed by a certain type of environmental noise. In accordance with Environmental Noise Directive (2002/49/EC) by the EU Parliament and Council, noise annoyance dose-effect relations are determined by noise maps and questionnaires with respondents living in a certain area. The aim of this study is to build a noise annoyance model using listening tests, by examining factors which effect road traffic noise annoyance levels. In this study, listening tests are prepared using sound clips of traffic noises which are listened to in laboratory conditions. Road traffic noises are recorded for each vehicle type, taking into account possible vehicle speeds, traffic flow types, road slopes and road surfaces. Sound clips are formed according to road types and filtered to simulate sound propagation in various city conditions. Sound clips are then filtered with façade sound insulation values to simulate the sounds heard inside houses. Respondents are asked how much they are annoyed when they listen to the sound clips with headphones and imagine they are resting inside their houses. The results are analyzed and responses are investigated to form a road traffic noise annoyance model. This model provides the opportunity to transform raw data (traffic, road and settlement) directly into annoyance. The information on the effects of traffic elements, road properties and settlement types on noise annoyance can easily be used for planning new areas or noise action plans.

Keywords

Listening test, Noise annoyance, Road traffic noise.

1. Introduction

Environmental noise is unwanted or harmful sound, usually generated by activities such as road traffic, railways, air transport, industry, recreation and construction. People are exposed to environmental noise at various places including their homes, schools or workplaces (Kang, 2007). The potential health effects of environmental noise include ear discomfort, speech interference, aural pain, sleep disturbance, startle and defense reactions, hearing impairment, cardiovascular effects, performance reduction, and annoyance responses (WHO, 2000).

Environmental noise annoyance and sleep disturbance effects are taken seriously by the European Union. The main objective of "Assessment and Management of Environmental Noise (2002/49/EC)" Directive (EU Parliament and Council, 2002) is to define a common approach intended to avoid, prevent or reduce the harmful effects, including annoyance, due to exposure to environmental noise. Turkey adapted this Directive (T.C. Çevre ve Orman Bakanlığı, 2010) with the same purposes and is working on implementing it.

The term, 'annoyance' is defined in the Directive as 'the degree of community noise annoyance as determined by means of field surveys'. The Directive states that dose-effect relations, that is the relation between annoyance and a noise indicator, should be used to assess the effect of noise on population. Noise indicator for annoyance given in the Directive is L_{den} , day-evening-night level in decibels. This indicator may be used to assess annoyance for road, rail and air traffic noise, and for industrial noise (EU Parliament and Council, 2002).

European Commission Working Groups published dose-effect relations for transportation noise, created from socio-acoustic surveys, made in countries of North Europe, North America and Australia (WG-HSEA, 2002). These relationships do not necessarily apply to other countries. Some dose effect relation studies conclude that, social, psychological or economic factors, are far more important than acoustic or physical factors (Guski, 1997) (Job, 1988). Numerous studies show that the

indicators used, such as A-weighted values or L_{den} and L_{night} , do not reflect many aspects of annoyance (Phan et al., 2009) (Persson Waye & Rylander, 2001) (Kang, 2007).

This study is part of a research for composing an approach for developing road traffic noise annoyance prediction model. In the research, noise mapping and socio-acoustic surveying and listening test techniques are used to develop and validate the prediction model for an urban area. In a previous study by the authors of this article, noise maps and socio-acoustic surveys were used to form dose-effect relations for road traffic noise for Besiktas district in Istanbul, Turkey (Badino et al., 2012). Dose-effect relations in Besiktas district proved to be different from relations recommended by European Commission (WG-HSEA, 2002). This divergence could be caused by differences in non-acoustical factors, by differences in characteristics of road vehicles or of built environment, or by inadequacy of noise indicators. In

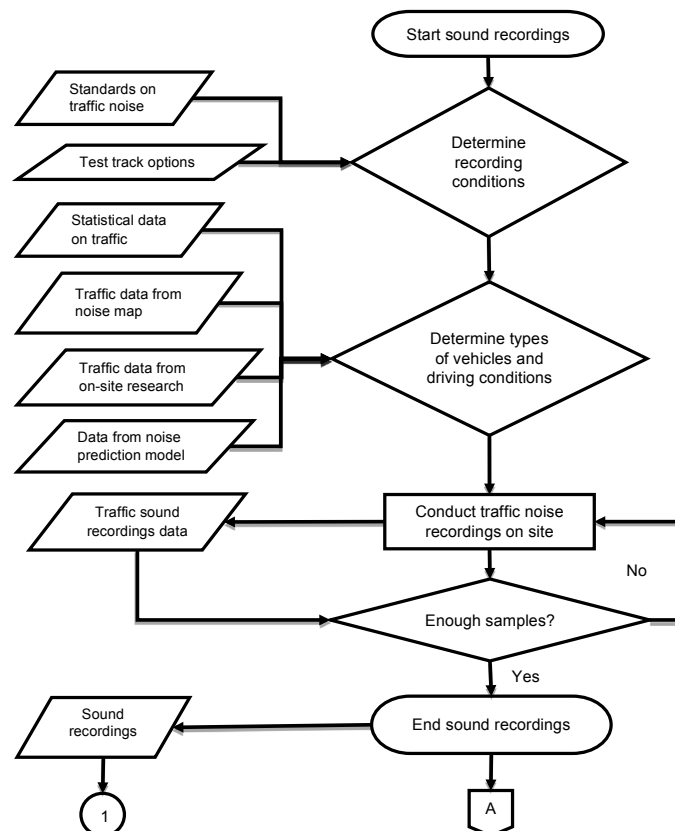


Figure 1.a. Methodology flowchart, Part 1: sound recordings.

this study, with the aim of analyzing the issue further, road traffic noise annoyance listening tests are designed for the same district. People living in the same district listen to traffic sounds at levels which may be heard inside their homes and rate the annoyance they experience. The results are analyzed to understand the factors effecting annoyance levels and a road traffic noise annoyance model is formed using analyzed results.

Listening tests are used to evaluate people's responses to noise in a controlled environment, such as a laboratory. Listening tests may be used for evaluating urban soundscapes or environmental noises such as transportation noise. Rychtarikova and Vermeir (2013) assessed soundscapes by listening tests using binaurally recorded sound in urban public places. Viollon et al. (2002) assessed how listener's judgments of a set of urban sound en-

vironments were affected by visual settings. Trolle et al. (2008), analyzed the auditory perception of environmental noises transmitted through a simulated window via listening tests. Yifan et al. (2008) experimented on annoyance ratings of noise samples with different frequency spectrums but same A-weighted levels. Barbot et al. (2008) investigated acoustic features of aircraft noise which could be improved by aircraft manufacturers from a sound design point of view. Lavandier et al. (2011) used aircraft flyover sounds to rate the level of activity disturbance due to the noise environment when carrying out memory and concentration tasks.

There are some listening test studies on certain properties of traffic noise annoyance. Freitas et al. (2012) executed listening tests for road traffic noise, using different road surfaces, car speeds and traffic densities. Trolle et al. (2015) investigated sound unpleasantness due to urban road traffic at crossroads by a listening test and discovered that type of crossroad, traffic lights and heavy vehicle content effect annoyance. Nilsson (2007) executed listening tests on road traffic noise with strong low frequency content and found them to be more annoying. Paviotti & Vogiatzis (2012) investigated pedestrian annoyance from scooter and motorbike noise and found masking effect by general traffic to be effective. Torija & Flindell (2014) examined low height roadside barrier's effects on annoyance by listening tests. Sandrock et al. (2008) executed listening tests on acute annoyance due to trams, buses and trucks, finding task performance and single pass-by versus realistic traffic flow to be effective in annoyance levels.

In this study, listening tests are conducted using sound clips of road traffic noises which are listened to in laboratory conditions. Road traffic noises are recorded for each vehicle type, taking into account possible vehicle speeds, traffic flow types, road slopes and road surfaces. Sound clips are formed according to road types and filtered to simulate sound propagation in various city conditions. Sound clips are then filtered with façade sound insulation values to simulate the traffic sounds

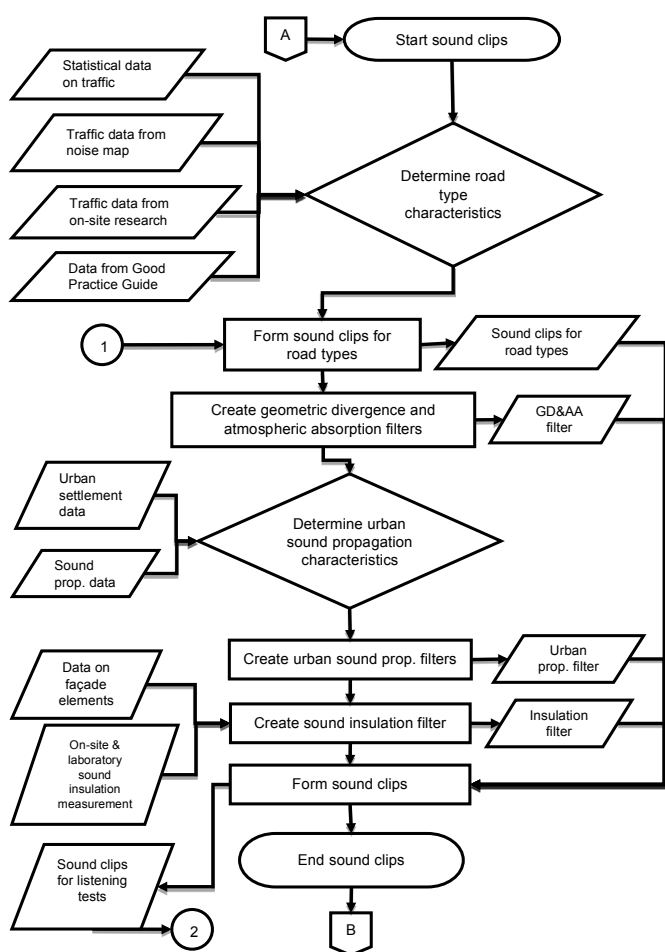


Figure 1.b. Methodology flowchart, Part 2: sound clips.

heard inside houses. Questionnaire respondents are asked to listen to the sound clips with headphones and imagine they are resting inside their houses. The results are analyzed and responses are investigated to form a noise annoyance model. This model helps to understand the dynamics of noise annoyance.

This study focusses on the modelling of road traffic noise annoyance by listening tests. Future studies will be on validating this model, using socio-acoustic survey results to transform it into a reliable prediction model. Environmental noise annoyance studies in EU require the main steps of acquiring data (traffic, road and settlement), forming noise maps via noise prediction models, and executing socio-acoustic surveys in order to establish dose-effect relations. Using an environmental noise annoyance prediction model created by listening tests provides the opportunity of directly predicting noise annoyance from acquired data. This prediction model would exclude noise indicators which have questionable reliability and which do not reflect many aspects of annoyance, determined by works of Phan et al. (2009), Persson Wayne & Rylander (2001) and Kang (2007). Because the main purpose of environmental noise control studies is to reduce harmful effects such as annoyance, a direct relation between on-site data and annoyance is valuable. These models can be created for different countries, for different settlements, and for different social and economic zones, taking into consideration Guski (1997) and Job's (1988) findings on the importance of non-acoustic factors. Annoyance model created by listening tests provides information on the effects of traffic elements, road properties and settlement types on noise annoyance, which can all be used directly in planning new areas or noise action plans.

2. Methodology and theoretical background

The methodology of this study brings together various methods used for sound recording, forming sound clips with sound filters and applying listening tests. Figure 1 shows the flow-

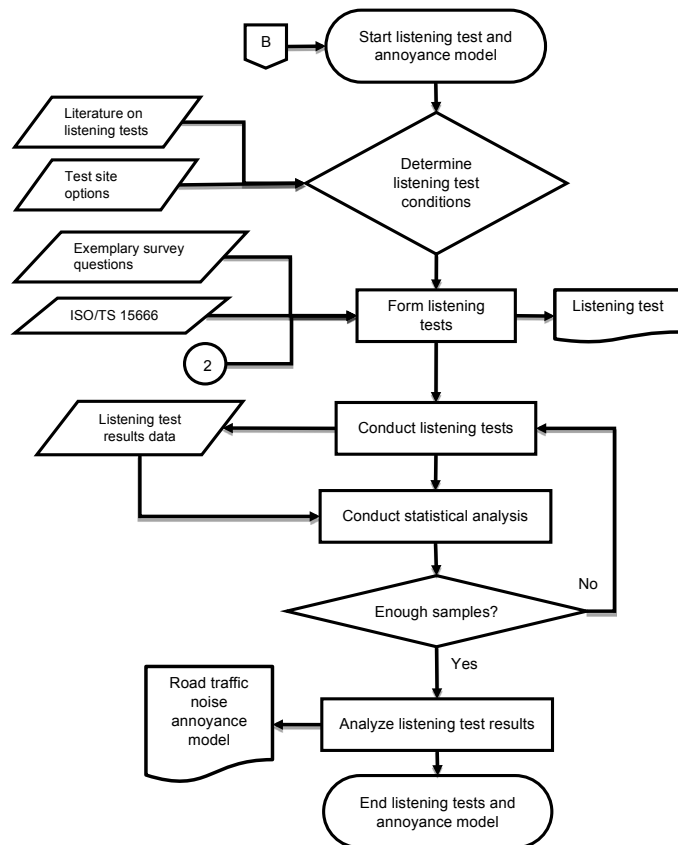


Figure 1.c. Methodology flowchart, Part 3: listening tests and annoyance model.

chart for the methodology in three parts, (a) sound recordings, (b) sound clips, (c) listening test and annoyance model. This chapter also explains the methodology in the same three headings. This methodology may be used for forming listening tests for different countries, for different traffic conditions or for different urban conditions, which will provide different annoyance models.

The detailed explanation of the methodology and the theoretical background of the study are given in the following sub-sections.

2.1. Traffic sound recordings

For traffic sound recordings, most common types of vehicles were determined by statistical information; driving conditions were determined by data from noise maps, noise prediction models and on-site research. Sound recordings were conducted in a similar methodology to traffic noise measurement standards.

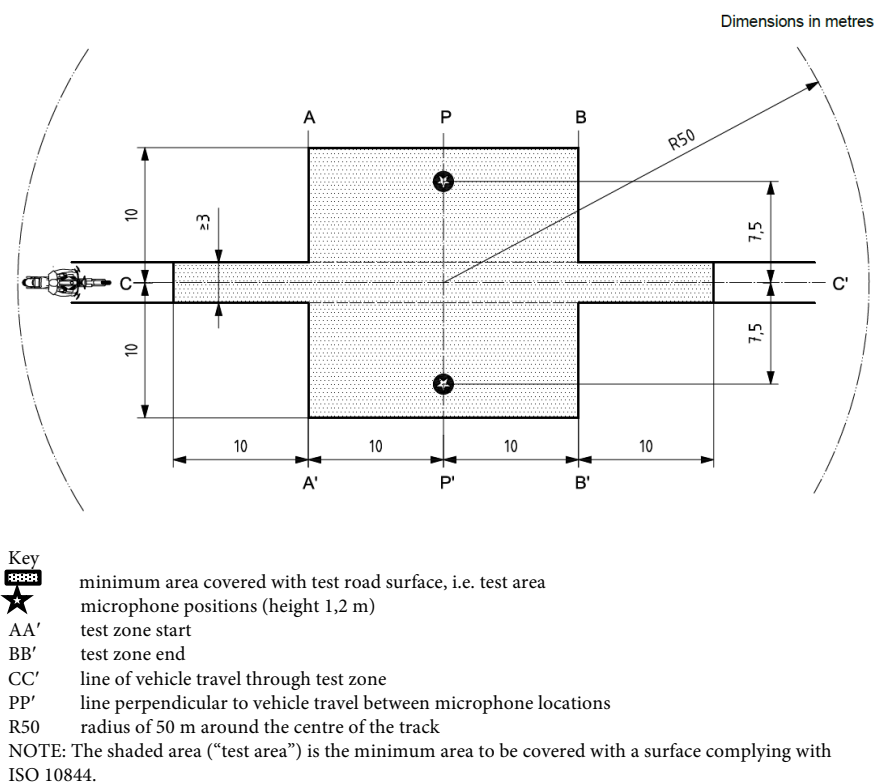


Figure 2. Test site dimensions (ISO 362-2, 2007).

2.1.1. Traffic sound recording standards

There are no guidelines for traffic sound recordings, therefore traffic noise measurement standards were used to guide the recordings. The related standards are, ISO 362-1 (2007), ISO 362-2 (2009) and ISO 10844 (2014). ISO 362-1 (2007) and ISO 362-2 (2009) standards are about measurement of noise emitted by accelerating road vehicles of various categories under typical urban traffic conditions. The specifications intend to reproduce the level of noise generated by the noise sources during normal driving in urban traffic.

The test track construction and surface shall meet the requirements of ISO 10844 (2014). The test site dimensions are shown in Figure 2. Within a radius of 50 m around the center of the track, the space shall be free of large reflecting objects such as fences, rocks, bridges or buildings. The test track and the surface of the site shall be dry and free from absorbing materials (ISO 362-1, 2007).

During the recordings, the geometry provided in the standards were followed. In the vicinity of the micro-

phone, there was no obstacle that could influence the acoustical field and no person remained between the microphone and the noise source. The distance from the microphone positions on the microphone line PP' to the perpendicular reference line CC' on the test track shall was $7.5 \text{ m} \pm 0.05 \text{ m}$. The microphone shall was located about 1.2 m above the ground level. The path of the centerline of the vehicle followed line CC' as closely as possible throughout the entire test, from the approach to line AA' until the rear of the vehicle passed line BB'. For accelerations and decelerations, the test speed was reached when the reference point was at line PP' (ISO 362-2, 2007). For fluid continuous traffic flow recordings, test speed was constant from AA' to BB'. Reference points of road vehicles are defined according to engine positions, which is mostly the front end of vehicles (ISO 362-1, 2007).

The test track is a test instrument and shall be protected from damage and be taken care of. The test track should be used only for noise measurements and should be kept clear from loose debris or dust during measurements (ISO 10844, 2014).

The background noise was measured before and after recordings. The recordings were made with the same microphones and microphone locations used during the test. The background noise should at least 10 dB below the A-weighted sound pressure level produced by the vehicle under test (ISO 362-1, 2007).

ISO 362 standard series recommend vehicle speed and acceleration for the measurement to be determined according to real urban traffic conditions, so that vehicle emission in urban traffic may be portrayed correctly. Inquiries among dwellers along various streets show that noise disturbance happens mainly along urban main streets, and during vehicle acceleration transients (ISO 362-1, 2007). According to ISO 362-1 (2007), the behavior of drivers depends on speed limits (traffic laws), traffic density, road arrangement (traffic lights, corners, etc.), driving purpose (commuting, pleasure, commercial, etc.), enforcement of traffic laws, and the way the vehicle behaves as an acoustical source under these conditions.

Annex A of ISO 362-1 (2007) gives the technical background for development of vehicle noise test procedure based on in-use operation in urban conditions. Standard recommends vehicle speed and acceleration for the measurement to be determined according to real urban traffic conditions, so that vehicle emission in urban traffic may be portrayed correctly.

2.1.2. Determining vehicles and driving conditions

Available statistical data may be used to determine the most common types of vehicles which may be used in recording vehicle sounds in traffic conditions. Driving conditions were determined by using data from noise maps, noise prediction model and on-site research.

The area under consideration was noise mapped for road traffic in a previous study and average speed (km/h) data used in road modelling of noise maps was taken into consideration.

As it was advised by the Directives (EU Parliament and Council, 2002) (T.C. Çevre ve Orman Bakanlığı,

2010), NMPB-Routes-96 (1995) was used in this study for traffic noise prediction modelling. In this model, given traffic flow types are fluid continuous, pulsed continuous, pulsed accelerating and pulsed decelerating. The traffic flows are categorized the same way in this study as well, for compatibility.

In "Good Practice Guide for Strategic Noise Mapping and the Production of Associated Data on Noise Exposure", (WG-AEN, 2006) the roads are classified as dead-end roads, service roads, collective roads, small main roads and main roads. The same classification is used in this study for compatibility purposes.

Annex A of ISO 362-1 (2007) gives the technical background for development of vehicle noise test procedure based on in-use operation in urban conditions. In the annex, the distribution of vehicle speed in urban traffic is examined and driving behavior is recorded on actual urban routes. Speed, acceleration and gears have been statistically examined in urban driving conditions. Standard recommends vehicle speed and acceleration for the measurement to be determined according to real urban traffic conditions, so that vehicle emission in urban traffic may be portrayed correctly. An on-site study by driving through the area at different times during the day was used to reveal the driving patterns.

2.2. Sound clips

The sound clips were formed for the purpose of helping to develop a road traffic noise model. The sound clips each simulated a traffic noise situation possible to hear inside houses in the area under consideration. First, road types and characteristics were determined to create the traffic noise heard 7.5 meters from road sources (ISO 10844, 2014). Then, sound propagation characteristics for the urban area were investigated and used for creating and applying sound propagation filters to sound clips. To simulate the traffic noise heard inside the houses, sound insulation values were applied as sound filters. All of these steps finally created the sound clips to use in the listening tests.

The length of sound clips in listen-

ing tests do not have a standard. Parizet et al. (2002) used binaural sound recordings of 10 seconds in various positions in a high-speed train as stimuli in listening tests. Viollon et al. (2002) assessed how listener's judgments of a set of urban sound environments were affected by visual settings. Each of the various sounds, which were road traffic noise, bird song and sounds due to human presence, lasted 20 seconds. Jeon et al. (2007) worked with various types of refrigerator noise in an anechoic chamber and in a real living environment. A total of 40 noise sources with duration of 5 seconds were presented randomly. Barbot et al. (2008) investigated acoustic features of aircraft noise which could be improved by aircraft manufacturers from a sound design point of view. The duration of all the stimuli were 40 seconds. Sandrock et al. (2008) executed listening tests on acute annoyance due to trams, buses and trucks, with stimuli 6 seconds long. Trolle et al. (2008), analysed the auditory perception of environmental noises transmitted through a simulated window via listening tests. The duration of each generated stimulus was 4 seconds. Yifan et al. (2008) experimented on annoyance ratings of 5 seconds long noise samples with different frequency spectrums but same A-weighted levels. Sound clips were formed with a duration of 20 seconds for this study. The number of vehicles needed for each type of road were distributed as evenly as possible on a 20 seconds long empty sound clip, on the software Audacity.

2.2.1. Determining road type characteristics

Road types in the area were determined for this study. Characteristics which influence traffic noise emission are, traffic volume, types of vehicles, traffic speed, traffic flow type and road surface. These had been determined in detail for major roads in the noise map model prepared for this area. European Commission's Good Practice Guide for Strategic Noise Mapping (WG-AEN, 2006) proposes some default values for traffic flow volume, these values were adapted to the area under consideration. Statistics of road motor vehicles

were also used. The on-site research recommended by Annex A of ISO 362-1 (2007) was used to validate traffic conditions in secondary roads. After using all of this data, traffic flow for all roads in the area was determined and grouped. For the use of this data in sound clips, road traffic volumes were adjusted 20 seconds.

2.2.2. Sound propagation filters

The sound clips formed represent different types of roads and traffic flow characteristics recorded at 7.5 meters from road sources, in open space conditions. Some common examples of urban sound propagation are calculated and applied as filters to sound clips at hand, in order to simulate traffic sounds in the city. Filters for geometric divergence and atmospheric absorption were created from literature. Filters for urban condition examples were calculated with noise mapping software.

2.2.2.1. Geometric divergence and atmospheric absorption

Filters for geometric divergence and atmospheric absorption have been created from literature. Geometric divergence for line sources is attenuation of 3 dB for doubling of distance. Because the sound recordings were conducted 7.5 m away from source, geometric divergence filter values for double distances such as 15 m and 30 m are used. The same principle is applied for atmospheric absorption using sound absorption values from ISO 9613-1 (1993).

2.2.2.2. Urban sound propagation

Urban sound propagation research in literature is based on experimental or theoretical works and examples on street canyon research clearly show this. Picaut et al. (2005) experimented on sound propagation in a street canyon, with various source and receiver locations on a street in Nantes, France. Nicol & Wilson (2004) investigated the effect of street dimensions and traffic density on noise levels in urban canyons, by noise measurements in Athens. Walerian et al. (2001) used a simulation program to calculate sound level distribution and ΔL on a canyon

street model. Schiff et al. (2010) executed a numerical investigation of sound propagation over multiple street canyons. Experimental research results are bounded by the on-site conditions and dimensions. Results of theoretical studies usually do not provide noise levels on façades and cannot reflect all the different settlement types in the area. Therefore, environmental noise prediction model recommended by the Directive, NMPB-Routes-96 (1995), was used to assess all types of sound propagation in these settlement types.

Various noise propagation conditions were simulated in SoundPlan 6.5 Noise Mapping Software, both in open space conditions and in urban conditions. The difference between the two conditions were used to create sound propagation filters, which were used on sound clips, in order to simulate traffic sounds in city conditions.

2.2.3. Sound insulation filters

Environmental noise annoyance focuses on environmental noise perceived inside houses. In order to simulate this effect, the sound clips were filtered by façade sound insulation values. Façade elements were determined by one of the on-site survey questions in the area, observation of façades in the area and statistical data on main wall elements.

Façade sound insulation to be used for filtering was determined by sound insulation measurements on-site (ISO 140-5, 1998). To validate these on-site measurements, building element laboratory measurements (ISO 10140-2, 2010) were used to calculate sound insulation of composite façade, using Equation 1 (Barron, 2003).

Where,

$TL_{façade}$: Sound transmission loss of composite façade, dB;

TL_{wall} : Sound transmission loss of wall, dB;

TL_{window} : Sound transmission loss of window, dB;

$A_{façade}$: Area of composite façade, $A_{wall} + A_{window}$, m²;

A_{wall} : Area of wall, m²;

A_{window} : Area of window, m².

$$TL_{façade} = 10 \log \left(\frac{A_{façade}}{\frac{1}{10^{TL_{wall}/10}} A_{wall} + \frac{1}{10^{TL_{window}/10}} A_{window}} \right) \quad (1)$$

2.3. Listening tests and annoyance model

For the listening tests, questions and sound clips were prepared, tests were conducted in laboratory conditions and results were analyzed.

20 seconds long sound clips were created to simulate the sound heard inside houses and to evaluate environmental noise annoyance. Different sound clips were created the road types, for compatible speeds, road slopes, surfaces, traffic flow types, and source-receiver distances. Effects of sound propagation in urban conditions were simulated for compatible road types. The effects of time of day, window condition and daily activity were also taken into consideration.

2.3.1. Questionnaire forms

Listening test questions were prepared in parts. Pre-criteria questions determined if the participant is competent to attend the survey. The first part of the listening tests included the same questions as the on-site socio-acoustic survey conducted in the area. The second part of the survey inquired into the annoyance of sound clips.

Pre-criteria for conducting the surveys were; minimum 12 months of residency in Besiktas District, lack of any hearing problems and being in the age range of 18 to 65.

In Part 1 of the listening test, personal information and environmental noise annoyance were questioned. Under the heading of 'personal information', gender, age, education level, duration of residence, time and period spend at home during day, noise sensitivity and noise annoyance at workplace were investigated. Under the heading of 'noise annoyance', traffic noise annoyance at home, for all day and only night periods were investigated in verbal and numerical scales. Wording of these questions and verbal and numerical scales were given in ISO/TS 15666 (2003). Also under the same heading, most annoying traffic elements and annoyance during dai-

Table 1. Part 2 questions in the listening test.

| | | | | | | | | | | |
|--|---|---|---|---|---|---|---|---|---|----|
| Part 2, Sub-part 1 and Sub-part 2 | | | | | | | | | | |
| XX) Imagining you are resting at home, how much does the sound clip you listened to, bother, disturb or annoy you? | | | | | | | | | | |
| <input type="checkbox"/> Not at all? <input type="checkbox"/> Slightly? <input type="checkbox"/> Moderately? <input type="checkbox"/> Very? <input type="checkbox"/> Extremely? | | | | | | | | | | |
| XX) Imagining you are resting at home, what number from 0 to 10 best shows how much you are bothered, disturbed or annoyed by the sound clip you listened to? | | | | | | | | | | |
| Not at all Extremely | | | | | | | | | | |
| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Part 2, Sub-part 3 (the question asks for only one time frame) | | | | | | | | | | |
| XX) Imagining you are resting at home, during <u>day time (07-19) / evening time (19-23) / night time (23-07)</u> , how much does the sound clip you listened to, bother, disturb or annoy you? | | | | | | | | | | |
| <input type="checkbox"/> Not at all? <input type="checkbox"/> Slightly? <input type="checkbox"/> Moderately? <input type="checkbox"/> Very? <input type="checkbox"/> Extremely? | | | | | | | | | | |
| XX) Imagining you are resting at home, during <u>day time (07-19) / evening time (19-23) / night time (23-07)</u> , what number from 0 to 10 best shows how much you are bothered, disturbed or annoyed by the sound clip you listened to? | | | | | | | | | | |
| Not at all Extremely | | | | | | | | | | |
| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Part 2, Sub-part 4 | | | | | | | | | | |
| XX) Imagining you are reading at home, how much does the sound clip you listened to, bother, disturb or annoy you? | | | | | | | | | | |
| <input type="checkbox"/> Not at all? <input type="checkbox"/> Slightly? <input type="checkbox"/> Moderately? <input type="checkbox"/> Very? <input type="checkbox"/> Extremely? | | | | | | | | | | |
| XX) Imagining you are reading at home, what number from 0 to 10 best shows how much you are bothered, disturbed or annoyed by the sound clip you listened to? | | | | | | | | | | |
| Not at all Extremely | | | | | | | | | | |
| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

ly activities are inquired using multiple-answer questions. Room positions in regards to main road, open windows during night and main wall elements are also questioned.

Part 2 of the listening test inquired about how much the sound clips bother, disturb or annoy the participants in

verbal and numerical scales (Table 1). Wording of these questions were similar to questions given in ISO/TS 15666 (2003). Verbal and numerical scales were the same as scales used in Part 1 and ISO/TS 15666 (2003). Six different tests were created to change the order of the sound clips in each test.

Part 2 was divided into four sub-parts to provide breaks if necessary. In sub-parts 1 and 2, wording of the questions did not change. The question was; "Imagining you are resting at home, how much does the sound clip you listened to, bother, disturb or annoy you?". In sub-part 3, a time frame was given in each question, such as day time (07-19), evening time (19-23) or night time (23-07). In sub-part 4, the activity changed from resting to reading. A short magazine article about travelling to Mars was read by participants. The article was divided in two parts, first part was read in quiet, while the second part was read with exposure to traffic noise.

2.3.2. Executing listening tests

Pilot listening tests were executed with 4 people, to identify the possible problems. Some explanatory phrases and warnings were added to the listening test as a result of this pilot study. The listening tests were conducted as face-to-face interviews with 40 people between the ages of 18 and 65, who live in the related district. The listening tests were executed in laboratory, where background noise was always monitored.

Headphones (MESA BMH.I-H42 binaural headset) were used to listen to sound clips. All participants signed a consent form and they were warned to stop the test if they felt any auditory problem. The investigator asked the questions, turned on the sound clips and typed the answers of the participants on a MS Excel worksheet; so that the participants could concentrate on the sound clips. 30 second breaks were given between each sound clip to ensure concentration and a fresh perception. Participants were free to express any opinions they had about the sound clips and the listening test.

2.3.3. Analyzing listening test and building model

Listening test results were statistically analyzed; Cronbach's alpha was computed for reliability and Spearman's correlation coefficient was calculated for factors affecting annoyance.

Verbal and numerical scales were used for sound clip annoyance ques-

tions. These different scales were converted and analyzed on a 100 scale. On the verbal scale, "not at all" was converted to 0, "slightly" to 25, "moderately" to 50, "very" to 75 and "extremely" to 100. On the numerical scale, 0 was 0, 1 was converted to 10, 2 to 20 and so on. For analyzing percentage of people annoyed (%A) and percentage of people highly annoyed (%HA) the cutoff points on a 100 scale are 50 for %A and 72 for %HA (WG-HSEA, 2002). On the verbal scale, cutoff point of 50 for %A referred to points 50, 75 and 100, which were "moderately", "very" and "extremely" respectively. Cutoff point of 72 for %HA referred to points 75 and 100, which were "very" and "extremely" respectively. %A was associated with the total number of responses for 5, 6, 7, 8, 9 and 10 (from 50 to 100 on the 100 scale) on the numerical scale, whereas %HA was associated with the total number of responses for 8, 9 and 10 (from 80 to 100 on the 100 scale) on the numerical scale.

Annoyance levels for each simulated traffic sound clip was examined for number of people annoyed and highly annoyed within the whole group of respondents, in order to calculate percentage of people annoyed (%A) and percentage of people highly annoyed (%HA). Averages of verbal and numerical scale results were used. %A and %HA levels for each sound clip were then compared to others with similar properties. For easy expression and comprehension, some factors which effect annoyance in a similar way were united.

3. Application of traffic sound recordings

The road traffic sound recordings were made using the most common vehicles in Istanbul city and the possible driving behaviors in the area under consideration.

3.1. Determining most common vehicles

Turkish Statistical Institute is responsible for collecting and disseminating the data which display the social and economic structure of Turkey. The publication "Road Motor Vehicle Statistics 2012", includes statistics of the

road motor vehicles such as, the current number of the vehicles according to their types, trademarks, fuel type, and model years by the end of year 2012, for each city (TurkStat, 2013b). According to Istanbul city statistics, in all motor vehicles, 52% of vehicles have diesel fueled motors and 46% of vehicles have gasoline fueled motors. Renault is the most common trademark in terms of cars, small trucks, trucks, buses and minibuses. Most common three trademarks and their percentages in the market are; Renault 15.4%, Ford 9.9% and Fiat 9.6%. Honda is the most common trademark for motorcycles with 25.2% market share. Most common engine size of cars is 1600 cc with 38.3%. The most common public transportation bus is Otokar Kent 290 LF with 29.4%.

The most common trademarks were used for sound recordings. The cars used for sound recordings were diesel fueled Renault and gasoline fueled Ford with engine size 1600 cc. These cars were also used to record horn sounds. Other vehicles used were, Honda motorcycle, Otokar Kent public transportation bus, Iveco minibus (blue minibus common in Besiktas area) and Renault Midlum Truck.

3.2. Determining most common driving conditions

Driving conditions were determined by using data from noise maps, noise prediction model and on-site research.

Average speed (km/h) data used in road modelling of noise maps in Besiktas district (Badino et al., 2012) was taken into consideration. The average speed for Barbaros Avenue in north direction received from radars was between 55 and 70 km/h for day, 60 and 65 km/h for evening, 75 and 80 km/h for night. The average speed for Barbaros Avenue in south direction received from radars was between 50 and 80 km/h for day, 50 and 85 km/h for evening, 65 and 95 km/h for night. The average speed for small main roads and collecting roads received from radars was between 40 and 50 km/h. The average speed for service roads and dead-end roads determined on-site were between 30 and 40 km/h.

Traffic flow types of fluid continu-

ous, pulsed continuous, pulsed accelerating and pulsed decelerating were used as advised in NMPB-Routes-96 (1995).

the roads are classified as dead-end roads, service roads, collective roads, small main roads and main roads as advised in Good Practice Guide (WGAEN, 2006).

As it was advised in Annex A of ISO 362-1 (2007), an on-site study by driving through the area (Besiktas) at different times during the day was used to reveal the driving patterns. On Barbaros Avenue, traffic flow was mostly fluid continuous during daytime and nighttime, it was mostly pulsed continuous during evening. Pulsed accelerating and pulsed decelerating traffic flows were existent due to traffic lights. For fluid continuous traffic flow, speed during daytime ranged from 50 to 80 km/h, while speed during nighttime ranged from 70 to 100 km/h. Traffic flow during evening hours was pulsed continuous, mostly stopping and starting in traffic. Average speed of heavy vehicles were between 30 km/h and 50 km/h.

For roads other than Barbaros, the average speed values from on-site study were consistent with data from noise map models. The traffic flow was fluid continuous for service roads and dead-end roads at all times. For small main roads and collective roads, traffic flow was mostly fluid continuous during daytime and nighttime, it was mostly pulsed continuous during evening. Pulsed accelerating and pulsed decelerating traffic flows were existent due to traffic lights and junctions.

Slope of roads were categorized as, horizontal (slope between: $0\% \leq p \leq 2\%$), rising or falling slope (slope between $2\% \leq p \leq 6\%$) (Wölfel et al. 2003).

3.3. Recording vehicle sounds

It is stated in ISO 10844 (2014) that the test track should be used only for noise measurements, but it was not possible to build a test track for this study. Available roads around the city were used as tracks for this study. Information on the sound recording conditions are given in Table 2. Recording equipment were binaural microphone, data acquisition board and a laptop.

Cars and motorcycles were recorded at a site where various road slopes and road surfaces were available. The site where bus, minibus and truck were recorded was chosen because it contained various road slopes and heavy vehicles and minibuses were not banned on this road. All tracks were in vast areas, with no large reflecting objects within a radius of 50 m. Meteorological data was taken from Meteorological General Directorate and background noise also recorded.

The recordings took place on only one side of the road, 7.5 m from vehicle's travel path. For each sound recording, a vehicle was driven at a specific speed or acceleration, with a specific traffic flow type, on a road with a specific slope and surface. Diesel and gasoline fueled cars were driven with speeds of 30, 50, 70 and 100 km/h. At 50 km/h, sounds were recorded with driving patterns fluid continuous, pulsed continuous, pulsed accelerating and pulsed decelerating. Vehicles driven on various road slopes, level (slope between: $0\% \leq p \leq 2\%$), rising and falling (slope between $2\% \leq p \leq 6\%$) were also recorded. Road surfaces used were smooth asphalt and paving stones. Cars were also used for recording horn sounds.

Motorcycle, minibus, bus and truck were driven and recorded in a similar way but with fewer variations. Driving speeds were 30 and 50 km/h; the same driving patterns and road slopes were used. The road surface was only smooth asphalt because it is not possible for these vehicles to be driven on streets with paving stones in Besiktas area. All recordings were conducted late at night to keep the background noise and other pass-by vehicles at a minimum.

4. Application of creating sound clips

The sound clips each simulated a traffic noise situation possible to hear inside houses in Besiktas area. Road types and characteristics were determined to create the traffic noise heard 7.5 meters from road sources. To simulate the traffic noise heard inside the houses in various urban conditions, urban sound propagation filters and façade sound insulation filters were

Table 2. Sound recording conditions.

| Title | Information | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|--|------|------|------|------|------|------|------|------|-----|-----|-----------------|------|------|------|------|------|------|------|------|------|-----|-----|------|------|------|------|------|------|------|------|--|------|------|------|------|------|------|------|------|-----|
| Measuring equipment | MESA BMH.I-H42 binaural microphone, 01dB dB4 acquisition board, dBFA software, Dell Latitude Laptop | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Recording for cars and motorcycle | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Date and time: | Between August 31 st 2014 23:00 and September 1 st 2014 02:00 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Test site: | Istanbul, Kucukcekmece District, Soyak Olimpiyakent housing development | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Weather: | 18.2°C temperature, 5 km/h SSW wind, 60% humidity | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Vehicle types: | Car: Ford Focus, gasoline fueled with engine size 1600 cc. Car: Renault Fluence diesel fueled with engine size 1500 cc. Motorcycle: Honda CBF 150, with engine size 150 cc. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Average background noise: | <table><tr><td>Hz</td><td>50</td><td>100</td><td>125</td><td>160</td><td>200</td><td>250</td><td>315</td><td>400</td><td>500</td></tr><tr><td>L_{eq}</td><td>24,4</td><td>25,9</td><td>23,4</td><td>21,6</td><td>19,8</td><td>16,4</td><td>14,7</td><td>15,9</td><td>16,3</td></tr><tr><td>630</td><td>800</td><td>1000</td><td>1250</td><td>1600</td><td>2000</td><td>2500</td><td>3150</td><td>4000</td><td>5000</td></tr><tr><td></td><td>14,8</td><td>13,4</td><td>16,3</td><td>15,8</td><td>14,8</td><td>13,4</td><td>12,2</td><td>11,4</td><td>8,7</td></tr></table> | Hz | 50 | 100 | 125 | 160 | 200 | 250 | 315 | 400 | 500 | L _{eq} | 24,4 | 25,9 | 23,4 | 21,6 | 19,8 | 16,4 | 14,7 | 15,9 | 16,3 | 630 | 800 | 1000 | 1250 | 1600 | 2000 | 2500 | 3150 | 4000 | 5000 | | 14,8 | 13,4 | 16,3 | 15,8 | 14,8 | 13,4 | 12,2 | 11,4 | 8,7 |
| Hz | 50 | 100 | 125 | 160 | 200 | 250 | 315 | 400 | 500 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| L _{eq} | 24,4 | 25,9 | 23,4 | 21,6 | 19,8 | 16,4 | 14,7 | 15,9 | 16,3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 630 | 800 | 1000 | 1250 | 1600 | 2000 | 2500 | 3150 | 4000 | 5000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 14,8 | 13,4 | 16,3 | 15,8 | 14,8 | 13,4 | 12,2 | 11,4 | 8,7 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Recording for minibus, bus and truck | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Date and time: | Between September 7 th 2014 23:00 and September 8 th 2014 02:00 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Test site: | Istanbul, Kartal District, Samandira 2 Koprulu Kavsak | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Weather: | 16.5°C temperature, 6 km/h NNE wind, 55% humidity | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Vehicle types: | Bus: Otokar Kent public transportation bus Minibus: Iveco blue minibus Truck: Renault Midlum truck | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Average background noise: | <table><tr><td>Hz</td><td>50</td><td>100</td><td>125</td><td>160</td><td>200</td><td>250</td><td>315</td><td>400</td><td>500</td></tr><tr><td>L_{eq}</td><td>20,5</td><td>22,3</td><td>19,2</td><td>18,4</td><td>16,9</td><td>14,7</td><td>9,8</td><td>12,9</td><td>12,5</td></tr><tr><td>630</td><td>800</td><td>1000</td><td>1250</td><td>1600</td><td>2000</td><td>2500</td><td>3150</td><td>4000</td><td>5000</td></tr><tr><td></td><td>9,3</td><td>8,4</td><td>8,2</td><td>6,6</td><td>7,1</td><td>7,3</td><td>6,8</td><td>6,1</td><td>5,3</td></tr></table> | Hz | 50 | 100 | 125 | 160 | 200 | 250 | 315 | 400 | 500 | L _{eq} | 20,5 | 22,3 | 19,2 | 18,4 | 16,9 | 14,7 | 9,8 | 12,9 | 12,5 | 630 | 800 | 1000 | 1250 | 1600 | 2000 | 2500 | 3150 | 4000 | 5000 | | 9,3 | 8,4 | 8,2 | 6,6 | 7,1 | 7,3 | 6,8 | 6,1 | 5,3 |
| Hz | 50 | 100 | 125 | 160 | 200 | 250 | 315 | 400 | 500 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| L _{eq} | 20,5 | 22,3 | 19,2 | 18,4 | 16,9 | 14,7 | 9,8 | 12,9 | 12,5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 630 | 800 | 1000 | 1250 | 1600 | 2000 | 2500 | 3150 | 4000 | 5000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 9,3 | 8,4 | 8,2 | 6,6 | 7,1 | 7,3 | 6,8 | 6,1 | 5,3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

used. Sound clips were formed with a duration of 20 seconds for this study. This value coincides with the road types explained in the next part of this study.

4.1. Determining road type characteristics in Besiktas District

In a previous study by the authors of this article, noise maps and socio-acoustic surveys were made for Besiktas district (Badino et al., 2012). Characteristics which influence traffic noise emission of the main roads, such as traffic volume, types of vehicles, traffic flow type and road surface had already been determined in detail for this noise map model. The main road, Barbaros Avenue, is a north-south dual carriageway with three lanes on each side, going through a highly populated urban area and is monitored by radars which record number and speed of light and heavy vehicles. The annual average traffic flow per hour to north and to south was calculated from radar data for day, evening and night. To use these traffic data in this study, the hourly data was transformed in 20 seconds data, by a division of 180. Table 3 gives average traffic volume on Barbaros Av-

Table 3. Average traffic volume on Barbaros Avenue adjusted to 20 seconds (rounded).

| | Barbaros Av. (to north) | | Barbaros Av. (to south) | |
|---------|-------------------------|------------|-------------------------|------------|
| | Light veh. | Heavy veh. | Light veh. | Heavy veh. |
| Day | 12 | 0.5 | 13 | 0.5 |
| Evening | 12 | 0.5 | 11 | 0.5 |
| Night | 7 | 0.25 | 6 | 0.25 |

Table 4. Traffic volume in 20 seconds for a total of both sides of Barbaros Avenue.

| | Car (Gasoline) | Car (Diesel) | Motorcycle | Minibus | Bus | Truck |
|---|-------------------|-----------------|------------|---------|-----|-------|
| Main road (Barbaros Avenue) Day & Evening | 10 | 10 | 2 | 2 | 1 | 0 |
| Main road (Barbaros Avenue) Night | 6 | 6 | 1 | 0 | 0 | 1 |

Table 5. Proposed default values for traffic volume (WG-AEN, 2006) and average and standard deviation values of traffic volume of road types around Barbaros Avenue.

| Road type (WG-AEN, 2006) | Traffic volume | | |
|---|--------------------------------|------------|----------|
| | day | evening | night |
| Dead-end roads | 175 | 50 | 25 |
| Service roads (mainly used by residents living there) | 350 | 100 | 50 |
| Collecting roads (collecting traffic from service roads and leading it to & from main roads) | 700 | 200 | 100 |
| Small main roads | 1400 | 400 | 200 |
| Main roads | Must undertake traffic counts. | | |
| Road types around Barbaros Av. | Traffic volume | | |
| | day | evening | night |
| Dead-end roads | 166 ± 45 | 150 ± 41 | 79 ± 22 |
| Service roads | 365 ± 55 | 327 ± 52 | 176 ± 23 |
| Collecting roads | 730 ± 175 | 616 ± 126 | 331 ± 81 |
| Small main roads | 1349 ± 154 | 1079 ± 123 | 615 ± 70 |

Table 6. Traffic volume in 20 seconds for secondary roads.

| | Car (Gasoline) | Car (Diesel) | Motorcycle | Minibus | Bus | Truck |
|------------------|-------------------|-----------------|------------|---------|-----|-------|
| Dead-end roads | 0 | 1 | 0 | 0 | 0 | 0 |
| Service roads | 1 | 1 | 0 | 0 | 0 | 0 |
| Collecting roads | 2 | 2 | 0 | 0 | 0 | 0 |
| Small main roads | 3 | 4 | 1 | 0 | 0 | 0 |

enue adjusted to 20 seconds; light vehicles include cars (gasoline and diesel fueled), motorcycles, and minibuses. Statistics of road motor vehicles in Istanbul show that 52% of vehicles have diesel fueled motors and 46% of vehicles have gasoline fueled motors, almost half and half. (TurkStat, 2013b) A traffic flow count on Barbaros Avenue proved about 4% of light vehicles to be minibuses and about 4% of light vehicles to be motorcycles. Heavy vehicles are actually the number of long vehicles (3 times the length of cars) counted by the radar system by Istanbul Met-

ropolitan Municipality, therefore heavy vehicles are buses in this case. Other heavy vehicles such as trucks, TIRs or oil tankers are only allowed to work in urban areas between 22:00 and 06:00. So, trucks can only be added to night time traffic flow. Minibuses work between 05:00 and 02:00, but they do not have a schedule. Buses work between 06:00 and 00:00. As a result of all this input, detailed traffic volume data for a total of both sides of Barbaros Avenue adjusted to 20 seconds, in order to simulate the main road, is given in Table 4.

There are many secondary roads around Barbaros Avenue and their traffic flow information have been included in noise map model. But preparing sound clips for each road would not be efficient, therefore, the secondary roads were grouped. European Commission's Good Practice Guide for Strategic Noise Mapping (WG-AEN, 2006) proposes some default values for traffic flow volume, as given in Table 5. The road types in this table can be used for grouping roads around Barbaros Avenue. The traffic volumes of secondary roads determined in the previous noise map were grouped in this study. Average and standard deviation values of traffic volume of road types around Barbaros Avenue are also given in Table 5. Average values for daytime are very close to default values of roads proposed by WG-AEN, so these values were used. Table 6 adjusts traffic volumes of road types for one hour into traffic volumes for 20 second sound clips to simulate secondary roads.

The number of vehicles given in Table 4 and Table 6 were used to form the sound clips from traffic sound recordings. The number of vehicles needed for each type of road were distributed as evenly as possible on a 20 seconds long empty sound clip, on the software Audacity. On the secondary road sound clips, where the number of vehicles are low, each vehicle's passing can be heard almost individually. On main road sound clips, where the number of vehicles are high, the passing of cars are not noticeable individually, but the passing of motorcycle, minibus, bus and truck are noticeable.

4.2. Creating and applying sound propagation filters

The sound clips formed represent different types of roads and traffic flow characteristics recorded at 7.5 meters from road sources, in open space conditions. Some common examples of urban sound propagation are calculated and applied as filters to sound clips at hand, in order to simulate traffic sounds in the city. Filters for geometric divergence and atmospheric absorption were created from literature. Filters for urban condition examples were calculated with noise mapping software.

4.2.1. Geometric divergence and atmospheric absorption

Because the sound recordings were conducted 7.5 m away from source, geometric divergence and atmospheric absorption filter values for double distances such as 15 m and 30 m were used. Sound absorption values (ISO 9613-1, 1993) are calculated for 14 °C, which is the yearly average temperature in Istanbul (MGM, 2014), and 50% relative humidity. Figure 3 shows filter values for a total of geometric divergence and atmospheric absorption to be applied for simulating different distances from source.

4.2.2. Urban sound propagation in Besiktas District

Map around Barbaros Avenue in Besiktas was studied for common urban settlements and these settlements were grouped regarding sound propagation. Urban settlement conditions considered were:

- Sound propagation from main road to perpendicular narrow streets
- Sound propagation from main road to second row of buildings through detached buildings
- Sound propagation from main road to second row of buildings through attached buildings
- Sound propagation from main road to second row of buildings through narrow opening
- Sound propagation in a street canyon

Examples of these settlements were simulated in noise mapping software,

Soundplan 6.5. Single receivers were placed at possible façades. The simulations were executed two times for each receiver, (1) for open space, with no

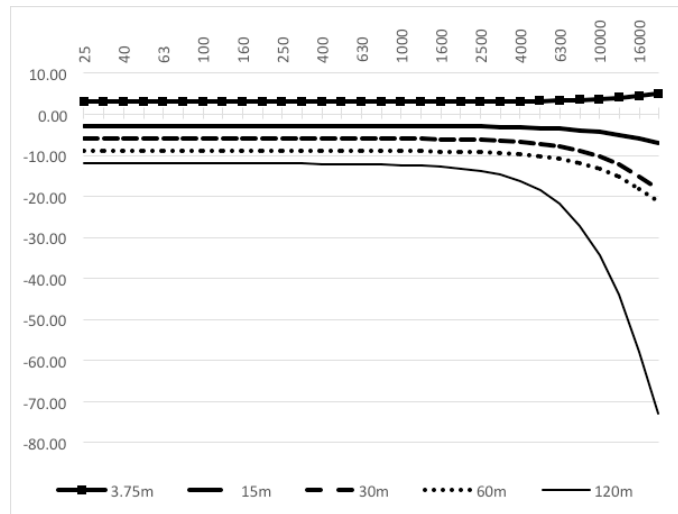


Figure 3. Filter values for a total of geometric divergence and atmospheric absorption to be applied for simulating different distances from source.

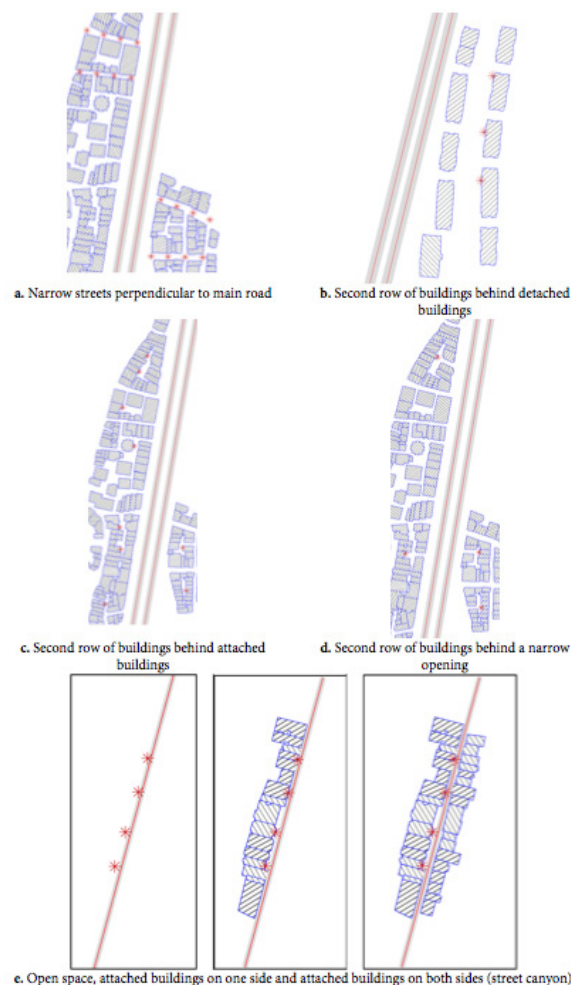
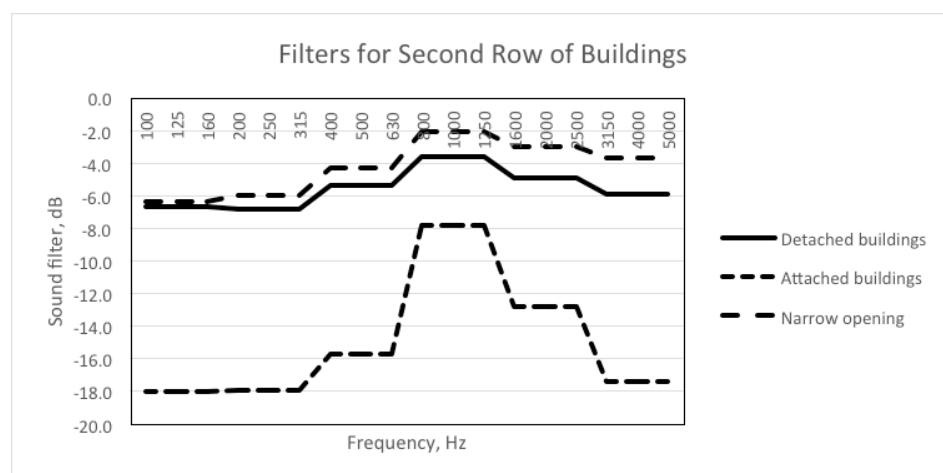
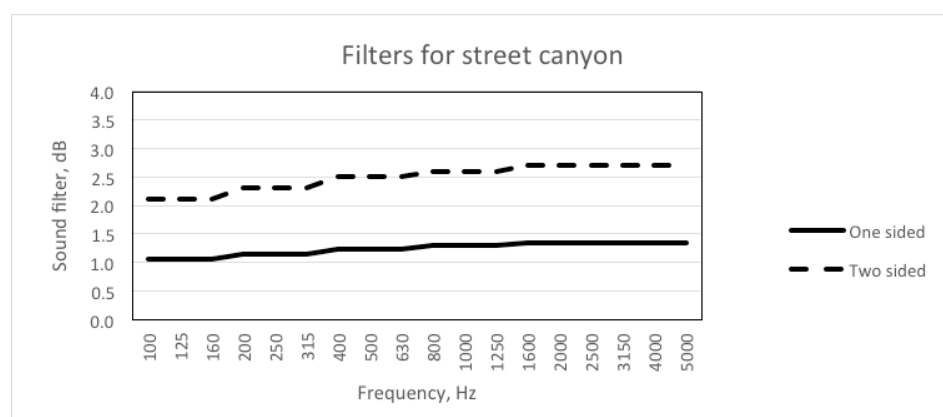


Figure 4. Map of areas around Barbaros Avenue and receivers (*), for simulation of sound propagation.



a. Sound filter for second row of buildings behind detached buildings, behind attached buildings and behind a narrow opening



b. Sound filter for narrow streets forming a street canyon, for attached buildings on only one side and attached buildings on both sides

Figure 5. Filters calculated using the difference between open space conditions and urban conditions.

buildings and (2) for urban conditions, with buildings. In the simulation, the topography was excluded, so the road and the buildings were all set at zero height. The height of the buildings were identical to real height of the buildings in the area. All the point receivers had the same height, 150 cm. Noise levels were calculated using NMPB Routes 96 (1995) method. The traffic data of the main parallel roads were identical. Number of light vehicles per hour was 2160, number of heavy vehicles per hour was 90. Velocity of light vehicles was 70 km/h, velocity of heavy vehicles was 50 km/h. The traffic was smooth-flowing and the road surface was asphalt concrete. This traffic data was similar to that used in listening test sound clips. Maps used for simulation and receiver points are given in Figure 4. Figure 5 shows the filters calculated using the difference between open

space conditions and urban conditions.

4.3. Sound insulation filters for Besiktas District

Environmental noise annoyance focuses on environmental noise perceived inside houses. In order to simulate this effect, the sound clips were filtered by façade sound insulation values. Façade sound insulation to be used for filtering was determined by determining façade elements, making sound insulation measurements on-site and using laboratory measurements. 18 on-site façade sound insulation measurements were made in houses in the area using existing traffic noise as source and living rooms or bedrooms as receiver room (ISO 140-5, 1998).

Façade elements were determined by one of the survey questions, observation of façades in the area and statistical data on main wall elements. One

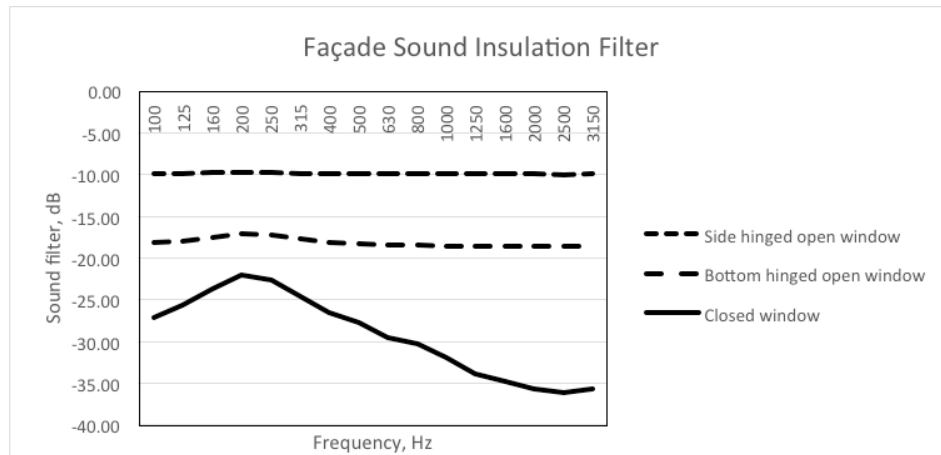


Figure 6. Sound insulation filters for closed, side hinged open and bottom hinged open window conditions.

of the previous on-site survey questions in the area (Badino et al., 2012) was “What is the main material of your façade wall?”. 65% of the respondents did not know the answer. 80% of the remaining responses were ‘brick’ and 20% were ‘aerated concrete’. Almost all the façades had double glazed windows. Studies on façade photographs revealed an average use of 45% transparent elements and 55% opaque elements. All residential buildings studied in the area had reinforced concrete frame constructions. Turkish Statistical Institute’s Building Permit Statistics from 2002 to 2012, showed that 95% of residential buildings are built using brick as the main wall material in reinforced concrete frame constructions (TurkStat, 2013a).

Results of laboratory sound insulation measurements (ISO 10140-2, 2010) for local building elements were received from a research study (Aşçıgil Dincer & Yılmaz Demirkale, 2015) (Yılmaz et al., 2012) for validation of on-site measurements. Laboratory sound insulation values of 145 mm thick plastered brick wall and most common double glazed window were used to calculate sound insulation of a commonly used façade in the area, using Equation 1. The resulting values validated the measurements on-site. Therefore, results of measurements on-site were selected to filter the sound clips.

Calculation techniques for composite walls were used to simulate the noise heard inside the house when a window is open. For a full open win-

dow (side hinged), a bedroom with façade dimensions 4 m x 3 m (12 m²) and a window of 0.8 m x 1.5 m (1.2 m²) was considered. For a partially open window (bottom hinged), the same dimensions were also considered. Figure 6 shows sound insulation filters for closed, side hinged open and bottom hinged open window conditions.

5. Application of listening tests and annoyance model

For the listening tests, questionnaires and sound clips were prepared, tests were conducted in laboratory conditions and results were analyzed.

The listening tests were executed in December 2014, in Istanbul Technical University, Faculty of Architecture, Building Physics and Environmental Control Laboratory, where background noise was always monitored.

5.1. Listening test sound clips

20 seconds long sound clips were created to simulate the sound heard inside houses and to evaluate environmental noise annoyance. Each sound clip represents a road type with a specific speed of vehicles and traffic flow, on a specific road slope and surface. All of these traffic and road characteristics are present in the area under consideration. The information on the number of vehicles for each road was given in Table 4 and Table 6. Filter for geometric divergence and atmospheric absorption was applied for possible source-receiver distances. Effect of motorcycle passing and horn sounds during pulsed flow, which are very of-

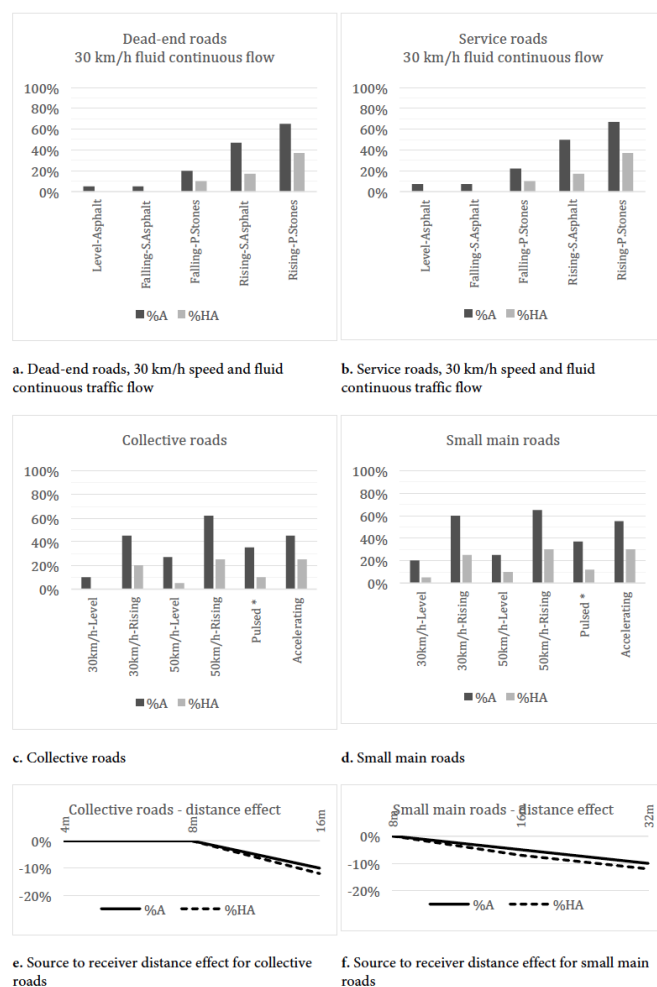


Figure 7. Traffic noise annoyance model for secondary roads in Besiktas area.

ten found to be annoying (Badino et al., 2012), were also investigated. Urban sound propagation filters were applied to main road sound clips, canyon effect filters were applied to secondary roads. Façade sound insulation filter was applied to all sound clips, except two main road sound clips were used for side hinged and bottom hinged open window façade insulation. Day, evening and night main road traffic flows were given in the sub-part 3. In sub-part 4, the effect of daily concentrating activity was investigated with a reading activity, while listening to main road noise.

5.2. Listening test results and annoyance model

Listening test results were statistically analyzed and were examined for factors effecting annoyance. Cronbach's alpha was computed for annoyance

questions and it proved that the survey had a good reliability by $\alpha = 0.704$.

Spearman Correlation results showed some moderate correlations. In terms of annoyance, women were more sleep disturbed and older people were more annoyed and more sleep disturbed. People whose bedrooms overlooked the street were more annoyed. In terms of activity annoyance, men were more annoyed while concentrating; older people and more educated people were more annoyed while resting.

Most annoying reported traffic elements were horns and motorcycles. Annoyance during daily activities were highest for resting and concentrating. These results on traffic elements and daily activities are similar to the results of the on-site survey (Badino et al., 2012).

Annoyance levels of respondents for each simulated traffic sound clip was analyzed to calculate percentage of people annoyed (%A) and percentage of people highly annoyed (%HA). Averages of verbal and numerical scale results were used. For easy expression and comprehension, some factors which effect annoyance in a similar way were united. Traffic which had pulsed decelerating flow had almost the same annoyance response as fluid continuous flow. So, pulsed decelerating flow is not mentioned in the results. Traffic on a falling slope had almost the same annoyance response as fluid continuous flow. So, falling slope is not mentioned in some of the results.

Figure 7 shows the %A and %HA results for secondary roads. For dead-end and service roads, on-site studies proved that traffic flow type is almost always fluid continuous and road surface may vary, smooth asphalt or paving stones. Rising slope and road surface (paving stones) were extremely effective in annoyance levels of dead-end and service roads, increasing annoyance up to 65%.

Figure 7 c and d show annoyance results for collective and small main roads. Traffic flow type, speed and slope varies on these road types and are important in assessing annoyance. Surfaces for these types of roads are always asphalt concrete. Falling slopes

are considered to have the same effect as fluid continuous flow. Rising slopes and accelerating flow provide the highest increase in annoyance levels. In cases where pulsed flow causes use of horns, %A increased by 15% and %HA increased by 10%.

Freitas et al. (2012) executed listening tests for road traffic noise, using different road surfaces, car speeds and traffic densities, and expressed the results in cumulative graphs. In that study, cobblestone pavement induced the highest rate of annoyance; dense asphalt and open asphalt rubber pavement annoyed people almost the same. Vehicle speed and traffic density were effective in determining annoyance.

Some roads were commonly used by courier motorcycles. Listening test results showed that, when 15% of the light vehicle traffic volume is replaced by motorcycles, 15% increase in %A and 5% increase in %HA was spotted. Nilsson (2007) found that annoyance increases when traffic noises have stronger low frequency content. Analysis of the sound clips showed that source-receiver distance and source characteristics are the main reasons of variation in the spectrum, therefore motorcycles and heavy vehicles recorded at the close range provided strong low frequency content. Paviotti et al. (2012) demonstrated that in motorcycle and scooter annoyance, masking by an increased general traffic is effective in reducing annoyance. In this study, masking effect was not specifically investigated but during sound clips of secondary road types, almost all the participants expressed their motorcycle annoyance verbally. No mention of motorcycles were made by the participants during main road sound clips.

Studies on-site and on maps showed that source receiver distance did not change significantly for dead-end and service roads. For collective and small main roads, the effects of source receiver distance were investigated for possible distances. The negative effects of distance may be added to traffic annoyance levels to reach a final annoyance level. Evaluation of canyon effect in secondary roads showed that it may increase %A by 10% and %HA by 5%.

Figure 8 shows the %A and %HA re-

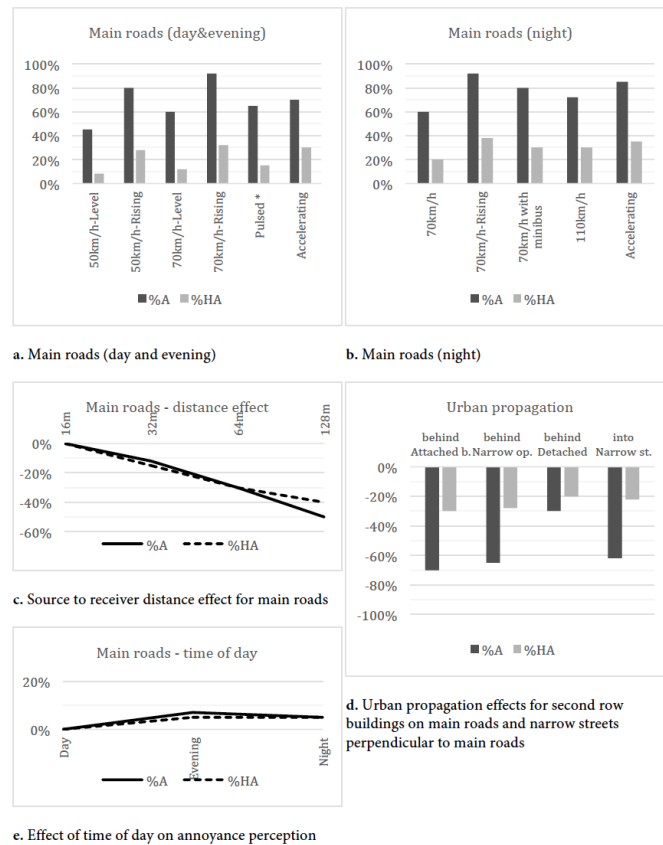


Figure 8. Traffic noise annoyance model for main roads in Besiktas area.

sults for main roads. Traffic flow type, speed and slope varies on these road types and are important in assessing annoyance. Surfaces for these types of roads are always asphalt concrete. Falling slopes are considered to have the same effect as fluid continuous flow. Rising slopes provide the highest increase in annoyance levels. In cases where pulsed flow causes use of horns, %A increased by 20% and %HA increased by 15%. Main road at night traffic was investigated in a similar way, but the respondents were asked to imagine they are listening to the sound clip a night. Traffic flow at night was also investigated including one minibus in 20 seconds, to take into account the time frame when minibuses work at night. The effect of the minibus on annoyance levels is quite valuable. The effects of source receiver distance were investigated for possible distances for the main roads. The negative effects of distance may be added to traffic annoyance levels to reach a final annoyance level.

Evaluation of urban propagation

effects for sound propagation from main road to second row of buildings through attached buildings, through detached buildings, through narrow openings, and from main road into perpendicular narrow streets showed substantial decreases in annoyance levels.

The Directive (EU Parliament and Council, 2002) defines noise indicator L_{den} as average levels during daytime, evening, and night-time, and applies a 5 dB penalty to noise in the evening and a 10 dB penalty to noise in the night. The effect of time was investigated, using one of the main road sound clips, three times, by asking the respondents how much they are annoyed during day time (07-19), evening time (19-23), and night time (23-07). The results showed insignificant differences, about 5% increase for evening and night.

6. Conclusion

In this study, listening tests were conducted for evaluating road traffic noise annoyance. Respondents living in a certain district listened to simulated traffic sounds which may be heard inside their homes and rated the annoyance they experienced while they imagined they were resting. The results showed the effect of traffic elements and road properties on road traffic noise annoyance.

As expected, traffic volume and speed have significant effects on annoyance. Falling slopes seem to have no influence, but rising slopes increase %A about 40% and %HA about 20%. Paving stones annoyed the respondents about 15% more than smooth asphalt road surfaces. Although pulsed continuous flow, with constantly starting and stopping sounds, proved to be more annoying than fluid continuous flow, pulsed accelerating is the most annoying flow type for all road types.

Addition of a single traffic element may cause influential changes in annoyance levels. Increase in motorcycle volume may increase %A by 15% and %HA by 5%. Use of horns in pulsed traffic may increase %A up to 20% and %HA up to 15%. Pass-by of a minibus in traffic may increase %A by 20% and %HA by 10%.

Settlement types and geometries can

cause critical changes in annoyance levels. For that reason, the listening test sound clips were designed according to the sound propagation properties in the district. In this settlement, source-receiver distances cause decreases up to 10% in secondary roads and up to 50% in main roads. Canyon effect in narrow streets increase %A by 10% and %HA by 5%. In this settlement, second row buildings behind attached buildings or behind a narrow opening have annoyance levels about 70% lower than open space conditions. The same condition behind detached buildings led to 30% lower annoyance levels. These effects would differ in different settlement geometries.

This model provides the opportunity to transform raw data (traffic, road and settlement) directly into annoyance. The information on the effects of traffic elements, road properties and settlement types on noise annoyance can easily be used for planning new areas or noise action plans. It is planned to develop a road traffic noise annoyance prediction model and validate the model by using the results of noise maps and socio-acoustic surveys in the same district. More models can be created for different settlements, traffic properties, social and economic conditions.

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Dinleme testleri ile karayolu trafiği gürültüsü rahatsızlığının modellenmesi

Gürültü rahatsızlığı çalışmaları, kişilerin gürültüye maruz kaldıklarında gösterdikleri tepkileri, kişilerin belirli bir tip çevresel gürültüye maruz kaldıklarında ne kadar rahatsız olduklarını sorgulayarak değerlendirir. Avrupa Parlamentosu ve Konseyi tarafından yayımlanan Çevresel Gürültü Yönetmeliği (2002/49/EC), Türkiye’de de ‘Çevresel Gürültünün Değerlendirilmesi ve Yönetimi Yönetmeliği’ olarak yayımlanmıştır. Bu yönetmeliklere göre gürültü rahatsızlığı, belirli bir bölgenin gürültü haritalarının ve bu bölgede yaşayan kişilerle yapılacak anketlerin karşılaştırılarak, doz-etki ilişkilerinin ortaya çıkartılması ile belirlenmelidir. Bu çalışma, gürültü rahatsızlığı konusunu derinlemesine incelemeyi ve modellemeyi amaçlamaktadır. Bu amaç doğrultusunda, karayolu trafiği gürültüsü rahatsızlık seviyelerini etkileyen faktörler incelenmekte ve dinleme testleri uygulanarak rahatsızlık modeli geliştirilmektedir. Bu çalışmada, trafik ses kayıtlarından oluşturulan ses parçaları, laboratuvar koşullarında katılımcılara dinletilerek dinleme testleri gerçekleştirilmiştir. Karayolu trafiği gürültüsü sesleri, her bir araç tipi için, farklı olası araç hızları, trafik akış tipleri, yol eğimi ve yol yüzeyleri için kaydedilmiştir. Kaydedilen araç sesleri, farklı yol tiplerinin seslerini oluşturmak amacıyla birleştirilmiştir. Sesin yayılım koşulları şehir içindeki çeşitli yerleşim tipleri için incelenmiş ve ses yayılım filtreleri oluşturularak ses parçalarına uygulanmıştır. Son olarak cephe ses yalıtım filtreleri uygulanmış ve ses parçaları ev içlerinde duyulan sesleri oluşturacak şekilde benzetim yapılmıştır. Laboratuvar ortamında, katılımcılardan kulaklıkla sesleri dinlemeleri ve dinlerken evlerinde dinlenmekte olduklarını hayal etmeleri istenmiştir. Rahatsızlıkları sözel ve sayısal ölçeklerle değerlendirilmiş ve sonuçlar analiz edilmiştir.

Farklı trafik koşullarını yansıtan gürültü rahatsızlığı modeli oluşturulmuştur.

Trafik hacmi ve araç hızı rahatsızlığı önemli ölçüde etkilemektedir. Yol eğiminin yokuş yukarı olması, gürültüden rahatsız olan kişi yüzdesini %40, çok rahatsız olan kişi yüzdesini %20 kadar arttırmaktadır. Yol yüzeyinin asfalt yerine taş döşenmesi kişileri yaklaşık olarak %15 daha fazla rahatsız etmiştir. Hızlanan trafik akışı en rahatsız edici akış tipidir. Trafikte motosiklet hacminin artması gürültüden rahatsız olan kişi yüzdesini %15, çok rahatsız olan kişi yüzdesini %5 kadar arttırabilmektedir. Trafikte kullanılan kornalar rahatsızlığı %20, çok rahatsız kişileri %15 kadar arttırabilmektedir. Bu alandaki yerleşimde, kanyon tipli sokaklar rahatsızlığı %10 arttırmaktadır. Ana yol ile arasında bitişik bina dizisi bulunan yerleşimlerde rahatsızlık %70 azalabilmekte, ayrık bina dizisi bulunuyorsa sadece %30 azaltabilmektedir.

Avrupa Birliği, gürültü rahatsızlığı çalışmalarında doz-etki ilişkilerini kurmak için veri toplama (trafik verisi, yol verisi, yerleşim verisi vs.), gürültü tahmin modelleri ile gürültü haritası oluşturma ve sosyo-akustik anketler gerçekleştirme ana adımlarını kullanmaktadır. Dinleme testleri ile oluşturulmuş bir çevresel gürültü rahatsızlığı modeli kullanmak ise gürültü rahatsızlığını doğrudan toplanan verilerden oluşturmayı sağlayacaktır. Bu durum çevresel gürültü kontrolü konusunun asıl amacı olan rahatsızlığı azaltmayı, kurulan doğrudan ilişki ile kolaylaştıracaktır. Bu tip rahatsızlık modelleri farklı ülkeler, farklı yerleşimler, farklı sosyal ve ekonomik bölgeler için oluşturulabilir. Karayolu gürültü rahatsızlığı modeli, trafik elemanlarının, yolların ve yerleşimlerin, gürültü rahatsızlığı üzerine etkilerini ortaya çıkartarak, yeni yerleşim alanlarının planlanmasında veya gürültü eylem planlarının oluşturulmasında yardımcı olacaktır.