Modeling of road traffic noise and traffic flow measures to reduce noise exposure in Antalya metropolitan municipality

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Abstract

Background Road traffic noise influencing directly public health in the modern cities is a growing problem in both developing and developed countries. The objective of this study was to model traffic-induced noise in Antalya province, validate the model with noise emission data, and to run the model for the noise preventive scenarios.

Methods In this study, modeling of traffic-induced noise was performed using SoundPLAN® software at Gazi Boulevard in the city of Antalya. Calculations were made according to NMPB-Routes 96, which have been accepted by environmental noise legislation of the European Union and Turkey. Fundamental data sets such as geographical, topographical and meteorological data, building information and population, traffic network, traffic volume and vehicle speed, and composition of types of vehicle were utilized for the development of noise prediction model. Eight preventive scenarios to reduce traffic-induced noise levels were simulated using the validated model considering traffic flow measures such as types of vehicles, vehicle speeds, types of road surface, redirecting portion of heavy vehicles to alternative routes and noise barrier usage.

Results Results showed that increase in heavy vehicle speeds in smooth road surface conditions caused more increase in exposures than that of light vehicle speed. It was highlighted that it would be appropriate to use porous road surface to reduce exposures on population on high-speed roads. Furthermore, the number of people that are exposed to noise is significantly reduced by precautions such as alternative routes for heavy vehicles and speed restriction. These precautions reduced noise exposures by 25.5–63.8%. The results showed that the usage of noise barrier at the alternative routes in case of porous asphalt road reduced population, dwellings, and area exposed to traffic noise which is greater than 75 dB(A) as 63.8, 40.5, and 60.0%, respectively.

Conclusion It could be concluded that the outcomes of the noise prediction models based on the generated scenarios could be used for the purpose of decision support system and could be helpful for decision-makers on the noise legislations.

Keywords Road traffic noise · Noise mapping · Traffic flow measures · Noise modeling software

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Introduction

Road traffic noise is a growing public health problem in both developing and developed countries. Nowadays, noise exposures that are related to road traffic directly influence public health in the modern cities [1]. The cost of health problems, which occurs due to exposures to road traffic noise are remarkably high. Protection of public health and reducing these costs are forcing public administrations to take measures in this regard. Acute exposure to noise may lead to temporary increase at the level of blood pressure and stress hormones. Furthermore, long-term exposure of noise may cause negative effect on human health [2]. Additionally, noise related to road traffic is associated with a large number of health problem. Numerous studies showed that the relationship among noise

levels, increase in high blood pressure, and myocardial infarction [3]. Excessive noise exposure is regarded as a serious problem by European Union. It has been reported that the cost of the human health problem associated with noise exposure in United Kingdom is 1.3 billion Euro. Sixty five percent of the people living in metropolitan city are exposed to day-evening-night equivalent sound level (L_{den}) of 60 dB(A), while more than 20% of people are also liable to night noise level (L_n) of >55 dB(A) [4]. In the year 2002, Environmental Noise Directive (END) by the European Parliament has been published for prevention, reduction and protection from noise which has the negative effects on human and public health [5]. Similarly, Regulation on Assessment and Management of Environmental Noise has been published by Turkish Ministry of Urbanization and Environment in 2010 [6]. Both regulations have imposed obligation on provisions of strategic noise mapping and including road traffic. In addition, action plans and necessary precautions to reduce noise reduction become law based on the results of the prepared noise map. Measures taken at the point of the noise mitigation is in the wide range. This diversity is emerged from engineering feasibility and cost of measures to be implemented. Analysis of the number of people affected by noise is of great importance in terms of the comparison of the costs of activities related to the prevention of noise. As a general rule, the number of people affected and the severity of adverse effects caused by the noise varies inversely. Starting from this point, noise reduction caused by road traffic in the European Union using the barrier is averagely estimated to be 8 dB(A) and the cost of barrier and annual maintenance are estimated to be approximately € 400/m² and € 77/m (per linear meter), respectively [7]. Similarly, the cost of the replacement of windows as examples of isolation measures to be implemented in households affected by noise is expected to 3000€ [8]. It can be concluded that the cost of activities to be implemented for noise reduction are not cheap as can be seen from the examples.

The primary goal of this paper was to (1) model traffic-induced noise in a main road connecting (Gazi Boulevard) to the west to the east side of Antalya City which is the most attractive tourism centre of Turkey, (2) validate the model with the measured traffic counting and noise emission data, and (3) simulate the validated model for traffic flow measures to reduce traffic-induced noise. Scenarios created in noise model can produce data for decision makers and planners.

Material and method

Noise model standard

There are two key components for the development of noise propagation models. One of them is the standard used in the calculation and the other is the modeling software which has

the user interface that make the calculations. In this study, NMPB Routes 96 Standard [9] was used for modeling purpose since this standard is recommended by END [5]. The noise regulations in Turkey is being harmonized with EU legislation. EU noise directive recommends the standard for road noise. For this reason, the NMPB Route 96 standard was used in this study. NMPB Routes 96 standard is based on noise propagation with a linear path concept. Several propagation paths exists between noise sources and receivers. Propagation paths are dependent on topography and obstacles located between noise sources and receivers. These propagation paths are related with long term noise levels ($L_{Ai,LT}$) as given in Eq. 1.

$$L_{Ai,LT} = 10 \times \log \left(p_i \times 10^{(0.1 \times L_{Ai,F})} + (1-p_i) \times 10^{(0.1 \times L_{Ai,H})} \right) \quad (1)$$

Where $L_{Ai,F}$ and $L_{Ai,H}$ are global assessment levels. “F” and “H” refers to suitable and homogeneous conditions, respectively. i is the source of noise. p_i is the possibility of the suitable conditions. $L_{Ai,F}$ and $L_{Ai,H}$ can be calculated based on (Eqs. 2 and 3).

$$L_{Ai,F} = L_{A,w} - A_{div} - A_{atm} - A_{bnd} - A_{grd,F} - A_{diff,F} \quad (2)$$

$$L_{Ai,H} = L_{A,w} - A_{div} - A_{atm} - A_{bnd} - A_{grd,H} - A_{diff,H} \quad (3)$$

Where $L_{A,w}$ is the sound power level, A_{div} is geometric propagation, A_{atm} is atmospherical absorption, A_{bnd} is boundary reduction, $A_{grd,F}$ is ground effect and A_{diff} is sound diffraction. A_{div} , A_{atm} , and A_{bnd} are used for each propagation path. Sound level is calculated for each sound propagation path that reaches from the source to the receiver. These calculations are performed separately for octave bands. Additionally, A_{grd} and A_{diff} are included in the calculation. Sound power level is calculated based on Eq. 4 considering sound energy flux.

$$L_{A,wi} = [(E_L + 10 \times \log Q_L) + (E_p + 10 \times \log Q_p)] + 20 + 10 \times \log(I_i) + R(j) \quad (4)$$

Where E_L and E_p are emission levels of light and heavy vehicle, respectively, Q is hourly vehicle flux, I_i is road length in meters and $R(j)$ is the normalized noise spectrum calculated according to EN 1793–3 standard [10] using the frequency of the sound emitted. “L” and “p” index refer to light and heavy vehicles.

In this study, $L_{Ai,LT}$ produced by the model can be adjusted to obtain L_d (daytime equivalent sound level), L_e (evening time equivalent sound level) and L_n (night time equivalent sound level) according to the END. Based on the Turkish standards of ISO 1996-2 [11], L_d , L_e , and L_n were defined at

the period of 07:00 am–19:00 pm, 19:00 pm–23:00 pm, and 23:00 pm–07:00 am, respectively. Additionally, L_{den} was calculated as follows:

$$L_{den} = 10 \times \log \frac{1}{24} \left(12 \times 10^{\frac{L_d}{10}} + 4 \times 10^{\frac{L_e+5}{10}} + 8 \times 10^{\frac{L_n+10}{10}} \right) \quad (5)$$

SoundPLAN® was used as environmental noise modeling program. The software consists of a series of sub-programs that work in coordination with each other. The implementation steps of the model were shown as a flowchart in Fig. 1.

Modeling study area

In this study, Gazi Boulevard in the city of Antalya as the study area was selected (Fig. 2). Fundamental data sets such as geospatial, topographical and meteorological data, building information and population in the study area, traffic network, traffic volume and vehicle speed, and composition of types of vehicle are required for the development of noise prediction model. Demographic data were gathered from Turkish Statistical Institute [12]. In this study, population statistics for 2014 was used. The appointment of the population data to buildings has been made considering the average population per square meters, i.e., building-areal population density, through dividing total population by total building area within the study area. Building area was multiplied by the population density to obtain the number of people in a building.

The study area modeled as continuous urban fabric (Fig. 2) including topography and building is a key element to affect the reflection and diffraction of noise propagation. In the continuous urban fabric, the height and geometry were used for the formation of data sets for buildings. The spot heights and the contour lines have been used to obtain the geospatial data and to create the digital elevation model. In addition, the roadway height profile and roadway geometry which were used as source data have been processed to geospatial data. CORINE (Coordination of Information on the Environment) land classification has been used in this study. Secondary data such as the number and location of traffic lighted intersections,

buildings, barriers, slopes and underpasses and overpasses information were obtained from Antalya Metropolitan Municipality. The data collected in this study brought together in the geospatial information system software (ArcMap software) was inputted to SoundPLAN® software where the model was built. Annual Average Daily Traffic (AADT) data were acquired from the Turkish General Directorate of Highways [13]. Meteorological data were obtained from publicly available sources. Suitable environmental conditions for the workspace (favorable conditions) were assumed to be 20 °C and the relative humidity of 70%. The dominant wind direction and intensity were inputted to the model.

Traffic counting

This study was conducted in the roadway that connects Antalya city (Turkey) to the west-east direction, which is quite a busy (Fig. 3). The road has buffer area of 22.15 km² consisting of 1.0 km (two semi-enclosed circles in 1 km diameter) in the direction of north and south with the length of 10 km. 206,848 persons in 41 neighborhood were included in the study. The annual average daily traffic of the roadway investigated by the year 2014 was 800,400 per day [14].

Vehicle counting was performed based on light and heavy vehicle categories from the traffic counting points given in Fig. 3 (Gazi 1, Gazi 2, Gazi 3, Gazi 4, Gazi 5 and Gazi 6) through cameras. Then, the camera was played in slow pace for traffic counting. While motorcycles, cars, and closed box vans (passenger) were classified as light vehicles, closed box vans (load), vans, trucks, trailers, minibuses, midibuses, buses, tractors, excavators, and caterpillar backhoe loaders were classified as heavy vehicles. In this study, the studied roadway was also modeled in software models. Special attention was paid for the traffic counting points that each segment has junction points at the beginning and at the end. Thus, the number of vehicles on each segment was checked at two points thereby making possible to determine the number of vehicles entering the road from each segment. Traffic counting was applied at daytime, evening, the time when the traffic flow peaked, and routine traffic flow time. In this study, night traffic counts were produced by using day and evening traffic counts

Fig. 1 The implementation steps of the model

Fig. 2 Continuous urban fabric of the study area

based on conversion factors described in the report published by the Turkish General Directorate of Highways in 2009 [13].

Measurement of noise emission

Validation of noise propagation models applied to the study area was performed by measured data at period of daytime, evening, and night. Road traffic noise levels were measured by using a Sound Level Meter (Svantek- SVAN 958), which can report 1 s to 24 h of continuous equivalent sound levels (Leq) in the range of 26–140 A-weighted decibels (dB(A)). Sound Level Meter was fixed to public buildings and measurements were carried out in side of roadway and holding the noise meter with the microphone tilted towards the roadway.

Noise levels were measured at the points shown in Fig. 3. Since all calculations in the model were performed at the height of 4 m above the ground based on END standards, the height of noise measurements was done at the same height. In order to prevent the effects of the noise coming from external sources on the noise caused by traffic, measurements were made at the points which is very close to the borders of the road. Traffic counts were made during peak hours of the time as possible in terms of traffic flow. Specifically, measurements were performed at 30 min before morning shifts and afternoon hours at the end of shifts for daytime period, at hours close to

daytime period and 1 h period after that for evening time period, and at hours close to evening time for night time period.

While noise emission from engine exists at the 30 cm above the ground in cars, emission caused by wheels assumed to be existed at 1 cm above the ground in the modeling program. Similarly, noise emission stemmed from engine in trucks or similar vehicles assumed to be at 75 cm above the ground and emission caused by wheels assumed to be the same as for cars. As for motorcycles, the single point was accepted as an emission source, which is 30 cm above the ground.

Scenarios

Eight different preventive scenarios with a base scenario to reduce traffic-induced noise using developed acoustic model and software were examined. The purpose of different scenarios is to gather data for decisions-makers. Table 1 presents variables for these scenarios with the base model. Base model (Scenario 1) was developed based on traffic flow data of 2014, the actual road geometry, and smooth asphalt as road surface. While constructing scenarios, types of vehicles, vehicle speed, types of road surface, redirecting portion of heavy vehicles to alternative routes and noise barrier usage were taken into

Fig. 3 Traffic counting and junction points in the study area

Table 1 Variables and situations in created scenarios

Scenarios	Heavy vehicle speed (km/h)	Light vehicle speed (km/h)	Types of road surface	Traffic flow data	Barrier status
1 (Base)	50	50	Smooth	2014	– / –
2	70	90	Smooth	2014	– / –
3	70	110	Smooth	2014	– / –
4	50	50	Porous	2014	– / –
5.1	70	90	Porous	2014	– / –
5.2	70	110	Porous	2014	– / –
6	50	50	Porous	(–) %80 HV	– / –
7	50	50	Porous	(–) %80 HV	+ / –
8	50	50	Porous	(–) %80 HV	+ / +

(–) %80 data of which 80% of heavy vehicles (HV) were redirected to use alternative routes in 2014

–/–: no barrier usage

+/–: barrier usage in main road

+/+ : barrier usage both in main road and alternative route

account. While the vehicles were classified as heavy and light, vehicle speeds used in the simulations were determined to be as 50, 70, 90, and 110 km/h. Smooth and porous road surface are commonly used in Turkey. Noise barriers, which is 3 m height, non-reflective, and flat, were used in the main and alternative routes in the model. In this study, the effect of administrative measures to ban usage of main roads by heavy vehicles were also tested. While Scenario (1–5.2) employs traffic flow data of 2014, Scenarios (6–7) uses data of which 80% of heavy vehicles are directed to use alternative routes.

Data availability We agree to share our data and materials.

Results and discussion

Model validation

The results of traffic counting based on heavy and light vehicles and traffic counting locations are given in Table 2. Validation of base model (Scenario-1) with noise levels predicted by SoundPLAN® was performed by measuring L_d , L_e , L_n and L_{den} values in the study area (Fig. 4). Regression analysis applied to the measured and simulated L_d , L_e , L_n , and L_{den} values yielded a linear regression equation with $R^2 = 0.710$, 0.749, 0.791, and 0.802, respectively. This indicates that there is a moderate correlation between the measured and simulated data. Based on these results, the highest R^2 value of 0.802 was determined for L_{den} values. Therefore, it was decided to use L_{den} for the evaluation of the results of model. Similarly, traffic forecasting model employing Federal Highway Administration (FHWA) using noise levels measured at a total of 72 points for 10 min measurements in three cities in United States in the period of 2011–2012 was developed. The

relationship in terms of R^2 between the model with measured results was determined to be in the range from 0.02 to 0.78 [1]. Additionally, the study conducted for the Antalya Province in 2015 showed that L_{den} produced from NMPB Routes 96 were closely related to L_{den} values obtained from 24-h measurements ($R^2 = 0.96$) [15]. In conclusion, the model prediction was reasonably accurate for L_{den} obtained from field data.

Model results

The impacts of types of vehicles, vehicle speed, redirecting portion of heavy vehicles to alternative routes, types of road surface, and noise barrier usage on population, dwellings, and area exposed to noise were investigated using developed model through Scenarios 2–8. The results of simulation are given in Table 3 with Fig. 5 for eight different scenarios. The developed model was used to determine the influence of scenarios on population and dwellings and area exposed to noise levels classified as $55 < L_{den} \leq 65$ dB(A) (Class-1), $65 < L_{den} \leq 75$ dB(A) (Class-2), and > 75 dB(A) (Class-3) as defined in both Turkish [6] and European Union [5] Legislations. Furthermore, each scenario was tabulated by comparing base scenario to examine the change occurred as percentage (Table 4). The change in population, dwellings, and area exposed to traffic noise in the modeled study area when compared to the base scenario at given noise level (dB(A)) was calculated as follows:

$$\Delta_p = \left(\frac{N_b - N_s}{N_b} \right) \times 100 \quad (6)$$

$$\Delta_d = \left(\frac{D_b - D_s}{D_b} \right) \times 100 \quad (7)$$

$$\Delta_a = \left(\frac{A_b - A_s}{A_b} \right) \times 100 \quad (8)$$

Table 2 The results of traffic counting based on types of vehicle and traffic counting locations

Traffic counting locations	The number of daily total vehicles	The number of light vehicles (number/h)			The number of heavy vehicles (number/h)		
		Day	Evening	Night	Day	Evening	Night
Aşık Veysel	41,900	2150	1092	116	680	465	98
Dumlupınar K1	52,288	2286	1196	296	1017	763	306
Dumlupınar K2	71,200	3060	1600	399	1432	1078	424
Fatih	35,304	1818	1118	420	271	237	182
Gazi 1	44,324	2832	1380	242	170	133	39
Gazi 2	6236	313	164	56	86	62	12
Gazi 3	42,308	2727	1329	221	146	115	36
Gazi 4	44,324	2832	1380	242	170	133	39
Gazi 5	46,412	2937	1477	251	194	143	44
Gazi 6	39,528	2484	1210	213	187	147	43
Gazi 7	18,388	944	708	216	146	115	36
Gazi 8	70,832	3054	1863	261	1542	835	350
Gazi 9	48,376	2512	1237	171	712	539	152
Hürriyet	48,376	2512	1237	171	712	539	152
Kızılırmak	34,404	1668	1126	408	333	240	208
Vatan	38,632	2304	1080	174	300	252	83
Yeni Hal	57,236	2180	1183	92	1557	1097	317
Yeşilırmak	32,052	1515	1007	408	336	255	191
Yıldırım Beyazıt	28,280	1452	893	355	217	190	135

Where Δ_p , Δ_d , and Δ_a (%) are the change in population (quantity), dwellings (quantity) and area (km^2),

respectively, exposed to traffic noise in the modeled study area when compared to the base scenario at given noise

Fig. 4 Comparison of the model results and field measurements

Table 3 The number of people and dwellings and area exposed to the noise levels based on scenarios

Scenarios	Area (km ²)			The number of dwellings			The number of people		
	Class-1 dB(A)	Class-2 dB(A)	Class-3 dB(A)	Class-1 dB(A)	Class-2 dB(A)	Class-3 dB(A)	Class-1 dB(A)	Class-2 dB(A)	Class-3 dB(A)
1 (Base)	13,975	5348	1771	20,700	6300	1000	138,600	46,800	8000
2	14,352	5633	1868	21,400	6600	1100	143,000	49,500	9000
3	14,596	5840	1937	21,800	6900	1200	145,800	51,400	9600
4	13,510	5043	1664	20,100	6000	1000	133,600	44,200	7600
5.1	13,528	5057	1681	20,200	6000	1000	134,500	44,700	7700
5.2	13,528	5057	1681	20,200	6000	1000	134,500	44,700	7700
6	12,312	4474	1175	15,900	4500	400	103,300	31,800	3300
7	11,963	4287	1155	15,200	4100	400	99,000	28,700	3300
8	11,794	4181	1054	14,500	4000	400	96,900	29,400	2900

level. N_b , D_b , and A_b are the number of people and dwellings and area, respectively, exposed to traffic noise when applied to the base scenario at given noise level and N_s , D_s , and A_s are the number of people and dwellings and area, respectively, exposed to traffic noise when applied to the scenarios at given noise levels. Since the best linear correlation was obtained for L_{den} value, the model results on L_{den} are given in Fig. 5 for different scenarios.

Impacts of vehicle speed

Vehicle speed is one of the most influential factors that affect the traffic related noise [16]. Regulation of vehicle speed in traffic depending on types of vehicle can reduce the traffic-induced noise [14]. The effects of vehicle speed on the number of people and dwellings and area exposed to the noise levels in the modeled area are presented in

Fig. 5 Road-traffic noise levels (L_{den}) at Gazi Boulevard in the city of Antalya as the study area based on scenarios

Table 4 Effects of scenarios on Δ_p , Δ_a , and Δ_d

Scenarios	Δ_p (%)			Δ_a (%)			Δ_d (%)		
	Class-1 dB(A)	Class-2 dB(A)	Class-3 dB(A)	Class-1 dB(A)	Class-2 dB(A)	Class-3 dB(A)	Class-1 dB(A)	Class-2 dB(A)	Class-3 dB(A)
1 (Base)	0.0	0.0	0.0	0	0	0	0	0	0
2	3.2	5.8	12.5	2.7	5.3	5.5	3.4	4.8	10.0
3	5.2	9.8	20.0	4.4	9.2	9.4	5.3	9.5	20.0
4	-3.6	-5.6	-5.0	-3.3	-5.7	-6.0	-2.9	-4.8	0.0
5.1	-3.0	-4.5	-3.8	-3.2	-5.4	-5.1	-2.4	-4.8	0.0
5.2	-3.0	-4.5	-3.8	-3.2	-5.4	-5.1	-2.4	-4.8	0.0
6	-25.5	-32.1	-58.8	-11.9	-16.3	-33.7	-23.2	-28.6	-60.0
7	-28.6	-38.7	-58.8	-14.4	-19.8	-34.8	-26.6	-34.9	-60.0
8	-30.1	-37.2	-63.8	-15.6	-21.8	-40.5	-30.0	-36.5	-60.0

Fig. 5 for Scenarios 1 through 5.2. Δ_p , Δ_a , and Δ_d are given in Table 4. The increase in vehicle speed in smooth road surface led to the increase in Δ_p , Δ_a , and Δ_d (Table 4 and Fig. 5). Regression analysis applied to Δ_p , Δ_a , and Δ_d as a function of vehicle speed yielded a linear relation with R^2 value of 0.999, 0.999 and 0.994, respectively. When vehicle speed increased from 90 to 110 km/h in Scenario 5.1 and 5.2 where porous road surface was used in model, it was observed that there was no change in Δ_p , Δ_a , and Δ_d . On the other hand, the marked increase in Δ_p , Δ_a , and Δ_d was recorded at the similar case with porous road surface application in Scenario 2 and 3. Therefore, it is evident that increase in heavy vehicle speed in smooth road surface conditions caused more increase in Δ_p , Δ_a , and Δ_d than that of light vehicle speed. When light and heavy vehicles speeds increased from 50 to 90 km/h and from 50 to 70 km/h, respectively, in Scenarios 1 and 2 having smooth road surface conditions, it was observed that Δ_p was 3.2, 5.8, and 12.5%; Δ_a was 2.7, 5.3, and 5.5; Δ_d was 3.4, 4.8, and 10.0 for Class-1, 2, and 3, respectively. On the other hand, with the similar speed conditions for Scenario 4 and 5.1, no or slight changes in Δ_p , Δ_a , and Δ_d were recorded for all classes with porous road surface. Similarly, Annecke et al. [17] reported that the magnitude of noise emission from vehicle rely on types and speed of vehicle. Increase in vehicle speed leads to an increase noise emission level. Andersen [18] investigated the effect of reduction in vehicle speed changes with 10 km/h intervals (driving with constant speed) on noise emission level. The results showed that for example, reduction in vehicle speed from 60 to 50 km/h caused 2.3 dB(A) and 1.7 dB(A) noise reduction for light and heavy vehicles, respectively. Bendtsen et al. [19] showed that for urban driving at speeds in the range of 30 to 60 km/h, a speed reduction of 10 km/h for light vehicles reduced the noise by up to 2 to 4 dB(A)

depending on the starting point. For heavy vehicles, the reduction potential was 2 to 3 dB(A).

Impacts of types of road surface

Minimum noise is believed to be associated with smoothness and an optimum porosity [20]. Seong et al. [16] stated that pavement type among several factors affect the amount of traffic noise. The influence of types of road surface on the number of people, dwellings and area exposed to the noise levels are presented in Fig. 5 and Table 4 for Scenarios 1, 3, 4, and 5.2. The results revealed that Scenario 3 with the smooth road surface increased Δ_p , Δ_a , and Δ_d up to 20, 10, and 20%, respectively. At the other side, Scenario 4 and 5.2 with porous road surface where low and high vehicle speeds are applied showed that reduction in Δ_p , Δ_a , and Δ_d was at low levels (<6%). Comparing Scenario 1 with 4 where light and heavy vehicles at low speed (50 km/h) are applied indicated that the change of road surface from smooth to porous reduced the exposures (Δ_p , Δ_a , and Δ_d) below 6% (Table 4). However, comparison of Scenario 3 with 5.2 where light and heavy vehicles at higher speeds (70 and 110 km/h, respectively) are applied showed that the change of road surface from smooth to porous remarkably reduced the exposures. This shows that replacing smooth surface with porous one is highly effective in reducing the level of exposures. In this context, it was understood that it would be appropriate to use porous road surface to reduce population exposures on high-speed roads. Bendtsen et al. [19] reported that on urban roads with speeds in the range from 40 to 60 km/h, noise reductions of 1 to 4 dB(A) can be achieved by using noise reducing thin layers or porous pavements. At higher speeds, the noise reducing potential for these pavements may be up to 6 dB(A) or even more. They added that usually, better noise reduction is obtained when noise reducing pavements is applied for light vehicles than heavy vehicles.

Impacts of directing alternative routes as traffic flow measures

Traffic calming schemes as traffic flow measures may cause heavy vehicles to choose other routes which is probably night-time bans on heavy vehicles [17] and it may reduce the traffic-induced noise. The effects of directing 80% of heavy vehicles to use alternative routes in the modeled area in 2014 are presented in Fig. 5 and Table 4. Scenario 6 with the porous road surface where low vehicles speed are applied resulted in up to 59, 34, and 60% reduction for Δ_p , Δ_a , and Δ_d , respectively, for the noise level of Class-3. Furthermore, when Scenario 4 and 6 with low vehicle speed (50 km/h) for both types of vehicles on porous roadway was compared, it was observed that directing 80% of heavy vehicles to use alternative routes reduced Δ_p , Δ_a , and Δ_d dramatically for the noise level of Class-1, Class-2, and Class-3. The level of exposure reduction was more prominent for the noise level of Class-3 for Δ_p , Δ_a , and Δ_d . Likewise, Annecke et al. [17] stated that the change in traffic volume affects the noise level. In the case of traffic composition, speed and driving patterns unchanged, the 50% reduction in traffic volume would cause a 3 dB(A) decrease in noise sound level regardless of the absolute number of vehicles. However, they indicated that it is rarely realistic to reduce traffic to an extent that significantly lessen noise levels on major roads. Bendtsen et al. [19] evaluated the effects of reduction in the amount of traffic on a road traffic management on noise emission. The results showed that a 10% reduction of traffic only leads to a 0.5 dB(A) noise decrease, whereas a 50% reduction decreases noise by 3 dB(A). On a road with 10% heavy vehicles, the noise is reduced by 1 to 2 dB(A) if all the heavy vehicles are removed.

Impacts of usage of noise barrier

Usage of noise barriers have substantial effects on the amount of traffic induced noise level [16, 21]. The influence of usage of noise barrier in the studied area on the number of people and dwellings and area exposed to the noise levels are presented in Fig. 5 and Table 4 for Scenarios 4, 6, 7, and 8. The results showed that in case of porous asphalt road, the usage of noise barrier at the alternative routes reduced Δ_p , Δ_a , and Δ_d up to 64, 40, and 60%, respectively. Additionally, while redirecting 80% of heavy vehicles to alternative routes had a very large impact on the reduction of exposures, barrier usage with the application of redirection of 80% of heavy vehicles to alternative routes had a partial impact on the low noise level (Class-1 and Class-2) and no pronounced effects on the high noise level of Class-3. Bendtsen et al. [19] indicated that conventional methods of traffic noise reduction like noise barriers provide a basic noise protection and are in some cases no longer sufficient. Maurer and Pöschl [22] pointed out that application of multifunctional noise barrier reduced the noise

Table 5 Assessment of the number of people exposed to noise due to scenarios in the modeled area

Scenarios	Noise categories (dB(A))			
	Class-1	Class-2	Class-3	Class-4
1	138,600	46,800	8000	13,448
2	143,000	49,500	9000	5348
3	145,800	51,400	9600	48
4	133,600	44,200	7600	21,448
5.1	134,500	44,700	7700	19,948
5.2	134,500	44,700	7700	19,948
6	103,300	31,800	3300	68,448
7	99,000	28,700	3300	75,848
8	96,900	29,400	2900	77,648

level at a rate of up to 6 dB(A) on condition that the speed limits of 100/80 km/h, 100/60 km/h or 80/60 km/h (for cars/trucks).

Evaluation of noise categories

Noise categories in terms of L_{den} were evaluated as Class-1, Class-2, and Class-3 as described previously. However, this may not always be sufficient classification for decision makers. Addition of “<55 dB(A)” (Class-4) categories is important to gain a new perspective for decision makers. Population exposed to noise level of Class-1, Class-2, Class-3, and Class-4 are presented in Table 5. No remarkable difference was detected when Scenario-2 was compared with 3 in terms of population exposed to Class-1, Class-2, and Class-3. However, population exposed to Class-4 noise level decreased from 5348 to 48. In other words, increase in light vehicle speed from 90 to 110 km/h led to a dramatic decrease in population exposed to noise level of Class-4. Therefore, Δ_p was calculated for the noise level of Class-4 changing with scenarios in Fig. 5. It can be concluded that redirecting 80% of heavy vehicles to alternative routes (Scenario 4 and 6) increased population exposed to Class-4 noise level. On the other hand, the usage of noise barrier had no significant effect on population exposed to Class-4 noise level (Scenario 6–7 and 6–8).

Conclusion

In this study, the sound propagation model was used to evaluate eight different noise preventive scenarios based on types of vehicle, types of road surface, vehicle speed, noise barrier applications and redirection portion of heavy vehicle as traffic flow measures on population and dwellings and area exposed to traffic-induced noise. Provided that the road surface is

smooth, as vehicle speed increased, the population, dwellings and area exposed to noise also increases. The increase in heavy vehicle speed compared to light vehicle speed led to more noise exposures. However, in the case of porous road surface, a 22% increase in light vehicles speed did not cause any change in exposures. In areas where noise levels and affected populations are high, it has been determined that the largest noise reduction measure is to reduce the proportion of heavy vehicles in traffic or to remove heavy vehicle traffic from buildings. With this application, reductions were achieved in noise exposure to population, area and dwellings with rates of up to 58.8, 33.7, and 60%, respectively. Applications of alternative route along the main roadway with usage of noise barrier did not significantly affect the exposures at the high noise levels, but affected at the low noise levels. In terms of classification of noise, it has been found that it is important to use noise category of “<55 dB(A)” as well as $55 < L_{den} \leq 65$ dB(A), $65 < L_{den} \leq 75$ dB(A), and > 75 dB(A) for decision makers. Furthermore, besides physical noise measures such as types of road surface and noise barrier applications, traffic flow measures to be taken by legislation such as speed limitation and types of vehicle limitation can also be taken into account.

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Compliance with ethical standards

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