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Evaluation of an urban tram noise impact: A mapping study in the Golden Horn

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ABSTRACT

Noise is often described as unwanted, disturbing, and health-threatening sounds. High levels of noise are generated from transport, and it is one of the common types of pollution that affects public health and comfort in modern built environments. The highways are the dominant mode of transport in many cities and the road traffic noise generally exceeds the recommended noise criteria. However, railways and trams could be significant contributors to the noise levels in urban areas. This study aims to investigate the noise exposure and potential sleep disturbance in settlements near the Eminönü-Alibeyköy tram line, including the impact of possible nighttime tram operations to address emerging public demand in the historical Golden Horn region. Current noise levels are measured in the field and compared to predictions generated by noise mapping software, which consider factors such as highways, rail systems, terrain, buildings, and other noise sources. The calculated noise levels are evaluated for each of the surrounding buildings based on the National Environmental Noise Code's specified limit values for the building's purpose and function. The results show that existing road traffic noise masks tram noise, with no statistically significant increase observed during operation. The study also evaluates the potential sleep disturbance that may occur if the tram operates during late night hours. The contribution of tram operations was predicted to increase the overall noise level of the acoustic environment by approximately 1 dBA and is classified as "None to Negligible" according to impact assessment criteria outlined in the Environmental Noise Measurement and Evaluation Guide of Türkiye.

Keywords: Noise Mapping, Tram Noise, Noise Evaluation, Sleep Disturbance

INTRODUCTION

Noise pollution is an unwelcome, disruptive, or potentially harmful sound that can affect public health and comfort in various ways around the world. Noise from transportation, such as roads, railways, and airports, is a common source of noise pollution in open areas. Traffic noise is a major source of noise pollution, as highways or major arterial roads are the dominant mode of transport in many cities. However, railways and trams could also be significant contributors to the noise levels in urban areas and have the potential to cause sleep disturbance. Tramway noise mapping has gained increasing attention in recent years due to the negative impact of tramway noise on the health and well-being of residents living near tramway lines.

The "Schall 03" methodology is recommended by the Directive for the calculation of tramway noise levels[1]. The Directive also mandates the periodic creation of strategic noise maps to provide an overview of noise levels in residential areas, and noise management action plans are developed to reduce unacceptable levels of noise exposure. The production and transmission of rolling noise generated by tramways can be influenced by several factors, including wheel design, track type, and the acoustic characteristics of the ground. Tramways use various types of tracks, such as conventional ballasted tracks, concrete slab tracks, and paved-in tracks for street running[2]. The various input parameters used in the calculations of tramway noise are discussed and the statistical analysis of the field measurements of the noise levels around tramways show that the type of permanent way, volume of traffic and the speed of tram has the most significant impact on the noise levels[3]. Integrating GIS and noise models automates the modeling process, deals with uncertainties, and applies standardized methods to study and quantify noise effects[4]. The tram noise emission on straight track sections using two different tram types is examined in Nantes, France. The study analyzes the effects of speed, tram type, and track type on noise source contributions and spectral features. Rolling noise is the primary noise source, and its correlation to speed and track type is significant. The noise spectral distribution and behavior are influenced by the type of tram, which is of secondary importance overall[5].

This study aims to investigate the noise exposure and potential sleep disturbance in settlements near the Eminönü-Alibeyköy tram line, including the impact of possible nighttime tram operations, in the historical Golden Horn region. This paper will present the measured and predicted noise levels, noise impact from Eminönü-Alibeyköy tram line compared to the National Environmental Noise Code's specified limit values and road traffic noise levels, and the potential sleep disturbance that may occur if the tram operates during late night hours.

Railway noise is composed by several components such as tram's electric motor, the rail-wheel interaction, braking and the announcements in stations. Although noise from electric motor is not dominant, the force applied against gravity increases with mass, resulting in more friction force and rail-wheel interaction. This leads to increased noise levels on the engine as the force required for movement also increases. Additionally, the perceived effect of noise levels is an important consideration.

The Eminönü-Alibeyköy Rail System Line project is in Istanbul and begins at the Eminönü coastal area, follows the Golden Horn coastline, and ends at Alibeyköy Bus Terminal. The line has 14 stations, and station names and tram line layout are given in Table 1 and Figure 1, respectively.

Table 1: EAT Hattı İstasyonları.

NO	Station	Chainage (km)
1	Eminönü	0+000
2	Küçükpazar	0+640

3	Cibali	1+130
4	Fener	1+130
5	Balat	2+680
6	Ayvansaray	3+470
7	Feshane	4+320
8	Eyüp Teleferik	4+920
9	Eyüp Devlet Hastanesi	5+870
10	Silahtarağa Mahallesi	6+910
11	Sakarya Mahallesi	7+540
12	Alibeyköy Merkez	8+140
13	Alibeyköy Metro	8+830
14	Alibeyköy Cep Otogarı	9+980

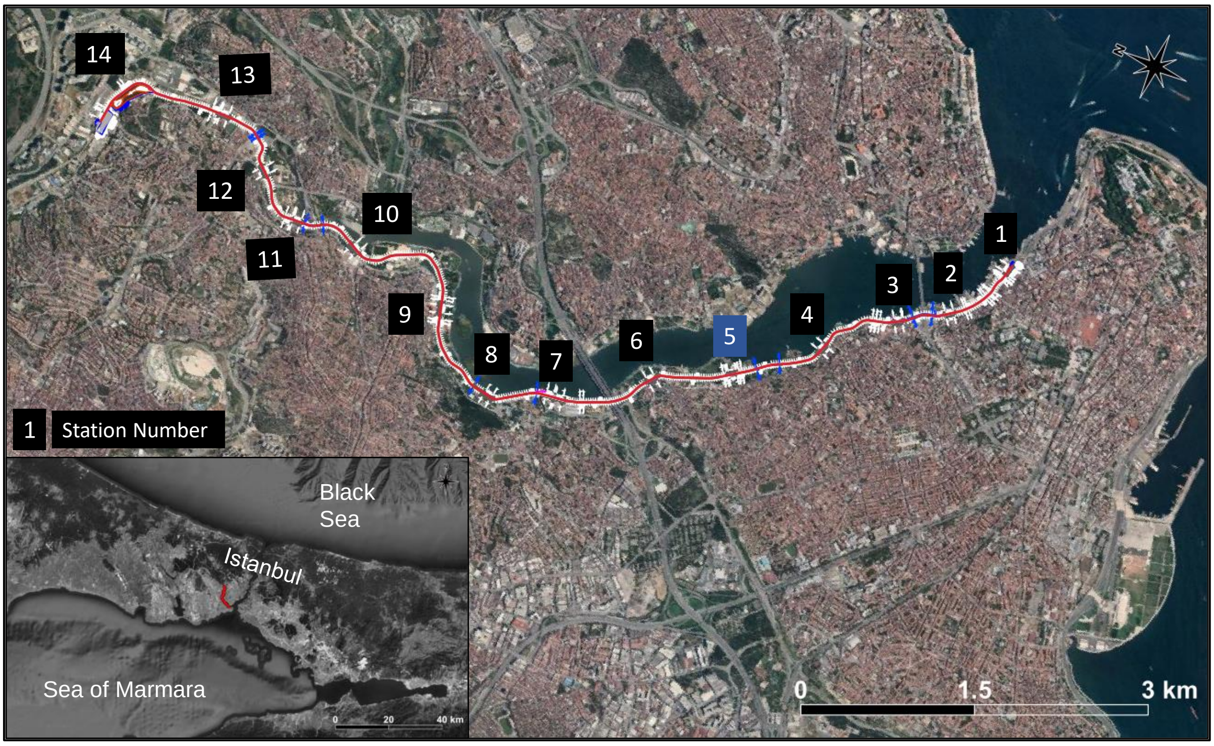


Figure 1. Eminönü – Alibeyköy Tram Line Layout

This study aims to determine the existing noise environment around Balat Station and model noise levels that occur during tram operation to predict marginal noise impact of The Eminönü-Alibeyköy Rail System Line project. Numerical simulation methods were used to calculate noise levels, considering the parameters of the arterial road lying parallel to the tram line, tram line, buildings, and vehicles to be used near the tram line. Environmental noise values were calculated for each floor of surrounding buildings, and it was checked whether the noise levels met the limit values specified in the Environmental Noise Evaluation and Management Regulation based on the purpose and function of the building.

MATERIALS AND METHODS

The common practice for transportation noise exposure assessment for noise and health research is three-dimensional noise propagation modelling with software complying with ISO TR 17534:2020 Acoustics — Software for the calculation of sound outdoors standard[6]. A three dimensional road and rail noise model considering terrain and atmosphere was built for Balat Station area by using IMMI, an environmental noise modelling software suite from IMMI Wolfel[7]. Noise modelling methodologies widely adopted in Europe and Turkiye have been prescribed under the Directive of 2002/49/EC[8].

Noise maps are typically created through a combination of acoustic measurements taken at critical points and computational methods that consider various conditions, such as sound propagation paths, distance attenuation, ground absorption, diffraction, absorption, and dispersive effects. Results are generated for each point to create a comprehensive map. Calculations can be made using the "Netherlands National Calculation Method RMR SRM II" and "ISO 9613-2" recommended by the "European Union Noise Directive (END)" and "Environmental Noise Assessment and Management Regulation of Turkiye (ENAMRT)."

Since the project area spans approximately 40 km2, calculations were made on a station basis to maximize equipment efficiency. The evaluation below focuses on Balat station, the starting point of the line.

Terrain Structure and GIS Data

To accurately map noise levels, it is essential to determine the project area, land elevations, and sound absorption coefficients, which are then entered into the software. The project area was divided into 0.25-0.4 km2 sections, accounting for potential disturbance areas. Figure 2.1 shows the 0.4 km2 study and calculation area selected for Balat station, including the topography of the land, surrounding structures, and nearby buildings.

As the project area has a similar land structure overall, a soil absorption coefficient of 0.4 was assigned. Digital maps of the area were obtained in 1/1000 and 1/5000 scales, including orthophotos and information provided by the contractor. Additionally, land use plans for the project were included in the computer simulation study (Figure 2 - Figure 15). The map layers contain data on government institutions, residences, businesses, and schools. Population data within the impact area was multiplied by the floor areas and number of floors in the project area to calculate the total gross living area. Population density data was assigned to approximately 200 buildings per station area, using average regional population density in the modeling studies.

Background Noise Measurements

The noise measurements were conducted in accordance with the TS 9315 ISO 1996-1 and TS ISO 1996-2 standards. During the noise measurements, omni-directional microphones were used, which can receive sound from all directions. The microphones were placed at a height of at least 1.5 meters from the ground. The meteorological windows specified in the ISO 1996-2 standard were evaluated to determine the suitability of noise for seasonal propagation, using parameters such as meteorological windows, wind speed, direction, and cloudiness in highway measurements, which are considered as sources. The measurements were evaluated according to M1, M2, M3, and M4 classifications. The radius of curvature (Rcur) and the distances between the source and the receiver were determined as the most important parameters when using meteorological windows. D/Rcur is the difference between the sound pressure level measured outdoors and the equivalent sound pressure level calculated indoors, and it is used to evaluate the impact of outdoor sound on indoor environments. The classifications specified in the ISO 1996-2 standard are presented in Table 2.

The air temperature during the measurements was between 15°C and 17°C. Based on these values, the meteorological window remains in classes between M2 and M4 during the measurements.

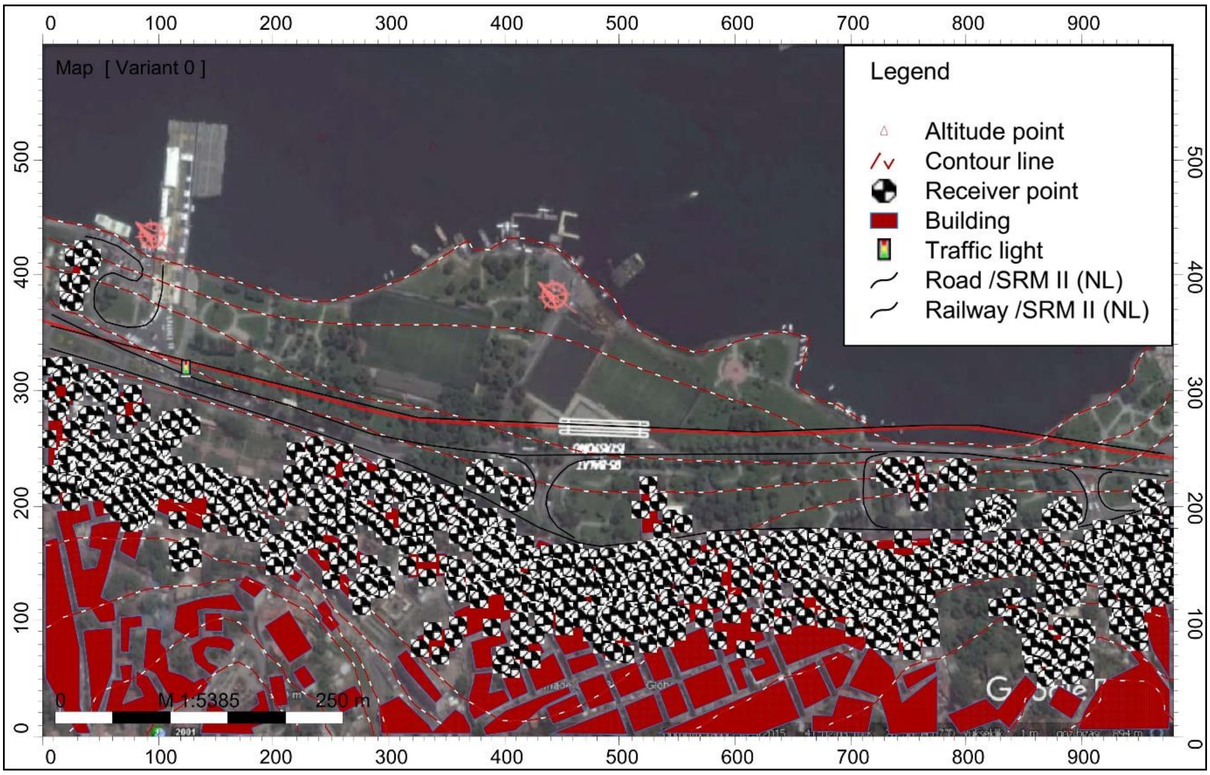


Figure 2: Noise Model - Balat Station

Table 2: Meteorological Classifications specified in ISO 1996-2.

Meteorological Window	D/Rcur Range	Representational Value	Attribution
M1	< -0,04	-0,08	Not preferred
M2	-0,04 … 0,04	0,00	Neutral
M3	0,04 … 0,12	0,08	Suitable
M4	> 0,12	0,16	Most suitable

Another factor that may affect the measurements is the influence of humans, animals, and other sources that occur outside the evaluated source. Since the measurements are made at 1-second intervals, the effects of these external sources can directly affect all measurement periods and can also occur instantaneously (such as human conversations, car horns, call to prayer, etc.). To prevent such situations, 1-minute intervals were selected. 15 Leq values were obtained in a 15-minute period.

Measurements were made in dBA units, at coordinates close to the station locations between 09:00 and 22:00 on December 16, 2017. The measurement point was selected to be near the highway and at a point where the effects of traffic noise could be compared with a simulation model. Throughout the project, measurements were taken in 3 points at each station point, for a total of 15 minutes. The location of the noise measurement studies for Balat Station and the obtained noise level graph are shown in Figure 3a and 3b. Statistical traffic noise levels are 81 LAeq, 82 La10, 77 LA50, 67 LA90 and 101 Lamax.

Methodology

Railway noise mapping is an essential tool for assessing the noise impact of railways on surrounding communities. There are several methods for railway noise mapping, including the RMR (Railway Noise Model), SRM II (SONBAT Railway Methodology II), and ISO 9613-2.

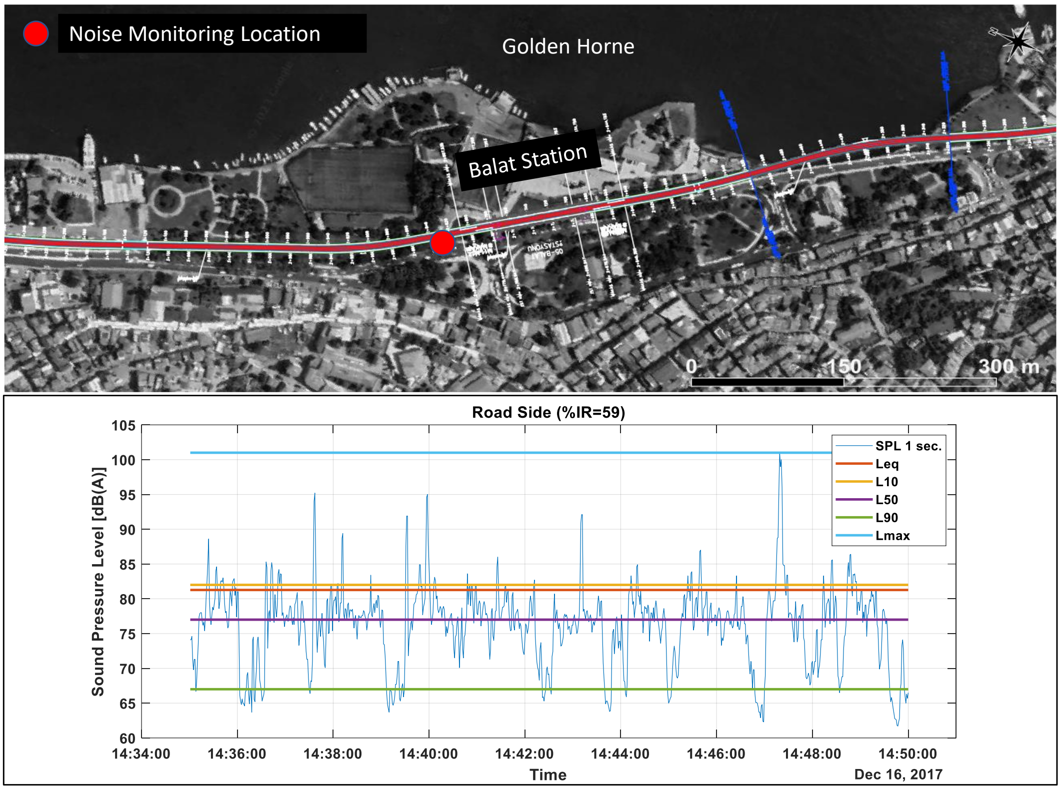


Figure 3: Noise measurement studies for Balat Station and the obtained noise level

RMR (Railway Noise Model) is a model developed by the United Kingdom Department of Transport for predicting the noise levels generated by railways. The model takes into account the train speed, track type, distance from the track, and other variables. RMR is a simplified method that can be used to assess the impact of railway noise in a relatively short period. However, it is not considered as accurate as other methods such as SRM II and ISO 9613-2. SRM II (SONBAT Railway Methodology II) is a methodology developed by the European Union for railway noise mapping. This method is more complex and takes into account a range of variables such as train speed, track type, curvature, and ground type. SRM II is a comprehensive method that provides a high level of accuracy, but it requires more data and computational power than RMR. ISO 9613-2 is an international standard that provides guidelines for noise prediction for rail, road, and air traffic. The standard takes into account a range of variables such as train speed, track type, curvature, ground type, and atmospheric conditions. It provides a high level of accuracy, but it is also more complex and requires more data and computational power than RMR.

It can be concluded that, RMR is a simple and quick method for assessing the impact of railway noise, while SRM II and ISO 9613-2 are more complex methods that provide a higher level of accuracy. The choice of method depends on the specific needs of the railway noise mapping project, the level of accuracy required, and the availability of data and computational resources.

In this study, noise maps were generated using the Wölfel IMMI 2017 noise simulation software, which was developed in compliance with the European Directive (END) 2002/49/EC of 25 June 2002. The software includes several transportation-based calculation methods, such as XPS 31-133/NMPB, RMR, SRM II, and ISO 9613-2 modules. The ISO 9613-2, XPS 31-133/NMPB, and SRM II Interim methods were also employed to generate the noise maps.

Land and building modeling is a critical aspect of noise mapping, as it helps to accurately represent the physical environment and noise sources in the simulation. Various approaches have been proposed for land and building modeling in noise mapping studies. One common method is to use GIS data to represent the topography and building characteristics of the area of interest. GIS data can include information such as building height, land use, and elevation, which are important factors that influence noise propagation.

In computer simulation studies, Geographic Information System (GIS) data at 1/1000 and 1/5000 scale were primarily used. These data include building and land elevation information, building classifications based on their intended use, and the number of floors. External sources provided population information that was not available in the GIS data and was entered into the simulation software. Maps were created based on the obtained information and classified according to the purpose of the buildings. This marks the completion of the first stage of the simulation study.

Once the terrain model, the first stage of computer simulation studies, was completed, noise sources such as highways (intersections and traffic lights), bus stops, and project buildings were entered into the noise simulation software. The second phase of the simulation study involved entering the planned speed and hourly numbers of trains that are expected to pass through the tram line during relevant periods, along with vehicle and brake category information from the SRM II Calculation method into the computer simulation.

In addition to noise measurement studies, vehicle counts were carried out to conduct detailed analyses. The noise model was entered separately from other sources, and background noise levels were determined. The obtained values were compared with the noise measurements performed.

The Republic of Turkey doesn't have its own noise calculation model for transportation noise like Serbia and Poland. However, Dutch SRM II noise calculation model is widely used according to directive of 2002/49/EC and TR/2004/IB/RN/02 in The Republic of Turkey [17]. Dutch RMR SRM II noise prediction model has three versions as 1996, 2006, 2009 and 2012 [18]. Netherlands uses the latest version 2012. However, the provisional method RMR96 SRM II proposed by the European Commission is outdated. RMR96 SRM II can be applicable on both railway and road traffics. [18]. RMR96 SRM II noise prediction model work on the octave bands such as median frequencies of 63, 125, 250, 500, 1000, 2000, 4000 and 8000 Hz and two different equations for each road and railway traffics. Road traffic prediction model in SRM II examines road vehicles in three different groups such as light vehicles (lv), medium vehicles (mv) and heavy vehicles (hv) [19]. In a same manner, trains are divided nine separate groups. A few of them are disc braked urban subway and rapid tram trains (category 7) and disc braked InterCity and slow trains (category 8) [20]. For a simplified calculation, overall A-weighted noise emission for trains is given Eq.1 below:

$$E = 10log\{\sum_{c=1}^{y} 10^{E_{nr,c}/10} + \sum_{c=1}^{y} 10^{E_{r,c}/10}\} \quad (1)$$

Where $E_{r,c}$ is emission term for braking trains, $E_{nr,c}$ is emission term for non-braking train. c and y are train category index and total number of categories respectively. Emission terms are determined from:

$$E_{nr,c} = a_c + b_c log v_c + 10 log Q_c + C_{b,c} \quad (2)$$

$$E_{r,c} = a_{r,c} + b_{r,c} log v_c + 10 log Q_{r,c} + C_{b,c} \quad (3)$$

Where Q_c , $Q_{r,c}$ and v_c are quantity of non-breaking trains, quantity of braking trains and average speed of trains in km/h respectively [20]. a and b are predefined constants given in [20].

The IMMI v2017 software, which is used for noise simulation studies, automatically performs some of the complex SRM II calculation steps after determining variables such as train type, number of trains passing per hour, and speed. The vehicle numbers and speeds reported by the Contractor for the project were entered into the software. The tram line was categorized as "Category 7," which includes many train categories, as per the calculation method (refer to Figure 44).

During the implementation of the project, the most intense operations are estimated to occur between 07:00-10:00 and 16:00-19:00. Therefore, all vehicles will make 20 trips per hour during the daytime period (07:00-19:00). During the night period, it is assumed that there will be six trips per hour on the entire line. The maximum speed of all vehicles in the project area is accepted as 50 km/h. Sample values entered into the noise simulation study are shown in the image below.

The road traffic noise equation follows a similar logic as the railway noise prediction. The corresponding equation in RMR96 SRM II is given below:

$$L_{Ei,m} = 10log\left(\frac{Q_m}{v_m}\right) + \alpha_{i,m} + \beta_{i,m}log\left(\frac{v_m}{v_{0,m}}\right) + C_{surface_{i,m}} + C_{H,m} \quad (4)$$

Where i and m are index for octave band and vehicle category respectively. Q, v, and v_0 are mean flow of vehicle per hour, mean speed in km/h and reference speed respectively. This model also contains correction constants such as $C_{surface}$ for road surface type and C_H for inclination of road. Alpha and beta are paremeters which determine the sound power level for vehicle categories. The constants are tabulated in [19].

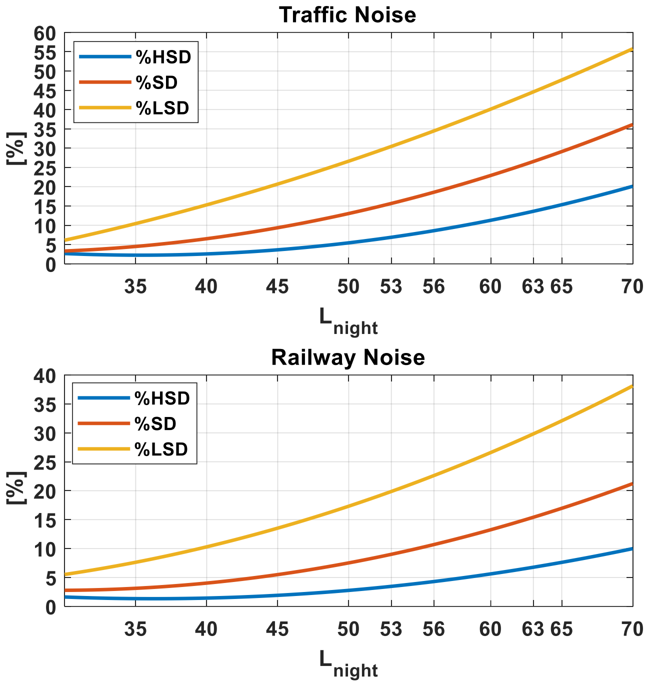
The second stage of noise simulation studies involves assigning noise values to the interior and exterior of the building. While the methods described above determine the Lp levels to be formed inside the building, indoor noise information alone does not provide sufficient data to create environmental noise maps. To determine the effect of sound pressure levels on the interior surfaces of the building on the receiver, additional calculations are necessary, including the reduction due to distance and other losses between the source and the receiver. However, these calculations are expected to match the equivalent noise level at the receiver and the noise levels found with the calculations that include other losses in the reduction factors.

These losses include reductions due to geometric deviation, atmospheric absorption, ground effect, and obstacles, which occur during sound propagation in the external environment, as specified in TS ISO 9613-2. Additionally, sound absorption of surfaces and reductions in transition losses, which occur during the passage of sound emitted from sound sources inside the building through building elements, as explained by the ISO 12354-4 and ISO 15712-4 standards, can also be included in the calculations. 10 dB transmission loss assuming open windows for hot summer night was conservatively assumed to predict internal noise level for sleeping areas.

With a sound transmission loss considering open windows (TL, Transmission Loss), the sound pressure level in interior of the building can be expressed using the following formula.

$$L_{p(interior)} = L_{p(exterior)} - TL$$

Sleep disturbed ratio for night hours determined by WHO is a helpful parameter to assess noise exposure on sleeping quality [40]. The adapted curves of percentage sleep disturbed for road and railway noise is given in Fig. 4 below. Sleep disturbance ratio is divided three different rates, high sleep disturbed (%HSD), sleep disturbed (%SD) and low sleep disturbed (%LSD). Curves from sleep disturbance are given Fig.4 below.



RESULTS

To model the situation before the construction and operation of the tram line, the existing conditions were considered. It was found that the main noise source was the existing highways, while there was no industrial facility along the estuary line which could be a significant source of noise. Other noise sources were deemed insignificant when considering the existing road traffic noise. Therefore, the current situation model was primarily based on road traffic noise.

The Balat station tram line was constructed at an elevation below 10 meters. Grid noise maps for the Balat station, indicating dBA levels for day and night, are provided in Figure 7 and Figure 8.

To analyze the scenario after the implementation of the tram line, the model incorporates the geometry of the tram line, the day and night schedules, the speed limits, and the superstructure parameters. For daytime operations, the tram is assumed to make one trip every two minutes, while for night-time operations, it is assumed to make one trip every five minutes. The maximum speed for the tram line is set at 60 km/h for the straight sections and 30 km/h for the curved sections. The model does not consider the announcement or any other instantaneous noise sources at the stations since they are not likely to cause significant changes in the Leq values. Like the previous situation, the model for the current situation preserves the existing road traffic while simulating the tram operations.

Upon analyzing the results of the noise simulation studies, it becomes apparent that the noise levels reaching structures near the tram line are at elevated levels in the present scenario. To provide a more comprehensive and comprehensible illustration, the structures in the Balat station region are presented as examples in Figures 9 and 10. It is observable that buildings located in proximity to the highway and particularly the junction points are the structures exposed to the highest noise levels.

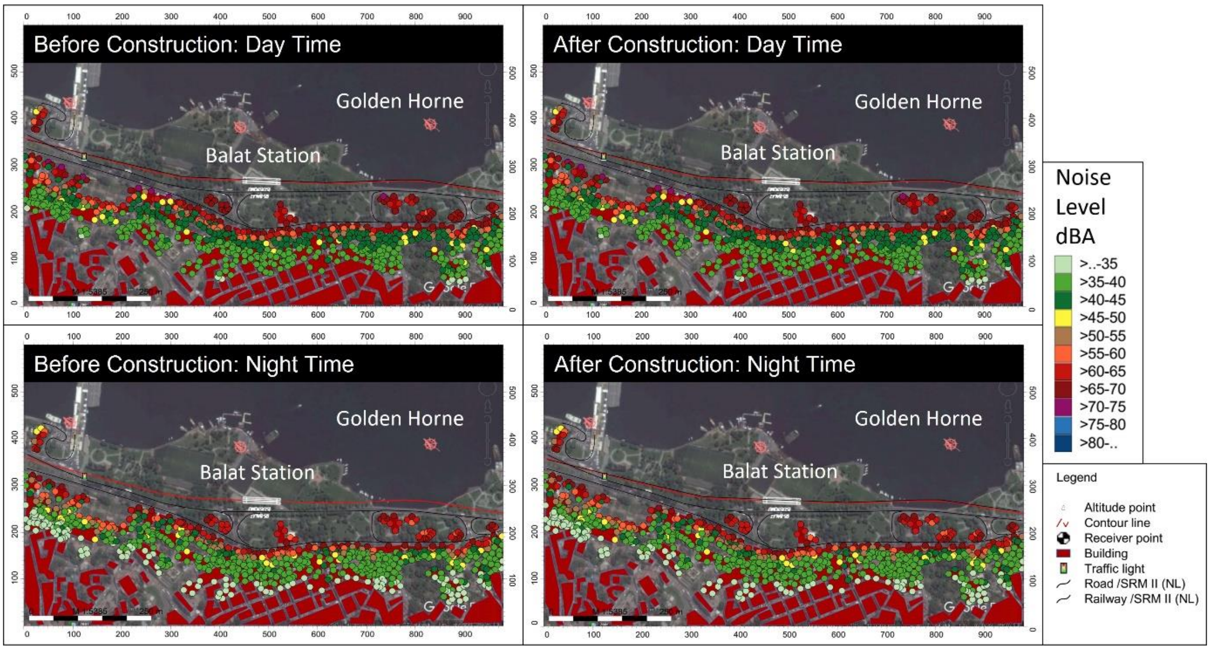


Figure 6: Balat station Buildings with the Highest Day time Exposure in the Balat Station Region

Table 4: Façade Sound Pressure Levels before Construction

Before the construction						
	minimum	maximum	average	± Sigma	q 0,1	q 0,9
Day	32	73	46	12	36	66
Night	30	70	43	12	33	63

Table 5: Façade Sound Pressure Levels after Construction

After the construction						
	minimum	maximum	average	± Sigma	q 0,1	q 0,9
Day	33	73	46	12	36	66
Night	30	70	43	12	33	63
Day (Tram only)	17	50	29	12	20	48
Night (Tram only)	14	44	26	12	17	43

The noise levels before the tram line was operational were modeled, and the average level was found to be 52.35 dBA in all examined areas. It is expected that the noise levels will increase by approximately 1 dBA after the tram line is put into operation. When comparing the measurement results of current road noise and the model results of the current situation, it is observed that the measurement values generally show 2-3 dBA higher results, possibly due to horn sounds from vehicles waiting at traffic lights, terrain, sensitivity in modeling, meteorology, and other factors.

Table 5 in the "Environmental Noise Measurement and Evaluation Guide" published by the Ministry of Environment and Urbanization summarizes the impact of the community on the change in noise level indicated in the chart above. Overall, the chart provides an overview of noise propagation for all daylight hours, helping to better understand the differences in noise level changes.

Table 6: Impact of Change in Noise Level.

Noise in Noise Level (dB)	Impact
0	None
3	Very little
3-5	Little

5-7	Intermediate
7-10	High
10-20	Very High

As depicted in the charts, the impact of the proposed tram line on noise levels falls under the category of "None to Very Little," based on the assessment criteria presented in the "Environmental Noise Measurement and Evaluation Guide," as the existing noise levels are anticipated to have a significant impact.

Table 7: Predicted Sleep Disturbance Levels before and after Construction

	Before the construction			**After the construction**		
Noise Source	**Road Noise Only**			**Road and Rail Noise**		
	maximum	**average**	**q 0,9**	**maximum**	**average**	**q 0,9**
Façade Noise Levels, $L_{night,}$	70	43	63	70	43	63
Indoor Noise Levels, $L_{night,}$	60	33	53	60	33	53
%HSD$_{Road}$	11.3	2.3	6.9	11.3	2.3	6.9
%SD$_{Road}$	22.9	3.9	15.6	22.9	3.9	15.6
%LSD$_{Road}$	40.1	8.7	30.4	40.1	8.7	30.4
%HSD$_{Rail}$	-	-	-	<3	<3	<3
%SD$_{Rail}$	-	-	-	5.2	<3	4.8
%LSD$_{Rail}$	-	-	-	12.8	4.2	12.2

In the section outlining the detailed simulation studies and data sources, it is noted that geographic information system data has been utilized to account for population. Accordingly, the impact of the tram line on the population has been analyzed and presented in Table 6.

DISCUSSION

Considering the field measurements and SRM II models in the literature; The SRM II calculation method can give different results from the measured values, since the rail wear, rail-wheel interaction, suspension effects can change in positions where the scissors, curves and speed are low. Due to the fact that the tram and rail systems have not yet been built within the scope of the project, it is evaluated that the noise levels of the rail systems in operation in the curves in previous similar studies may differ by 10-15 dBA in terms of the equivalent noise level (Leq) indicator compared to the model outputs. Although the tram crossings do not cause noise in the project in terms of equivalent noise level; The disturbance that may occur at the momentary crossings in the curve and switch areas can be estimated by adding the 10-15 dBA noise level to the results only during the train crossing.

In the current situation, it is seen that the noise levels are below the specified limit values of the Regulation on Evaluation and Management of Environmental Noise and if there is no significant increase in the existing road traffic after the tram line is put into operation, the increase in noise levels will be extremely limited and will remain below the specified limit values of the Regulation on Evaluation and Management of Environmental Noise.

CONCLUSION

In recent years, the significance of managing environmental noise has increased substantially, particularly due to the growth of populations and the expansion of transportation routes and industrial activities in new residential areas. Urban areas, in particular, experience high noise levels from road, air, and railway activities. To ensure accurate and effective noise simulation studies, scientific calculation methods must incorporate meticulous data, such as land structure, geographic information system data, population numbers, and traffic data. This study utilizes a numerical simulation method to model noise levels along the Eminönü-Alibeyköy tram line route and evaluate the effects of tram operation on the environment. However, the study does not consider the possible effects of changes in road traffic, land use and zoning plans, population densities, and housing use rates on environmental noise. The simulation results indicate that the existing road-borne noise masks the tram noise, resulting in no significant increase in noise levels. Furthermore, the expected noise increase of approximately 1 dBA after the tram line's operation is assessed as "None to Very Little" impact according to the "Environmental Noise Measurement and Evaluation Guide."

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