Field Study of the Noise Exposure Inside Running Metro Unit

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Abstract

The noise levels inside metro units are considered a significant problem that makes passengers suffer from severe damage, especially for those who use the metro periodically. This research evaluates the acoustic environment inside the metro car and studies factors affecting the noise levels inside metro units and developing models for estimate noise in the metro unit while moving between stations. Greater Cairo Metro (GCM) Line 1 has been selected as a case study. A sound level meter was used to measure the equivalent sound level in dBA and evaluate the noise inside metro units. The results indicate that the noise levels are unacceptable compared with the international noise exposure standards. The highest measured noise level inside metro units is 91.2 dBA. These unacceptable noise levels led to more investigation of factors that may affect noise levels inside metro units. Other data have been collected, such as the speed of the train and the track alignment details. The results showed that the noise increases with the increase of the train speed until the speed reaches a specific value, then it decreases depending on the maintenance status and the train type. In addition, the noise levels through curved underground tracks are higher than the levels along straight surface tracks by 18 dB(A).

Keywords: Metro; Noise Pollution; Environmental Noise; Speed; Horizontal Alignment.

1. Introduction

Metro is an essential component of the public transit system in urban facilities [1]. Following the practical urban progress of all countries, rail transit becomes a major urban transit mode in developed countries for its advantages such as mass transit capacity, safety and reliability, fast speed, and comfort. Metro is believed to be more environmentally friendly than other public transport modes. Also, it reduces the number of cars on the road, which in turn reduces the air pollution and traffic congestion caused by individual vehicles. For these advantages, big cities have a considerable scale of rail transit routes which have gradually become the first choice of transport tool by the majority of the citizens [2, 3]. Metro becomes the key point of urban transportation development strategy due to its social and economic properties and is regarded as the backbone of the urban transit system. Despite all the mentioned advantages, noise exposure due to transportation noise as railway and traffic noise has been reported to affect millions of people worldwide and has been related to various health-related issues [4, 5].

There is a lot of research and information about the noise impact on hearing health [6]. The World Health Organization (WHO) acknowledges environmental noise as one of the top environmental risks for health and wellbeing. Noise exposure can lead to various effects depending on noise level and duration [7]. Noise-induced

hearing loss is irreversible damage to the ears caused by exposure to high noise levels [8]. Exposure to high levels of noise has adverse effects in the short and long term. The long-term effects include damage to human health, as shown in Figure 1. It is feasible that repeated exposure to high noise levels at railway-centered stations may damage the hearing and circulatory systems of transit riders [9-11]. On the other hand, for the short-term effect, the high levels of noise on station platforms create an unpleasant environment for passengers waiting for their train. Riders have difficulty holding conversations with fellow passengers or on their phones. Research into annoyance caused by noise shows that people exposed to high noise levels have problems in concentration, making even silent activities, such as reading problems [12, 13]. However, little is known regarding this effect.
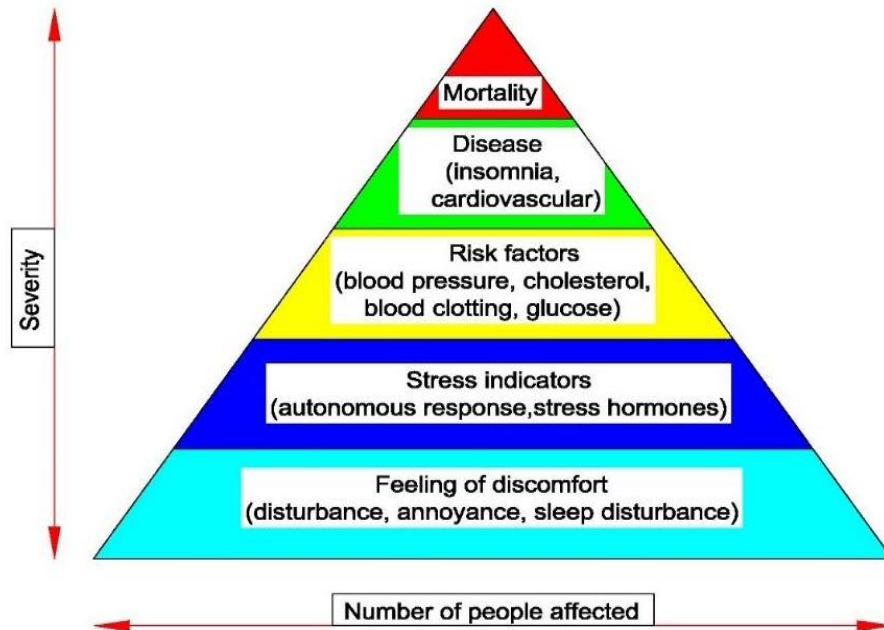

Figure 1. WHO pyramid of health effects of noise

Noise is considered an "unpleasant sound" [14]. Noise can be described in terms of three variables: amplitude (loud or soft), frequency (pitch), and time pattern (variability). These combine to create the intensity of the noise [15]. The most crucial noise source from railways is the rolling noise caused by wheel and rail vibrations induced at the wheel/rail contact, resulting from increased speed, braking system, and neglect of the periodic maintenance for rolling stock or rail elements [16]. There are other sources of railway noise: High alarms are used on platforms and while meeting another train in the opposite direction.

The railway car's noise can irritate passengers, especially when windows are open while the train moves inside the tunnel [17]. Noise can reach commuters inside the metro units in three ways [18]. Figure 2 shows the three ways noise can get commuters inside metro units: 1) External airborne sound and flow turbulence cause pressure fluctuations on the car shell, which transmits a portion to the interior. 2) structure-borne vibration is transmitted from wheels, motors, and under-car equipment along solid paths to interior surfaces, which vibrate and radiate noise inside.3) Airborne noise from the interior [19]. The primary parameter for the Sound Pressure level (SPL) is an A-weighted equivalent continuous sound pressure level or L_{Aeq} [20].
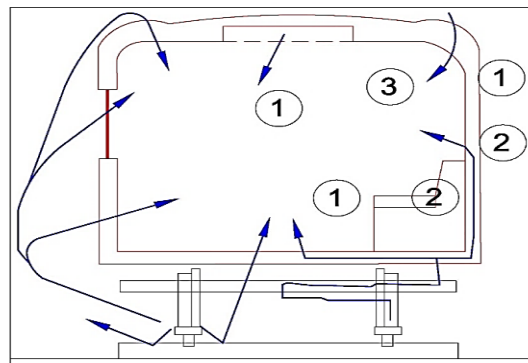

Figure 2. The three ways noise can reach commuters inside metro units

A study by M. A. Abdalla conducted a field survey to compare the statistical noise levels released from buses and some of the GCM Line1 stations and the Tram. Noise levels measured onboard exceeded the maximum allowed noise of 68 dB(A), where the equivalent continuous noise level L_{Aeq} measured lay within the range of 70-77.5 dB(A). The Max level L_{Amax} reached 90 dB(A) due to the use of alarm signals with a duration of 3 seconds. When the train is in the tunnel, the measured noise level onboard was more significant than the noise level at the surface (at-grade). This is caused by reflections of sound at the subway wall, which increase noise levels [21].

Another study conducted by Mostafa E Aly investigated GCM noise problems and related health hazards when the noise is measured on the station platform and inside metro units. A comparison has been conducted between different noise parameters and international criteria to show that noise levels in underground stations of the GCM line 2 are rejected [22]. The international standards used in comparisons were adopted by the US Department of Housing and Urban Development [23, 24]. Measurements of equivalent sound level L_{Aeq} in dB(A) are taken at each platform. L_{Amax} ranges from 87.8 to 102.5 dBA. The max value of L_{Amax} was shown between El-Gamaah and El-Behoos stations, and this is due to the tunnel entry. L_{99} is in the range of unacceptable according to the criteria adopted by USHUD and the noise pollution index (LNP), calculated from the measurements of noise levels measured in dBA.

A study by Shimokura and Soeta has indicated that the L_{Aeq} of train noise in underground stations is 5 dB higher than that of in-ground stations. Because the walls and the ceiling of the underground stations are regularly covered with reflective fire-resistant materials (e.g., steel or vitreous enamel panels), sound reflections and reverberations lead to an increase in train noise. The L_{Aeq} of train noise has been different by platform types. The L_{Aeq} of train noise on island platforms was 2.3 dB higher than that inside platform [25].

Another study by Shimokura and Soeta has indicated that the A-weighted sound pressure levels in the underground stations are 6.4 dB higher than that in the surface stations. For the surface stations, the averaged L_{Aeq} and IACC on the side platform are 3.3 dB larger and lower than those on island platforms. For the underground stations, the averaged L_{Aeq} on island platforms is 3.3 dB higher than that on side platforms when a train comes into the station. The L_{Aeq} at the entrance and exit ends of the platform are high when a train comes into and goes from the station [26].

Even though passengers take more time inside the metro units, it hardly could be found in the literature. The contributions of this study are to assess the noise levels inside metro units and develop new relations between noise levels and the speed of trains regardless the train's type. Moreover, the factors that may affect the noise levels are investigated.

2. Research Methodology

The methodology is divided into three parts. The first one discusses the workflow of the research. Then, the second one illustrates the needed data and the process of data collection. Finally, the third part describes the case study region.

2.1. Research Workflow

The workflow is depicted in Figure 3, where the measurements of noise levels have been made inside the units while traveling the units to evaluate the noise problem and to suggest solutions to the problem followed by the data analysis. Then, a comparison between Sound Pressure Level (SPL) inside the metro units between stations is conducted with the international standards of noise exposure. Also, factors (train speed, horizontal and vertical geometry, the type of train, tunnel, or surface stations) that may have noise effects have been tested.
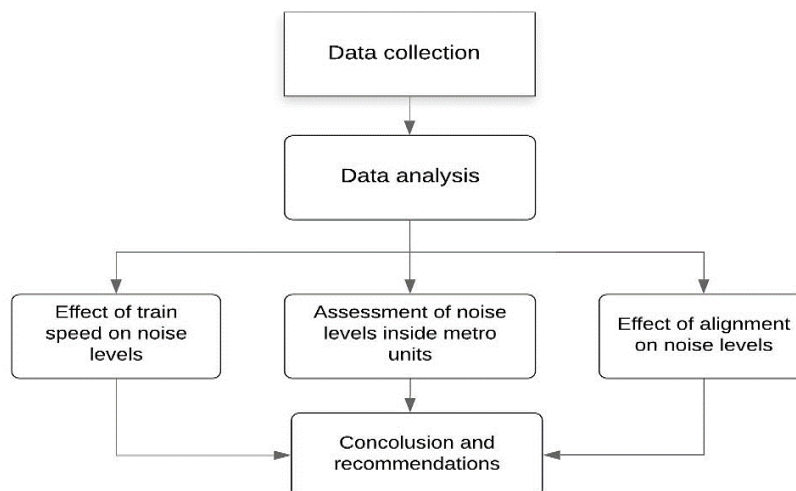
Figure 3. Research workflow

2.2. Data Collection

Three datasets were collected for this study, including sound level measurements, train speed data, and alignment. The first dataset was the measurements of the equivalent sound level in dBA, Leq, which have been made inside the metro units between line 1 stations starting from Marg to Ain Helwan station for the three-train type during off-peak hours to avoid commuter noise. These data were crucial in noise assessment in Line 1 and to conduct a comparison with the international standards of noise exposure. For this dataset, the measurements of the equivalent sound level in dBA, Leq, which has been made inside the metro units between line1 stations sound level meter tool has been used. A sound level meter is used for sound measurements. It is generally a handheld instrument with a microphone. The best type of microphone for sound level meters is the condenser microphone, which combines precision with stability and reliability. The diaphragm of the microphone responds to changes in air pressure caused by sound waves. That is why the instrument is sometimes referred to as an SPL Meter. In this study, the data has been collected using Sound Level Meter UT352.

The speed of trains between the stations was measured using the Androsensor mobile application. This type of data was used to test the effect of the train speed on the noise level. Finally, the geometrical alignment of Line 1 was used to study the impact of the curved track and type of station (underground or surface) on the noise level. Figure (4a) shows the GCM network, while Figure (4b) focuses on the study area.
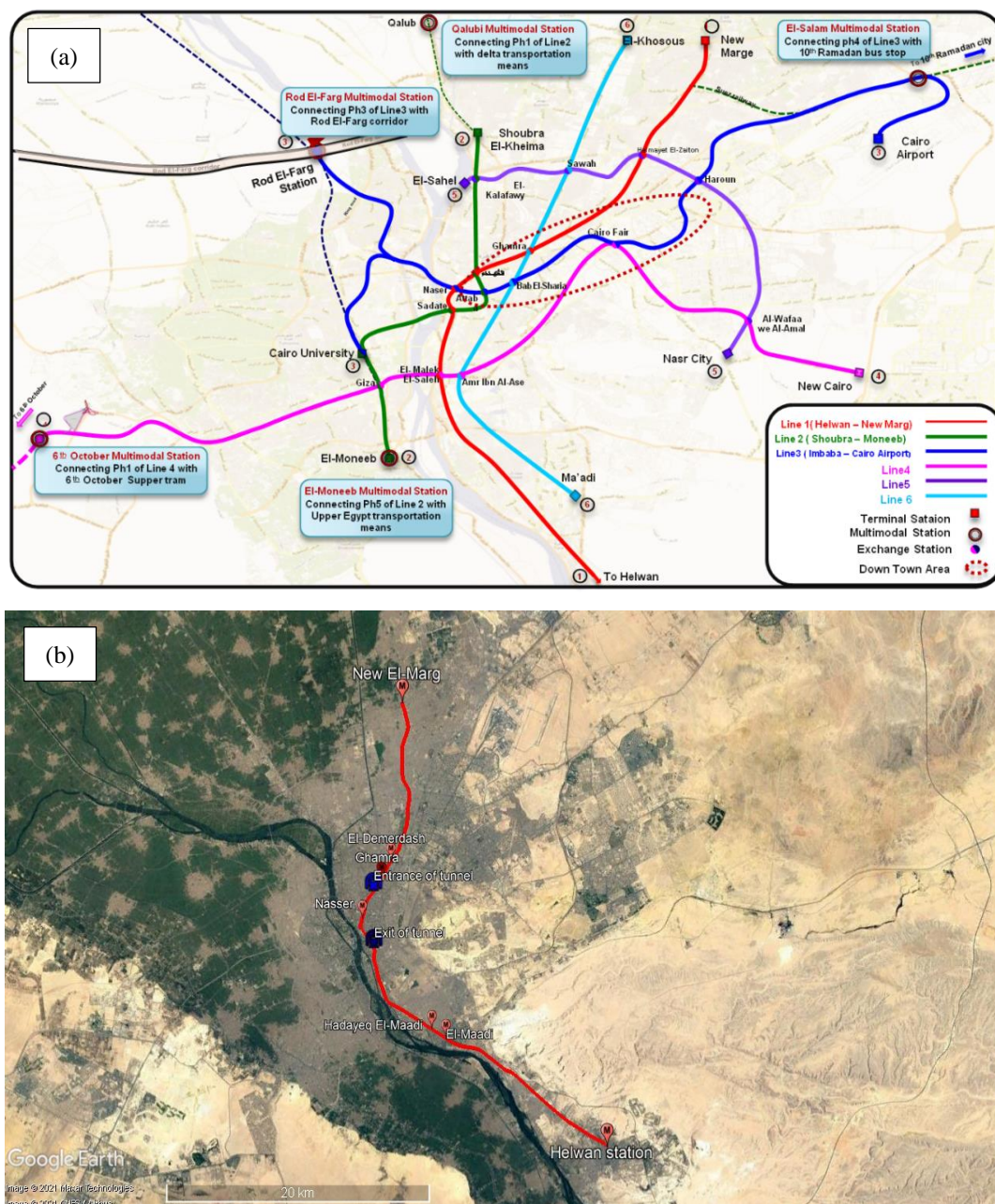

Figure 4. (a) Greater Cairo Metro networks; (b) Alignment of line 1 in Greater Cairo Metro

2.3. Noise-speed Estimation Model Development

Linear regression is a common simple modeling technique that has been used in all fields of science and engineering. Here, this technique is used, and the models were validated by the R-squared and the Mean Absolute Percentage Error (MAPE) as Goodness of Fit measures (GOF).

3. Data Description

Due to the variation in the type of rolling stock in GCM, three types were classified for data measuring. Table 1 shows the specification of these three types. For each type, SPL has been recorded using a sound level meter along line1 inside the metro units as mentioned previously. Table 2 shows a sample of the Min, Max, and Mean measured SPL along line 1 inside metro units for type C.

Table 1. Specification of rolling stocks in GCM line 1

	Type of rolling stock	Operating year	Braking system	Ventilation system
Type A	TOSHIBA KINKI SHARYO MADE BY AOI SEMAF	30 units: 1996-1997 39 Units: 2001-2009	1.Pneumatic Brake 2. Regenerative Brake with dynamic resistor	Spider fans 9-11 fans per car
Type B	ALSTHOM-ATLANTIQUE (TCO) ANF INDUSTRIE	52 units: 1981-1982 47 units:1988-1989	1. Pneumatic Brake 2. Regenerative Brake with dynamic resistor	Normal fans 13 fans per car
Type C	HYNDAI ROTEM (MFG by A.O.I-SEMAF 2015)	60 units: 2015-2016	1. Pneumatic Brake 2. Regenerative Brake with dynamic resistor	Air conditioning 2 AIRCON units per car

Table 2. A sample of the Min, Max, and Mean measured SPL (dBA) along line 1 inside metro units for type C

From station	To station	Min SPL	Max SPL	Mean SPL
Saray El-Qobaa	Hammamat El-Qobaa	61.05	80.05	69.72
Hammamat El-Qobaa	Kobry El-Qobaa	62.49	86.31	72.46
Kobry El-Qobaa	Manshiet El-Sadr	61.97	85.55	71.57
Manshiet El-Sadr	El-Demerdash	60.03	80.24	72.92
El-Demerdash	Ghamra	61.04	82.38	72.92
Ghamra	Entrance of Tunnels	62.34	81.47	74.52
Entrance of Tunnels	El-Shadaa	60.90	83.92	72.57
El-Shadaa	Orabi	61.85	85.83	73.30
Orabi	Nasser	61.02	82.53	73.14
Nasser	Sadat	60.88	87.21	74.65
Sadat	Saad Zaghloul	61.52	84.51	73.16
Saad Zaghloul	Exit of tunnel	65.12	83.87	75.40
Exit of tunnel	Sayyeda Zeinab	60.58	76.93	67.40

3.1. Determination and Assessment of Noise Inside the Metro Units

For the noise determination and evaluation, L_{Aeq}, L_{Amax}, LNP, and L_{99} have been calculated and then compared with the international standards of noise exposure shown in Table 3. L_{Aeq}, L_{Amax}, LNP, and L_{99} can be defined as follows:

L_{Aeq}: A-weighted equivalent continuous sound pressure level during a single noise event, Leq can be described mathematically by the following equation [27]:

$$Leq = 10log_{10}\left(\frac{1}{T_M}\int_Q^{T_M}\left(\frac{P(t)}{P_0}\right)^2 dt\right) \tag{1}$$

Where Leq is the equivalent continuous linear weighted sound pressure level re 20µPa, determined over a measured time interval Tm (sec); P(t) is the instantaneous sound pressure of the sound signal; P0 is the reference sound pressure of 20µPa; L_{Amax}: maximum sound pressure level during a single noise event; LNP: the noise pollution index that considers the deviation of the readings from the mean. It can be calculated from Equation 2 [28].

$$LNP = L_{Aeq} + 2.56\,\sigma \tag{2}$$

Where; σ = the standard deviation of the readings; L_{99}: is the background noise level, which represents mostly the lowest noise level during a single noise event (i.e., L_{99} represents the noise level exceeded for 99% of the measurement period).

Table 3. US. Department of Housing and Urban Development (USHUD) criteria for L$_{Amax}$, L$_{99}$, and LNP

Parameter	Limits dB(A)	Status
	L$_{Amax}$ < 63.5	Clearly acceptable
	63.5 < L$_{Amax}$ < 73.5	Normally acceptable
L$_{Amax}$	73.5 < L$_{Amax}$ < 86	Normally unacceptable
	L$_{Amax}$ > 86	Clearly unacceptable
	L$_{99}$ < 35	Clearly acceptable
	35 < L$_{99}$ < 53	Normally acceptable
L$_{99}$	53 < L$_{99}$ < 68	Normally unacceptable
	L$_{99}$ > 68	Clearly unacceptable
	LNP < 68	Clearly acceptable
	68 < LNP < 73	Normally acceptable
LNP	73 < LNP < 88	Normally unacceptable
	LNP > 88	Clearly unacceptable

3.2. Effect of Speed

The second objective of this research is to study the effect of train speeds as a crucial parameter affecting the noise level. For the three types, the measured SPL and train speed between two surface stations with no curved track was recorded. The purpose of that is to avoid the noise produced due to horizontal alignment and to the amplification of noise through tunnels. So, the selected data for this issue were taken between Hadayaq El-Maadi and Maadi stations. The distance between these two stations is 1.25 km. Figure 5 shows the chosen track between Hadayaq El-Maadi and Maadi stations for a speed noise study. Also, the speed profile has been divided into two parts; the acceleration part and the deceleration part. The purpose of this division is to avoid the noise produced from braking as its effect takes place during deceleration.

Figure 5. Selected track between Hadayaq El-Maadi and Maadi stations for a speed noise study

3.3. The Effect of Horizontal Alignment and Station Types on Noise

Finally, the third objective of this research is studying the effect of horizontal alignment and station types (surface or underground) on noise levels. To study these two parameters, the following measurements were taken into consideration to select the data suitable for this issue:

- Noise levels between two surface stations without any horizontal curves;
- Noise levels between two surface stations with horizontal curves;
- Noise levels between two underground stations without any horizontal curves;
- Noise levels between two underground stations with horizontal curves;

Table 4 shows more details for the selected tracks.

Table 4. Data concerning the selected tracks in studying the effect of horizontal alignment and station types

|	Surface track		Underground	
	Straight track	**Curved track**	**Straight track**	**Curved track**
From station	Hadayeq El-Maadi	El-Demerdash	Orabi	Nasser
To station	El-Maadi	Ghamra	Nasser	Sadat
Radius (m)	-	1100	-	298
Super elevation(mm)	-	61	-	140
Track length (m)	1250	1130	530	700

4. Results

4.1. Assessment of Noise Inside the Metro Units

Figure 6 shows the maximum noise level for the three types along line 1 compared with the international standards of maximum noise exposure. The following can be noticed from this figure:
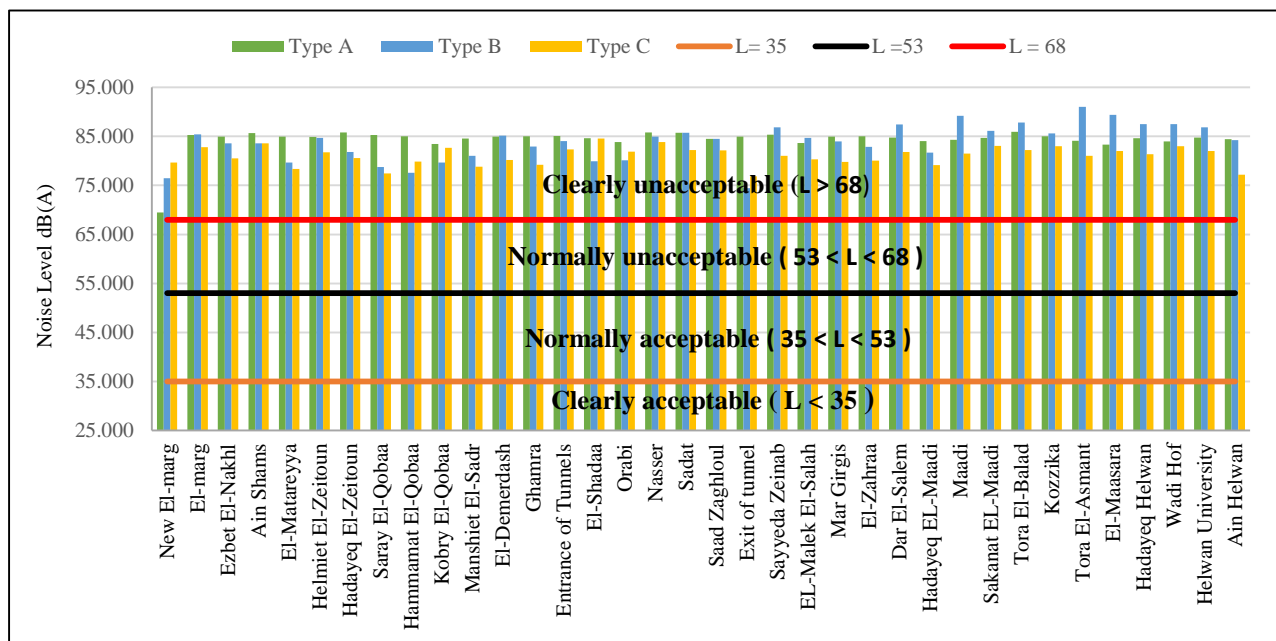
- For type A, the lowest and highest L_{Amax} were 78.24 between New El-Marg and El-Marg stations, and 86.65 between Entrance of Tunnels and El-Shadaa station, respectively;

- For type B, the lowest and highest L_{Amax} were 78.07 between New El-Marg and El-Marg stations, and 92.09 between Hadayeq Helwan and Wadi Hof stations, respectively;

- For type C, the lowest and highest L_{Amax} were 76.93 between Exit of the tunnel and Sayyeda Zeinab stations, and 88.49 between El-Matareyya and Helmet El-Zeitoun stations, respectively;

- All the measured L_{Amax} for the three types through Line 1 lie in a range between 76.92 and 92.08, which is unacceptable based on Table 3;

- Type B was the worst type in terms of L_{Amax} as it exceeds 86.00 dBA, which is clearly unacceptable;

- Type A was better than type B, but the recorded L_{Amax} exceed 86.00 dBA, which is clearly unacceptable. Also, it can be noticed that there is no large fluctuation in the recorded L_{Amax};

- Type C was the best in terms of LAmax.

Figure 7 shows the Background noise index (L_{99}) for the three types along line 1 compared with the international standards. The following can be noticed from this figure:

- For type A, the lowest and highest L_{99} were 69.47 between New El-Marg and El-Marg stations 85.92 between Nasser and Sadat stations, respectively;

- For type B, the lowest and highest L_{99} were 74.43 between Exit of the tunnel and Sayyeda Zeinab stations and 91.03 between Tora El-Asmant and El-Maasra stations, respectively;

- For type C, the lowest and highest L_{99} were 76.85 between the Exit of the tunnel and Sayyeda Zeinab stations and 84.59 between El-Shadaa and Orabi stations, respectively;

- All the measured L_{99} for the three types through Line 1 lie in the range between 69.472 and 91.03, which are unacceptable based on Table 3;

- Type B was the worst type in terms of L_{99} as it exceeds 68.00 dBA, which is unacceptable;

- Type A was better than type B, but the recorded L_{99} exceed 68.00 dBA, which is unacceptable. Also, it can be noticed there is no large fluctuation in the recorded L_{99};

- Type C was the best in terms of L_{99}.
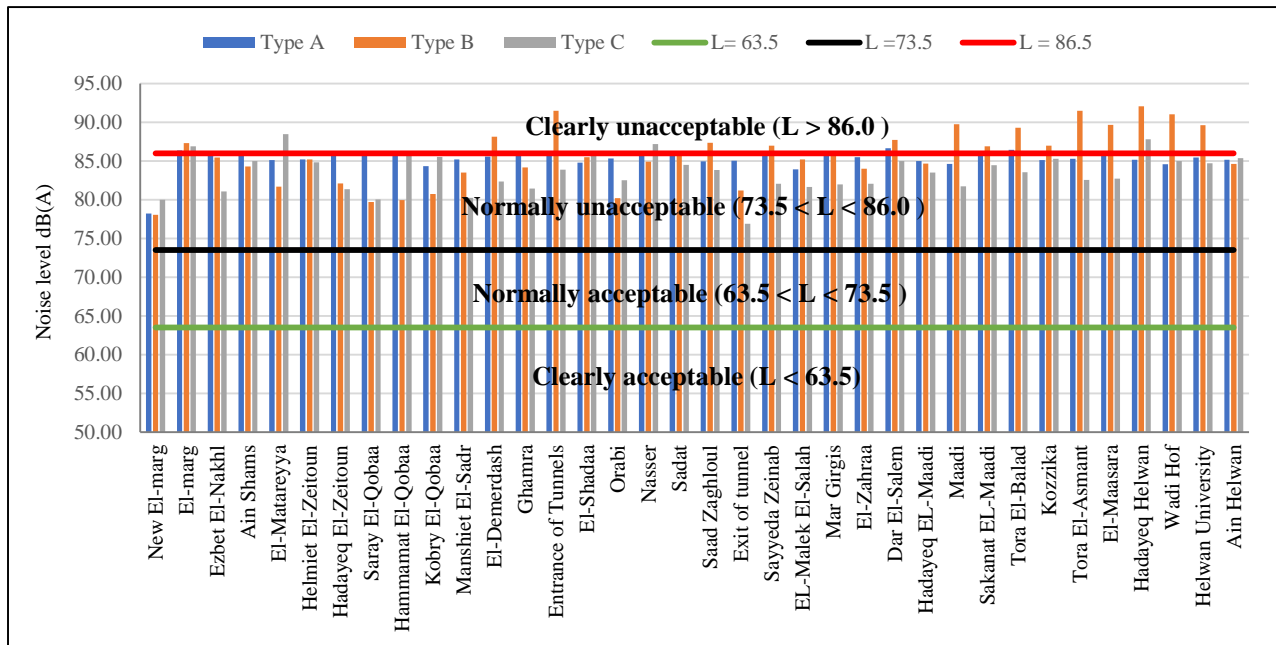
Figure 6. Maximum noise level for the three types along line 1 inside the metro unit compared with the international standards of maximum noise exposure

Figure 7. Background noise index (L99) for the three types along line 1 inside the metro unit compared with the international standards of Background noise index

Figure 8 shows the Noise Pollution index (LNP) for the three types along line 1 compared with the international standards. The following can be noticed from this figure:

- For type A, the lowest and highest LNP was 79.35 between Ghamra station and Entrance of tunnel 89.93 between Entrance of Tunnels and El-Shadaa station, respectively;

- For type B, the lowest and highest LNP was 77.67 between New El-Marg and El-Marg stations and 100.76 between Tora Asmant and El-Massara stations, respectively;

- For type C, the lowest and highest LNP was 76.91 between Ain Helwan and Helwan stations and 90.55 between Nasser and Sadat stations, respectively;

- All the measured LNP for the three types through Line 1 lie in the range between 79.35 and 100.76, which are unacceptable based on Table 3;

- Type B was the worst type in terms of LNP as it exceeded 88.00 dBA, which is unacceptable;

- Type A was better than type B, but the recorded LNP exceeded 73.00 dBA, which is normally unacceptable. Also, it can be noticed that there is no large fluctuation in the recorded L99;

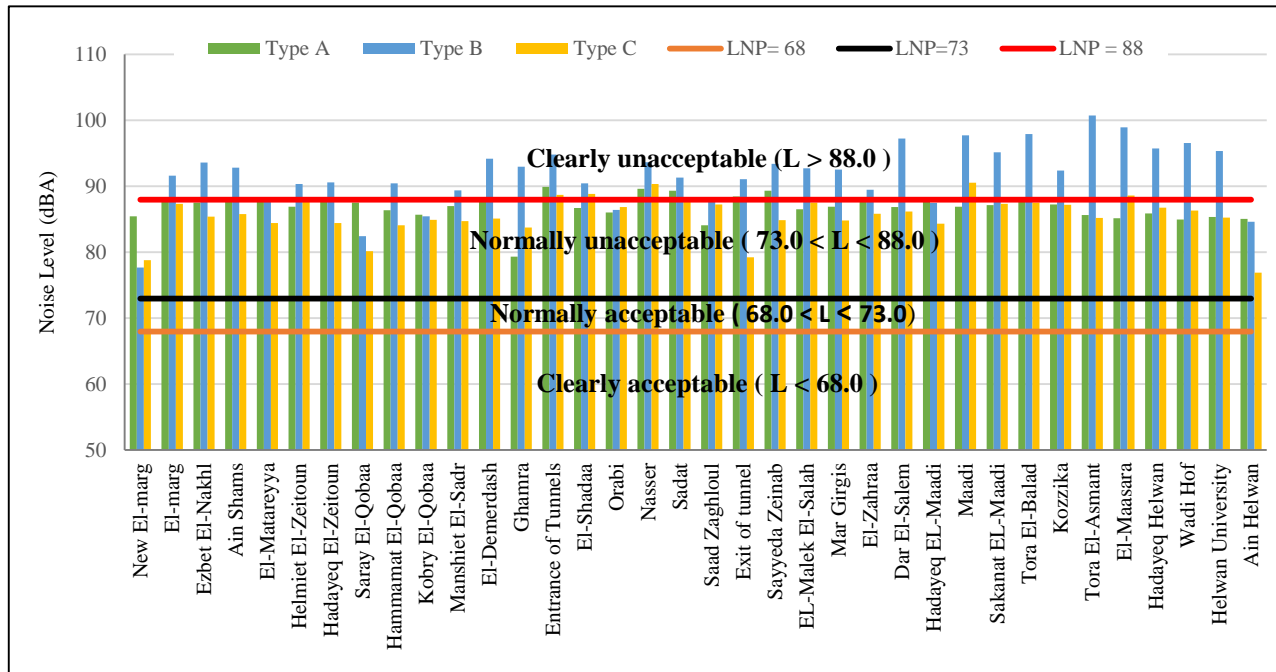- Type C was the best in terms of LNP.

Figure 8. Noise pollution index (LNP) for the three types along line 1 inside the metro unit compared with the international standards of Noise pollution index

4.2. A Speed Impact Assessment

Figures 9 to 11 show the speed profile with the noise for the types A, B, and C, respectively, within the selected stations.
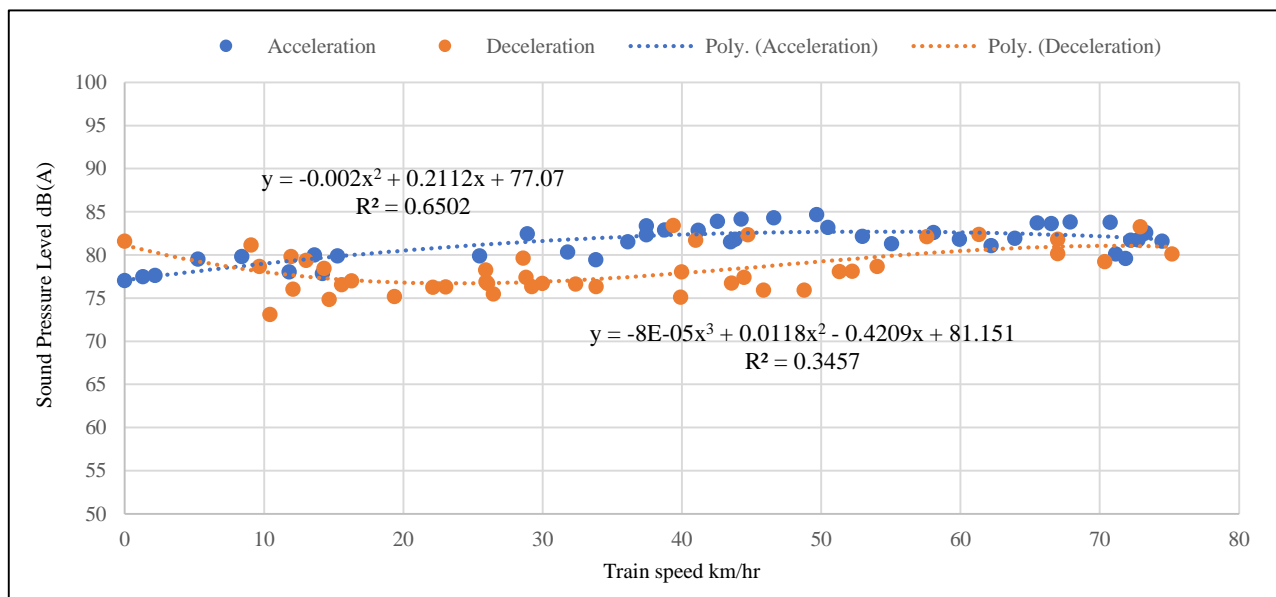

Figure 1. Speed profile with the noise for the type A

The following can be noticed from Figures 9 to 11:

- The maximum speed recorded within the selected track was 75 km/hr., 84 km/hr, and 83 km/hr for types A, B, and c, respectively.

- During the acceleration part, the maximum and minimum noise recorded was 84.66 dBA, and 77.02 dBA for type A, while these values were 84.87 dBA and 65.34 dBA for type B. For type C, these values were 67.85 dBA and 52.42 dBA.

- During the deceleration part, the maximum and minimum noise recorded was 83.41 dBA and 73.10 dBA for type A, while these values were 87.00 dBA and 63.72 dBA for type B. For type C these values were 72.87 dBA and 50.05 dBA.

- Type C is the train with the highest speed along the selected track. However, the values of noise levels were the least compared with types A and B.
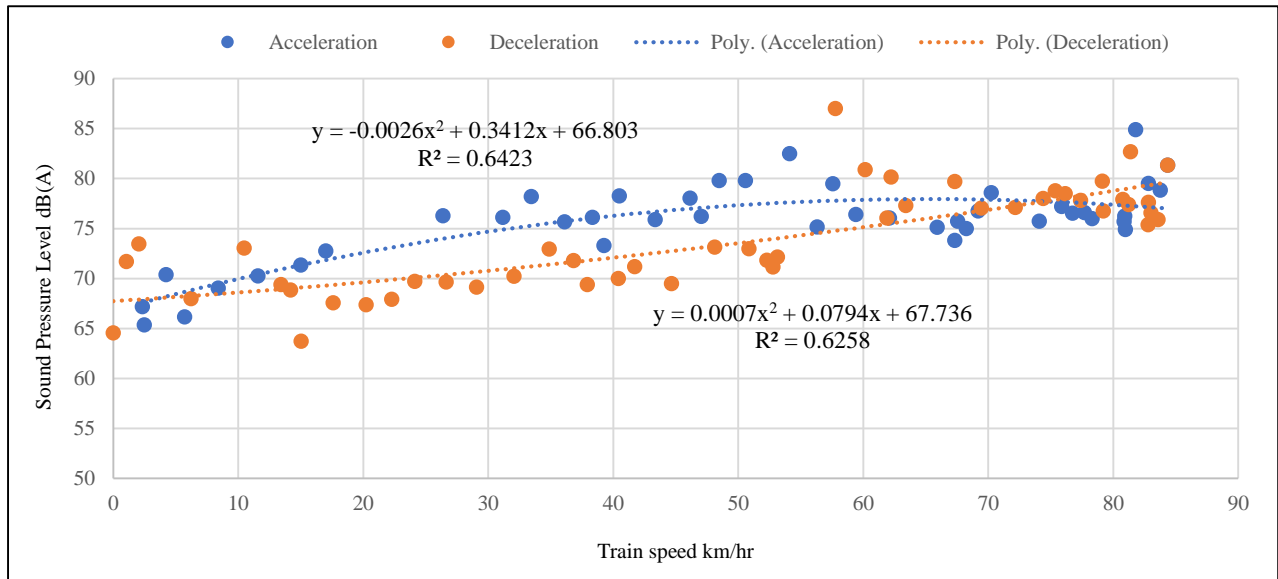

Figure 10. Speed profile with the noise for the type B
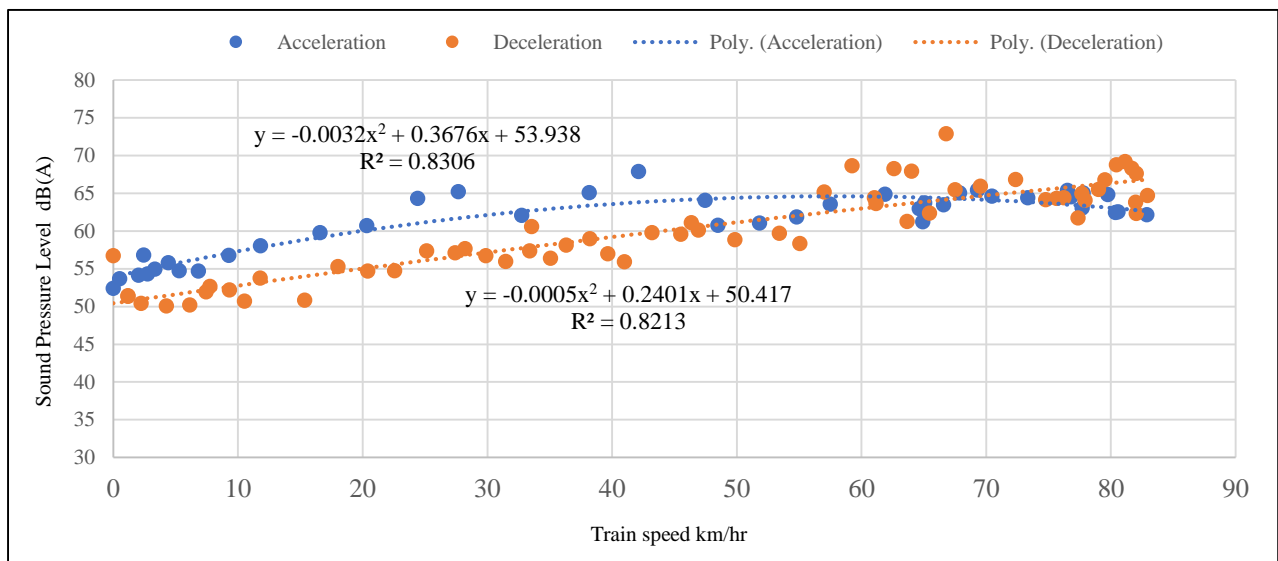

Figure 11. Speed profile with the noise for the type C

Based on Table 3, L_{Amax} is acceptable within the range of 63.5dBA and 73.5 dBA for train movement along a straight surface track. Type C did not exceed this limit, while type B has exceeded this limit at a speed of 25 km/hr. Besides, type A has exceeded the allowed limits at the beginning of the train motion.

The linear regression analysis has been used to calibrate and validate models that describe the speed- noise relationship through the train acceleration and deceleration. The following table shows the calibrated models and the coefficient of determination for each model.

Table 5. The calibrated models and the coefficient of determination for each type.

| Type	Acceleration	R^2	Deceleration	R^2
A	$SPL = -0.002S^2 + 0.2112S + 77.07$	0.6502	$SPL = -8E-05S^3 + 0.0118S^2 - 0.4209S + 81.151$	0.3457
B	$SPL = -0.0026S^2 + 0.3412S + 66.803$	0.6423	$SPL = 0.0007S^2 + 0.0794S + 67.736$	0.6258
C	$SPL = -0.0032S^2 + 0.3676S + 53.938$	0.8306	$SPL = -0.0005S^2 + 0.2401S + 50.417$	0.8213

Where SPL = sound pressure level in dB(A) and S = speed of the train in km/hr.

As shown in Table 5, the R-squared values for model C are all above 0.80, which reflects that model C fits the data to some extent. Also, the R-squared values for models A, B are less than 0.60, which reflects a relatively poor prediction power of the models. MAPE has been used for validating type c models. MAPE values were 2.08 and 2.97 for acceleration and deceleration models, respectively.
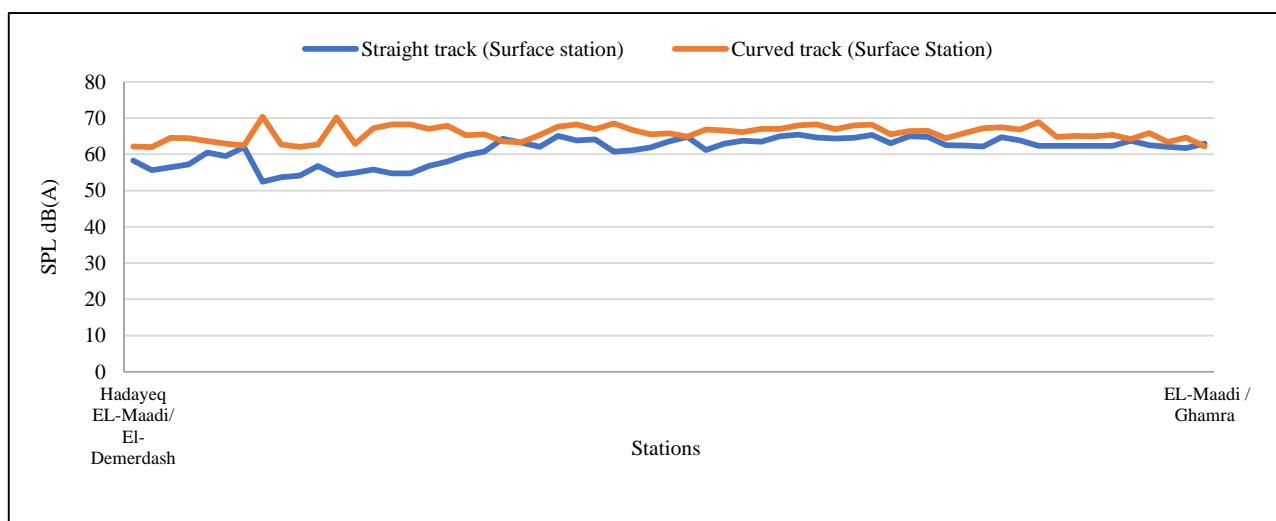
4.3. The Effect of Horizontal Alignment and Station Types on Noise

Figure 12 shows the noise levels profile between two surface stations with a straight track (Hadayeq El-Maadi /El-Maadi) compared with the noise levels profile between two underground stations with a straight track (Orabi /Nasser), while Figure 13 shows the noise levels profile between two surface stations with a straight track (Hadayeq El-Maadi /El-Maadi) compared with the noise levels profile between two surface stations with a curved track (El-Demerdash /Ghamra). The following can be concluded from the two figures:

- The noise levels between underground stations with the straight track are larger than those between surface stations with a straight track.

- The noise levels between surface stations with the curved track are larger than those between surface stations with a straight track.
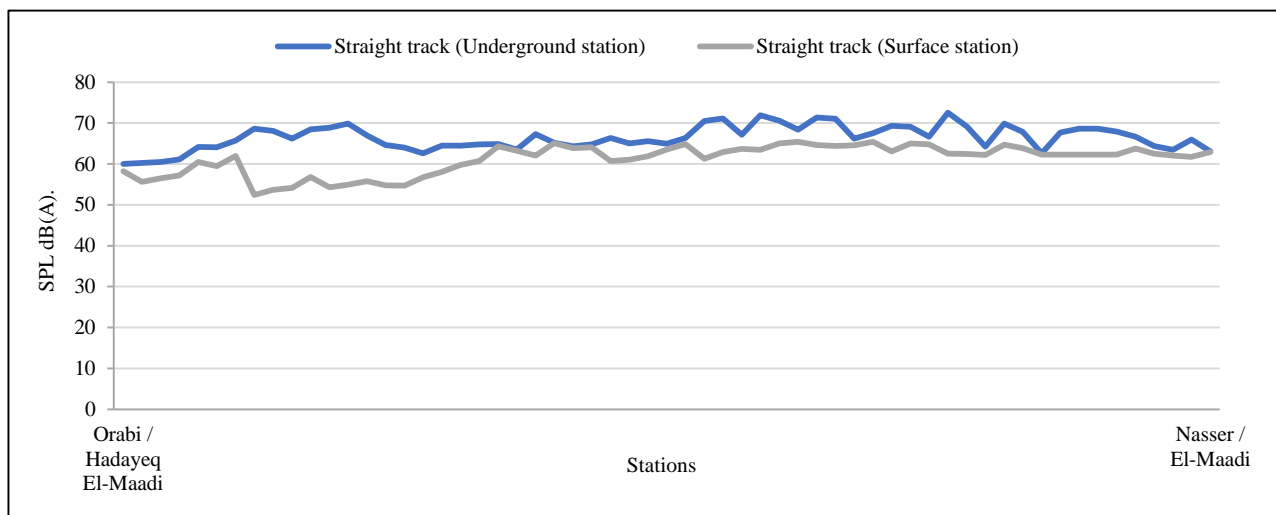
Figure 12. The noise levels between two surface stations with a straight track (Hadayeq El-Maadi / El Maadi) compared with the noise levels profile between two underground stations with a straight track (Orabi/Nasser)

Figure 13. The noise levels profile between two surface stations with a straight track (Hadayeq El-Maadi / El-Maadi) compared with the noise levels profile between two surface stations with a curved track (El-Demerdash /Ghamra)

For more investigation in the effect of horizontal alignment between station (open track or in the tunnel) on noise, and because the distance and train speed between stations are not constant, L_{Amax}, L_{Aeq}, L_{99}, and LNP have been used

to compare the noise levels between the mentioned stations in Table 4. Table 6 shows the values of these parameters. The following can be concluded from this table:

- The lowest values were between surface stations with a straight track, while the highest values were between underground stations with the curved track.

- The values of these parameters between underground stations with the straight track were less than that between underground stations with the curved track, but at the same time, the values were higher than those between surface stations with the curved track.

Table 6. L_{Amax}, L_{Aeq}, L_{99}, and LNP between the selected stations

	Surface track		Underground	
	Straight track	**Curved track**	**Straight track**	**Curved track**
From station	Hadayeq El-Maadi	El-Demerdash	Orabi	Nasser
To station	El-Maadi	Ghamra	Nasser	Sadat
L_{Amax}	72.87	82.38	82.53	87.21
L_{Aeq}	70.85	72.92	73.14	74.65
L_{99}	79.17	80.16	81.87	83.85
LNP	84.35	85.12	86.87	90.37

5. Discussion

It is clear from the previous analysis and results that LAmax, L99, and LNP exceed the international standards of noise exposure with a range reach to (5-18) dBA, especially in type A, B inside the metro units along line 1. The increase in noise levels, which is observed in types A and B, is due to the poor ventilation system of the units. This causes the passengers to open the windows to compensate for the required quantity of air. On the contrary, the noise levels of type C were much less than those of types A and B. This is because type C is the newest deployed type with a newer braking system and produces less noise. Also, the units are air-conditioned with a good ventilation system, and there no need for open windows. Also, the windows themselves are sound-proof windows, which prevent outside noise from entering the units. The closing of the side windows attenuates the noise inside the units by about 15 to 20 dBA.

In general, the noise levels of the three studied types are different. The noise levels are unacceptable compared with the international standards of noise exposure. The high noise levels make passengers suffer from severe damage, which may deteriorate especially for those passengers who use the metro periodically. The noise produced from one or more of the following sources: Aerodynamic and mechanical noises of the train, The train siren, The brakes when applied, Two trains passing by each other at the same moment, which is a frequent event, The passengers themselves and the recorded attention sound systems inside the units, The condition of the railway infrastructure is an important factor in the high noise levels in the three types, and The short distance between stations, which does not allow an increase in speed to reduce the equivalent noise during the trip between the stations.

The unacceptable noise levels compared with the international standards of noise exposure led to more investigation on factors that may affect noise levels inside metro units, such as the speed of the train, the horizontal alignment, and the type of station. Concerning the noise-speed relationship, the noise is directly proportional to the speed of the train regardless of the type of the train until the train reaches a certain speed, and then noise starts to decrease again. The cause of this phenomenon is that at high speeds, the friction decreases, and so the produced noise decreases as well. The speed at which the noise curve decrease is different from one type to another depending on the maintenance status and the train type.

Based on the results reported for the linear regression models in Table 5, model C is the best in terms of GOF when compared to other models. It can be concluded that noise is directly proportional to the train speed as shown in type C models, but the noise has been affected by some other factors rather than the train speed for type A and B models. As for type A and B models, the models are weak in describing the speed-noise relationship as more factors related to the train type itself affect noise levels that cannot be faded

The second point is the speed at which the produced noise exceeds the international standards of maximum noise exposure. Those speeds are as follow:

- For type C, the produced noise did not exceed the permissible limits along the study track;

- For type B, the produced noise exceeded the permissible limits along the study track at a speed of 25 km/hr;

- For type A, the produced noise exceeded the permissible limits along the study track since the train starts moving.

Type C has better performance than types A and B in terms of the noise produced due to the previously mentioned reasons. And so, it has been selected to study the effect of horizontal alignment and station types (surface or underground) on noise levels.

Regarding the effect of horizontal alignment and station types (surface or underground) on noise levels, it can be concluded from the analysis of this part is that the noise through underground tracks has the highest values. On the other hand, the noise along surface tracks has lower values. The reasons for these results are as follow:

- The sound reflections and reverberations at the tunnel cause an increase in train noise;

- During the train movement over the curved track, there is an additional force affecting the track. This force causes a much disturbance on noise levels higher than the noise levels produced by the movement on a straight track.

6. Conclusions

This paper assesses the noise inside the metro units for GCM as one of the most critical environmental issues. It discusses the effect of speed, rolling stocks type, and line alignment on noise level as the commuters spend most of the time inside the metro unit. The main findings from this research are summarized in the following points:

- The noise levels are unacceptable compared with the international standards of noise exposure inside the metro units along Line 1.

- The highest noise levels recorded were for types A and B, due to poor braking system and poor ventilation system of the units, which causes the passengers to open the windows to compensate for the required quantity of air. This case allows the outer noise to enter the train units.

- The noise levels of type C were much less than those of types A and B for the following reasons. The first reason is that Type C is the newest deployed type with a newer braking system and produces less noise. The second reason is that the units are air-conditioned with a good ventilation system and the windows themselves are sound-proof windows. The closure of side windows attenuates the noise inside by 10 to 20 dBA.

- During acceleration, the noise is directly proportional to the train speed regardless of train's type. The noise increases with the increase of the train speed until the train reaches a certain speed. This speed is found to be 82.5, 78, 64.5 km/hr for types A, B, and C, respectively. After this speed limit, the noise starts to decrease.

- During deceleration and braking interval, the noise levels are high due to additional noise sources, such as the braking system and the railway infrastructure condition.

- For the train movement on a straight track, type C did not exceed the permissible limit. On the contrary, type B exceeded the permissible limits at a speed of 25 km/hr. For type A, the noise levels exceeded the permissible limits from the beginning of the train motion. For types A and B, the noise excess is within a range between (10-15) dBA.

- In general, the track alignment influences the noise level. The noise levels through underground tracks are higher than those through surface tracks by about (5-10) dBA.

- The highest noise levels are when the train moves through curved underground tracks followed by straight underground tracks, while the lowest noise levels are through straight surface tracks.

Based on the above results, it recommended to:

- Chang the maintenance plans for both rolling stocks and infrastructure to be compatible with the international standards of noise levels.

- Construction specification must contain items for covering the tunnel walls with sound-absorbing materials to be used in noise abatement strategy.

- Upgrading the currently used system for alerting and guiding inside the train units and within the stations,

- Using a ballast layer during the design of tracks to absorb and reduce the sound radiation from rails and sleepers, especially for underground tracks.

7. Declarations

7.1. Author Contributions

Conceptualization, M.Y., H.Z., A.K. and A.Z.; data collection and processing, M.N. and A.K.; analysis and interpretation of the data, M.N. and H.Z.; writing - original draft preparation, M.N. and H.Z.; writing - review and editing, M.N., H.Z., A.K. and A.Z. All authors have read and agreed to the published version of the manuscript.

7.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

7.3. Funding

7.4. Conflicts of Interest

The authors declare no conflict of interest.

8. References

[1] Zewei, G. U. O., and L. I. Zhi. "Influence of Nanchang Metro Construction on Urban Traffic." Journal of Landscape Research 12, no. 6 (2020): 9-14. doi:10.16785/j.issn1943-989x.2020.6.003.

[2] Yunquan, Z. H. A. N. G. "Analysis on the Features of Urban Rail Transit [J]." Urban Planning Forum 6, (1999): 40-43.

[3] Chang-fu, Huang, and Xia Yuan. "Research on the Role of Urban Rail Transit in Promoting Economic Development." Procedia Engineering 21 (2011): 520–525. doi:10.1016/j.proeng.2011.11.2046.

[4] Cai, Yutong, Wilma L. Zijlema, Elin Pettersen Sørgjerd, Dany Doiron, Kees de Hoogh, Susan Hodgson, Bruce Wolffenbuttel, et al. "Impact of Road Traffic Noise on Obesity Measures: Observational Study of Three European Cohorts." Environmental Research 191 (December 2020): 110013. doi:10.1016/j.envres.2020.110013.

[5] Christensen, Jeppe Schultz, Ole Raaschou-Nielsen, Anne Tjønneland, Kim Overvad, Rikke B. Nordsborg, Matthias Ketzel, Thorkild IA Sørensen, and Mette Sørensen. "Road Traffic and Railway Noise Exposures and Adiposity in Adults: A Cross-Sectional Analysis of the Danish Diet, Cancer, and Health Cohort." Environmental Health Perspectives 124, no. 3 (March 2016): 329–335. doi:10.1289/ehp.1409052.

[6] Clark, Charlotte, Clare Crumpler, and Hilary Notley. "Evidence for Environmental Noise Effects on Health for the United Kingdom Policy Context: A Systematic Review of the Effects of Environmental Noise on Mental Health, Wellbeing, Quality of Life, Cancer, Dementia, Birth, Reproductive Outcomes, and Cognition." International Journal of Environmental Research and Public Health 17, no. 2 (January 7, 2020): 393. doi:10.3390/ijerph17020393.

[7] World Health Organization. "Environmental noise guidelines for the European region." (2018). Available online: https://www.euro.who.int/en/publications/abstracts/environmental-noise-guidelines-for-the-european-region-2018 (accessed on September 2020).

[8] Garbala, M., and L. Gomez-Agustina. "Passenger noise exposure in London underground." Proceedings of the Institute of Acoustics 37, no. 2 (2015).

[9] Wen, Yueming, Jiawei Leng, Xiaobing Shen, Gang Han, Lijun Sun, and Fei Yu. "Environmental and Health Effects of Ventilation in Subway Stations: A Literature Review." International Journal of Environmental Research and Public Health 17, no. 3 (February 8, 2020): 1084. doi:10.3390/ijerph17031084.

[10] Nang, Ei Ei Khaing, Gulifeiya Abuduxike, Pawel Posadzki, Ushashree Divakar, Nanthini Visvalingam, Nuraini Nazeha, Gerard Dunleavy, et al. "Review of the Potential Health Effects of Light and Environmental Exposures in Underground Workplaces." Tunnelling and Underground Space Technology 84 (February 2019): 201–209. doi:10.1016/j.tust.2018.11.022.

[11] Tao, Ziyu, Yimin Wang, Chao Zou, Qi Li, and Yue Luo. "Assessment of Ventilation Noise Impact from Metro Depot with over-Track Platform Structure on Workers and Nearby Inhabitants." Environmental Science and Pollution Research 26, no. 9 (February 4, 2019): 9203–9218. doi:10.1007/s11356-019-04378-w.

[12] Garcia, Amando. Environmental urban noise. WIT press (2001).

[13] Loukaitou-Sideris, Anastasia, and Alexander Schaffer. "Too Loud to Hear the Train! Noise Assessment, Implications, and Mitigation Strategies on Light Rail Platforms." Journal of Planning Education and Research 34, no. 3 (July 11, 2014): 339–351. doi:10.1177/0739456x14540938.

[14] Butnaru, Corina, Bogdan Cobzeanu, Alexandra Lungu, Marioara Poenaru, Razvan Hainarosie, and Tudor Radulescu. "Environmental Noise: Health and Policy - An Up To Date Mini Review." Environmental Engineering and Management Journal 18, no. 3 (2019): 749–755. doi:10.30638/eemj.2019.068.

[15] East Corridor Project: Final Environmental Impact Statement. US Department of Transportation Federal Transit Administration District, and the Regional Transportation, (2009).

[16] Mark J. Nieuwenhuijsen and Haneen Khreis, "Advances in Transportation and Health" (2020). doi:10.1016/c2018-0-04993-2.

[17] Kamal.M, "Egypt state of the Environment Report in Noise." Ministry of state for environmental Affairs: Arab Republic of Egypt, (2006).

[18] Harris, Cyril M., Handbook of Noise Control. 2nd edition. New York: McGraw-Hill book Company (1979).

[19] Hussein. M, Abd Elkader. M, El-khateeb. A, and Ismail. M, "Effect of Architectural Treatments on Acoustic Environment Case Study: Underground Stations," Ain Shams University, (2010).

[20] Kotb. A, "Recovery Methods of Negative Environmental Impacts for Urban Railway Lines," Ain Shams University, (2003).

[21] Abdalla. M, "A comparative statistical study of noise levels due to underground train in Greater Cairo.," Eng. Res. Bull 4, (1993): 151-159.

[22] Aly, Mostafa E. "Noise Assessment Inside the Greater Cairo Underground Second-Line Metro." Sadhana 30, no. 1 (February 2005): 47–55. doi:10.1007/bf02710078.

[23] Department of Housing and Urban Development (HUD). "Noise assessment guidelines." BBN Report. No. 2176, (August, 1971).

[24] Department of Housing and Urban Development. "The noise guidebook (HUD 953-DPC)", (1985).

[25] Shimokura, R., and Soeta, Y. "Spatial Characteristics of Noises in Platforms and Vehicles of train". In INTER-NOISE and NOISE-CON Congress and Conference Proceedings, (October 2008), 2008.7: 2533-2543). Institute of Noise Control Engineering.

[26] Shimokura, Ryota, and Yoshiharu Soeta. "Characteristics of Train Noise in Above-Ground and Underground Stations with Side and Island Platforms." Journal of Sound and Vibration 330, no. 8 (April 2011): 1621–1633. doi:10.1016/j.jsv.2010.10.021.

[27] Forbes, Catherine, Merran Evans, Nicholas Hastings, and Brian Peacock. "Statistical Distributions" (November 29, 2010). doi:10.1002/9780470627242.

[28] Don, C.G., and I.G. Rees. "Road Traffic Sound Level Distributions." Journal of Sound and Vibration 100, no. 1 (May 1985): 41–53. doi:10.1016/0022-460x(85)90341-4.