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MODELLING OF TRAFFIC NOISE ALONG URBAN CORRIDOR: A CASE STUDY OF AMMAN

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Abstract

Noise became one of the main environmental indicators of the quality of urban life. The aim of this study was to develop a traffic noise model for an arterial road in Amman, the capital of Jordan, which was being subjected to a persistent increase in traffic and its related issues. The characteristics of the traffic and its relevant noise were analysed to develop a noise prediction model using an adaptive neuro-fuzzy inference system (ANFIS). A geographic information system (GIS) was then implemented to model the current noise along the arterial road. The results of ANFIS model showed that traffic delays and the percentage of heavy vehicles were the main causes of traffic noise generation within the urban area. However, the developed ANFIS model can simulate traffic noise with a relatively low root mean square error. Furthermore, this study will help to improve the perception about traffic noise and its development along arterial roads.

Keywords:

Bus line noise;
Noise measurement;
Noise modelling;
Noise pollution;
Traffic impacts.

1 Introduction

Traffic congestion has become a serious "urban illness", giving rise to problems such as travel time delays, increase in traffic accidents as well as traffic noise. Traffic noise is a major threat to human health, especially in urban areas and/or where there is high traffic volume and speed [1]. It affects most of the community such as homes, places of worship, patients in hospitals and students at schools. Furthermore, excessive noise is a major environmental complaint [2]. The adverse health effects of traffic noise are not limited to high blood pressure, impaired hearing sensitivity of human beings, ischemic heart disease, anger, anxiety, headaches, sleep disturbance, stress, and psychological disorders as well as lower performance by students and employees [3], but also depend mainly on the severity of the traffic noise and the duration of exposure to it. Accordingly, the noise impacts may be additive or synergistic. In addition, as developing countries have chronic problems related to data availability and accuracy, hence, a noise model will help them to save on time and resources as well as minimise costs.

There are many sources of traffic noise, and these sources can be categorized into three groups, namely, propulsion, tyre-pavement, and aerodynamic noise, as shown in Fig. 1a. Propulsion noise refers to the sounds generated by vehicle parts such as the engine and exhaust as well as the honking of the horn. Aerodynamic noise is generated as a result of the passage of a vehicle through the air. The major contributor to traffic noise is vehicle flow [4]. The tyre-roadway interaction is the largest component of traffic noise. The noise generated by the interaction of truck tyres can be up to 10 times greater than that of a small passenger car. However, as shown in Fig. 1b, the interaction and influence of each noise source vary, depending on the driving behaviour and speed. For instance, the tyre-pavement interaction is the main source of noise from vehicles travelling at speeds higher than 50 km/h. Furthermore, the speed of the traffic may be a main contributor to traffic noise. For instance,

increasing the speed of a vehicle by 10 km/h will raise the noise level by at least 1 dB due to the tyre-pavement interaction [6].

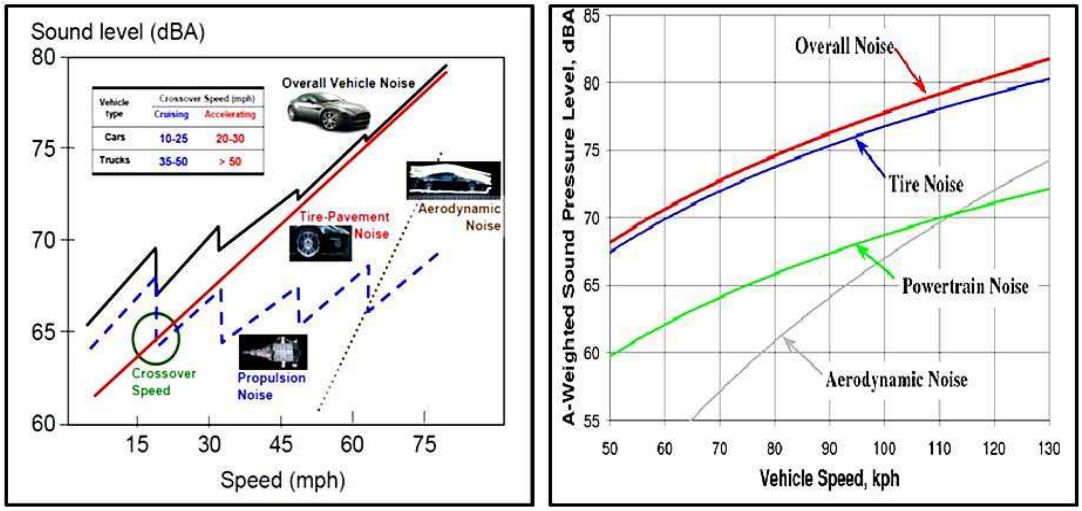


Fig. 1: a) Noise sources and their interactions with vehicle speed, b) speed-noise relationship [5].

Diesel fuel vehicles (heavy) generate relatively more noise than small passenger vehicles [6]. In addition, they contribute to more noise in traffic jams [7]. This may be due to the larger contact area (interaction) between the tyres of heavy vehicles and the road surface. Furthermore, there is a relationship between traffic noise and traffic delays. The impact of the type of vehicle on the noise level was investigated by P. Pamanikabud & P. Vivitjinda, who grouped the vehicles in Thailand into eight categories. The study showed that trucks are more correlated to traffic noise than automobiles [8]. On the other hand, road characteristics such as the type and roughness of the pavement, road width, road gradient, pavement conditions as well as distance from the road affect traffic noise [9]. Moreover, developing spatial noise maps in metropolitan cities and their acoustical characteristics is a modern trend for establishing plans and policies to minimize or prevent the hazardous impacts of traffic noise [10]. It is used to model the existing and future noise levels and their related impacts, thus the action plans may be developed.

Usually, noise levels are mapped using a geographic information system (GIS) to quantify and visualize the effects of noise based on the measurement of noise levels at various locations [11]. Furthermore, Tansatcha et al. studied the factors affecting the generation of traffic noise such as traffic volume and combinations, number of lanes, shoulder width, and spot speeds. They concluded that these factors significantly affect the traffic noise produced by all types of vehicles [12]. However, the traffic segments, kinematics and speed distribution usually are unknown at urban locations especially in developing countries. Furthermore, traffic acceleration complicates the traffic noise modelling [13]. However, there is a demand to evaluate the impacts of road repairs and maintenance on all aspects [14].

Traffic congestion is a contemporary problem in urban areas. In the case of arterial roads, urban traffic congestion is contributed by the limited transportation infrastructure, insufficient traffic management, and increasing urban motorization. Traffic congestion has a negative impact on the environment and the quality of life, of which noise is considered as the most important issue. However, in in Amman city the number of registered vehicles has been increasing significantly over the last few years. For instance, in 2019, there were 1.677 million registered vehicles in Jordan, of which 1.2 million were small passenger vehicles [19]. Consequently, to help the city absorb these increases, the city planners decided to construct a high-speed bus line (HSBL) along Queen Rania Al-Abdullah (QRA) Street. Furthermore, to accomplish the construction of the HSBL, geometric design alterations were made to the QRA arterial road, which led to traffic delays as well as an increase in traffic noise. Therefore, this study aims to evaluate the impacts of traffic characteristics using traffic state estimations (TSEs) of traffic noise and developing a spatial map of the noise along an arterial road at Queen Rania Al-Abdullah (QRA) Street in Amman city. Moreover, it will help better understand the heterogeneous traffic noise and model it using an ANFIS model. However, actual traffic noise data and information are scarce in Amman. Thus, this study will provide urban planners with insights as to how to quantify the effects of noise on the surrounding neighbourhood and to develop infrastructural

references for their plans. First, both the traffic noise and characteristics at an arterial road in Amman city were measured and analysed. A noise prediction model was then developed to simulate the traffic noise that was relevant to the traffic characteristics using an ANFIS. Finally, a noise map of the study area was developed using a GIS.

2 Methodology

2.1 Study area

Amman, the capital of Jordan, has a population of about 4.4 million people. The city's population has increased by 65 % over the last decade. Likewise, during the same period, the number of registered vehicles has increased by 85 % [15]. However, actual noise data on Amman city is relatively scarce, and so, this study will help city planners to improve their perception about the noise in the city.

The selected Queen Rania Al-Abudallah (QRA) arterial street in Amman, which has a total length of 9 km, beginning from the Sweileh interchange and ending at the Interior roundabout, has more than ten million vehicles passing along it annually. Moreover, it has five interchanges and one at-grade intersection. This road is one of the most crowded roads in the country, and it links the central governates. In addition, based on the EU noise directive 2002/49/EC, it is considered as a major road and can be selected as a case study for noise research [20]. However, vehicle movements at the intersections are usually altered according to various driving behaviours such as acceleration, lane changing and delayed time. Consequently, the main intersections on the QRA Street were selected for this study. Fig. 2 shows the intersections along the QRA road.



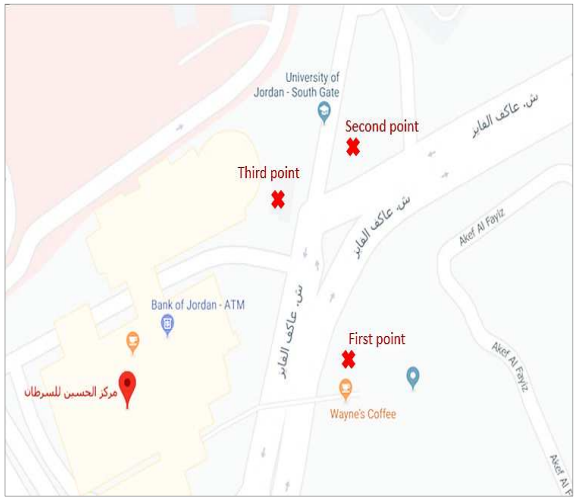
a) Sweileh interchange



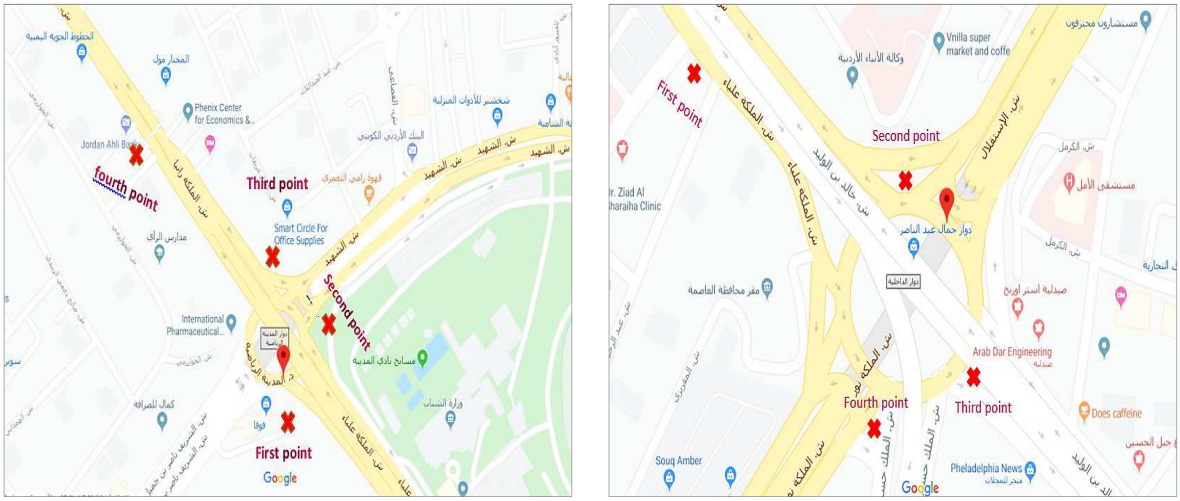
b) Dawriyat



c) University Mosque



d) Hussein Cancer Center



e) Al Madeneh f) f) Dakhliya

Fig. 2: Intersections along the QRA.

2.2 Data collection and analysis

To meet the objectives of the study several traffic variables were considered in this study, which were categorized into dependent and independent variables. This study conducted a field observation from 4th November 2019 until 28th November 2019. The noise and traffic characterising were conducted simultaneously, it started at 7:30 am and extended to 5:00 pm with various time at each location. Fig. 2 also displays the sampling points at each intersection in the study area. The observed traffic variables were traffic volume, average traffic speed, percentage of heavy vehicles, road surface gradient, traffic delay, length of traffic queue, percentage of passenger cars and volume-to-capacity V/C ratio. Moreover, the traffic variables were considered as the independent variables; while the traffic noise was considered as the dependent variable. However, the main basic variables that are usually used to describe the traffic on any road are volume or flow rate, speed and traffic density [4].

The noise sampling was performed at the entrance and exit of the leg of each intersection, as indicated by the red crosses in Fig. 2. The BESANTEK BST-SL2 sound level meter was used in this study to measure traffic noise. This series is capable of covering a wide range of applications and performance criteria, including noise pollution studies for the quantification of almost any noise, but especially for industrial, environmental and aircraft noise. The Nord Test Method was implemented as reference method for equivalent traffic noise [16]. The measurement was done using a roadside microphone equipped with a wind protector, and which was positioned at the roadside at a height of 1.2 m and at a distance of more than 5 m from the facades of buildings [17].

The device was used to measure the average traffic noise by a method known as the Statistical Pass-By (SPB) method. This method, which is used for the measurement of outdoor traffic noise, including the noise resulting from the tyre-pavement interaction, mechanical noise as well as aerodynamic noise [5]. To obtain accurate measurements using the SPB method, the roadway must be relatively level and free of acoustically reflective surfaces within a distance of 30 m. At each location, the measurements were extended for 15 times for duration of 20 min. A TSE was implemented to analyse the data on the traffic characteristics. A TSE is an efficient tool that is usually implemented to simulate the main traffic characteristics such as traffic speed, traffic volume and traffic density. Furthermore, it plays a significant role in the development of traffic and transportation plans as well as the management of traffic operations.

2.3 Development of noise prediction model

The MATLAB software (7.14) was implemented to develop a noise prediction model based on the traffic characteristics by means of the ANFIS modelling technique. ANFIS is a multilayer feed-forward network that performs a fuzzy logic function on incoming signals. The fuzzy logic structuring process mainly consists of the following steps. First, picking out the independent input variables; second, developing the membership functions MF; and third, generating the fuzzy rules that control the modelling process [18]. In order to improve the accuracy of ANFIS modelling the shape of optimum MF is usually defined by trying of various shapes. The shape is updated and modified to

mimic the relation between the inputs and output during the training phase. Furthermore, the training is repeated many times to achieve the required error. For a first-order Sugeno fuzzy model, a common set of two fuzzy rules and a set of if-then rules are described as follows:

Rule 1*:* if x is A_1 and y is B_1 then $f_1 = p_1x + q_1y + r_1$, (1)

Rule 2*:* if x is A_2 and y is B_2 then $f_2 = p_2x + q_2y + r_2$, (2)

where A_i or B_j is a linguistic label (grade), such as “low” or “less”, and p_1, q_1, p_2, q_2 are the design parameters determined by the system developer. Additionally, in order to assess the performance of the model, the root mean square error (RMSE) is usually used. The equation for the RMSE is shown below:

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(X_t - X_o)^2}{n}}, \quad (3)$$

where X_t is the actual output, X_o is the predicted output, and n is the number of outputs.

3 Results and discussion

The main traffic characteristics at each interchange and intersection are presented in Table 1, which shows the main parameters that are usually used to describe the traffic on each roadway, namely, the traffic volume, average speed as well as the volume-to-capacity V/C ratio. Moreover, it presents the common variables that are directly related to traffic noise such as the road slope, percentage of heavy vehicles, traffic delay and queue length.

The highest percentage of heavy vehicles was at the Dakhliya interchange; this can be justified as it is the end of the route for many ring public transportation lines. In addition, the Dakhilya roundabout is considered as a transfer point to the main bus terminal in the city. The second largest percentage of heavy vehicles was at the University Mosque intersection. This was because the intersection is very close to the main and largest university in Jordan, and there are heavy bus movements throughout the day to cope with the demand from students for transportation. On the other hand, the maximum delay was at the Al Madeneh interchange, due to the occurrence of work zones for the HSBL, which caused different interruptions to the traffic flow, resulting in a high delay value. The delay at Dakhliya was the second largest delay, and this was due to the high V/C ratio. Field observations indicated that the mean traffic speed was mostly in the range of 23 - 37 km/h, while the percentage of heavy vehicles was about 20 %.

Table 1: Main traffic characteristics at each intersection.

Location	Traffic volume [veh/h]	Volume/ capacity V/C [%]	Traffic delay [sec]	Queue length [m]	% slope	Average speed [km/h]	% of heavy vehicles	% of passenger cars
Sweileh	8,352	1.01	56	48	2.8%	30.2	18.8	81.2
Dawriyat	6,140	0.7	28	17	2%	33	15.3	81.7
University Mosque	6,766	1.02	64	44	4.2%	27.7	20.8	79.2
Hussain Cancer Centre	20,523	0.64	36	14	2.5%	37	18.6	81.4
Al Madeneh	29,667	5.8	1,563	71	2.2%	28.5	19.7	80.3
Dakhliya	21,793	5.4	1,200	65	1.9%	23.6	22.5	77.5

Along with other traffic parameters noise was also measured simultaneously at each location. The average maximum and minimum noise at each location are shown in Fig. 3. There was no variance between the maximum and the minimum noise at the Dakhliya interchange, and this could be due to the closeness of Dakhliya interchange to the city centre. Furthermore, all the interchange legs were over-saturated; consequently, the headway or gaps were close to the minimum. On the other hand, since the University Mosque intersection is controlled by a traffic signal, with green and red phases, the variation between the mean maximum and minimum noise was the largest.

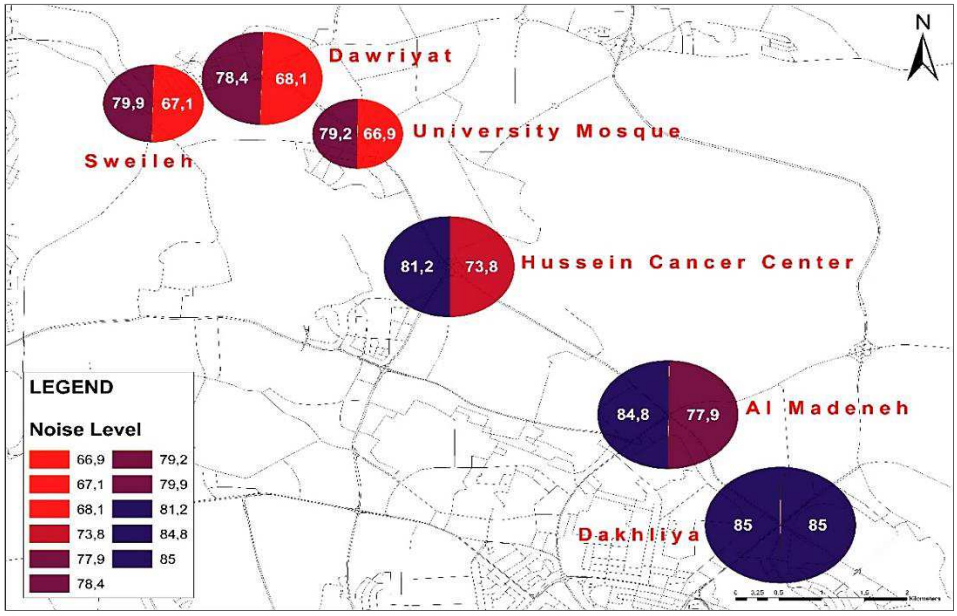
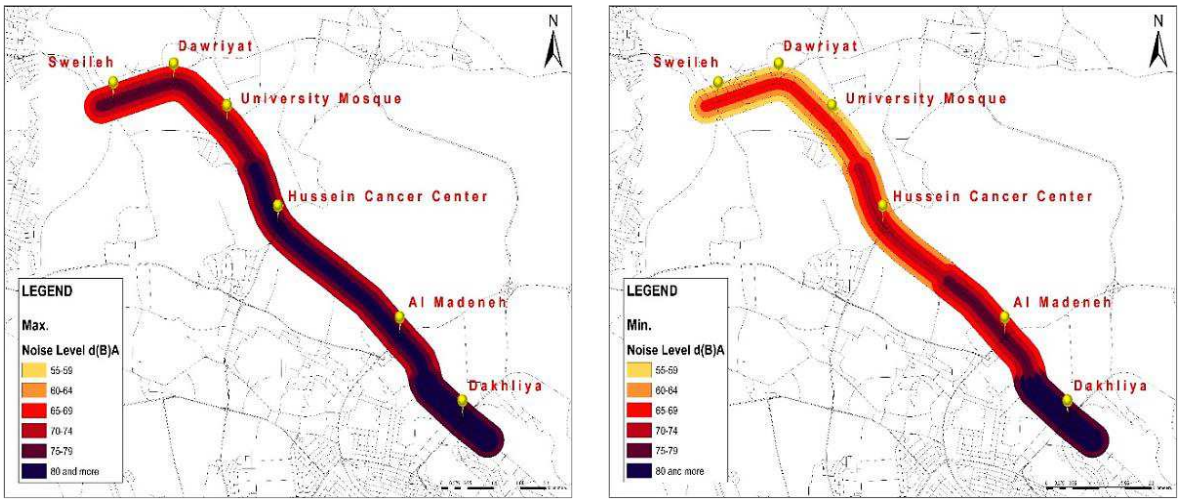


Fig. 3: Measured maximum and minimum noise at each intersection.

Fig. 4a and Fig. 4b show the maximum and minimum traffic noise that developed along the QRA road, as well as the buffer, and the degree of variation in the maximum and minimum average noise between the study locations. This map was important in determining the exposure of population to the noise. The lowest degree of traffic noise was at the beginning of the QRA route at Sweileh, which is considered as a neighbouring town bordering Amman city and linking it to the northern and central governates; while the highest noise pollution was at the Dakhliya interchange, which is considered as one of the busiest interchanges in the country. In addition, it links the main roads in Amman with the city centre.



a) Maximum noise b) Minimum noise

Fig. 4: Maximum and minimum noise along the QRA road.

ANFIS was used to finalise the noise modelling. First, an in-depth assessment was performed to select the most representative inputs, these inputs are summarized in Table 1. Fig. 5 presents a summary of the optimum fifteen inputs of noise combinations. These combinations were single input-output, double inputs-outputs and triple inputs-outputs. The RMSE values obtained due to the noise modelling for both the training and checking phases are presented in Fig. 5. On the single-input level, the traffic delay and traffic volume showed the lowest $RMSE_{Checking}$, with values of 2.8 and 5.8 for traffic delay and traffic volume, respectively. Furthermore, for the double inputs, the best combination was between the traffic delay and percentage of heavy vehicles, with the RMSE for training being 0.2 and for checking being 4.2, respectively. Whereas, in case of triple inputs, the combination of

V/C %, traffic delay and percentage of heavy Vehicles had the lowest $RMSE_{training}$ = 0.25 and for $RMSE_{checking}$ = 36.7. On comparing all combinations of inputs, results in Fig. 5 shows that the combination between traffic delay and percentage of heavy vehicles is optimum because of its ability to model noise with lowest error.

These results depicts that better noise modelling can be achieved by using traffic delay variable because all combinations (single, double and triple) with lowest RMSE had traffic delay variable. It is also observed that heavy vehicles movement is the main cause of traffic noise and its related disturbance. This is a longstanding issue at urban areas and is the main cause of traffic delay since it moves, stops and accelerates slowly [21].

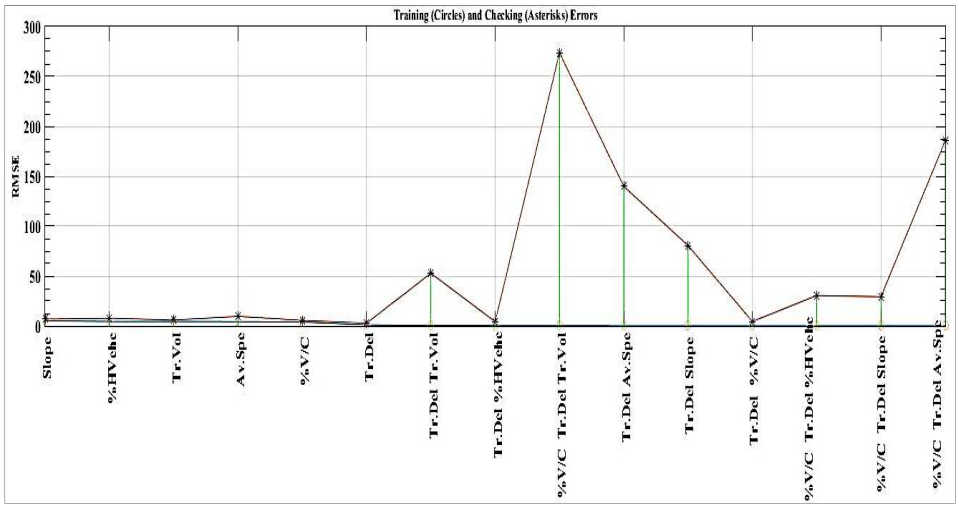
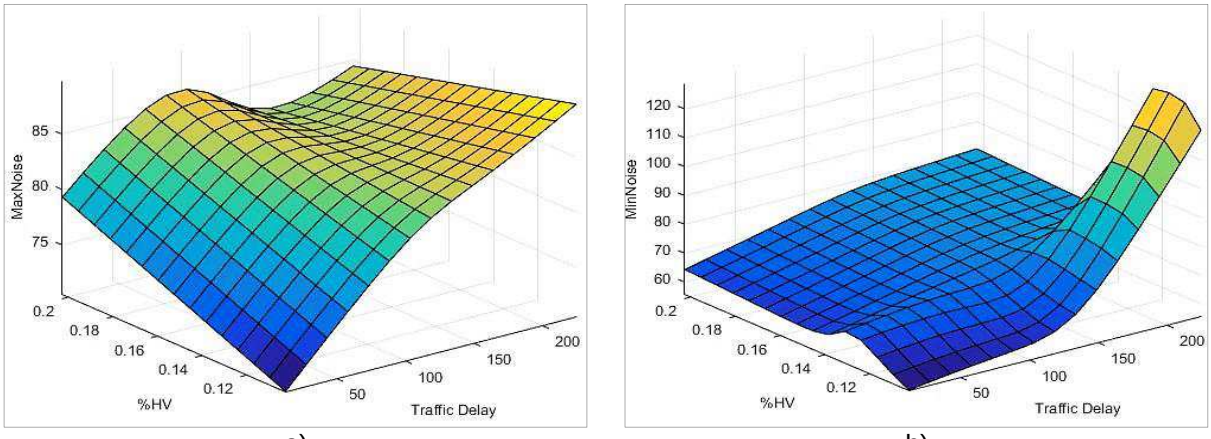


Fig. 5: Summary of optimum input combinations.

Therefore, based on the results displayed in Fig. 5, the optimum training function with inputs of traffic delay and percentage of heavy vehicles was selected to ensure minimum error in noise modelling. The final ANFIS model was obtained using three generalized bell curve membership functions. Fig. 6a and 6b shows the effects of various traffic delays and percentages of heavy vehicles at the roads with the resultant maximum and minimum noise levels. Results show that a 20% increase in the percentage of heavy vehicles significantly increases the noise level, and this may be due to the reported noise from heavy vehicles and high contact area between the tyres of vehicles and the road surface [22]. Moreover, increase in heavy vehicles delays traffic by reducing the traffic speed [23], and this happens due to the inverse relation of % HV to road capacity. Similar results were reported by Rodriguez et al.[24]. On the other hand, the minimum noise level was sensitive to traffic delay, where it increased significantly as the delay increased. Traffic delay also turns out to have higher influence in the generation of noise, which could be due to not only the vehicle noise but constant horns that are normally seen in case of traffic congestion and delay.



a) b)

Fig. 6: Surface response to traffic delay, % of heavy vehicles, and a) maximum noise, b) minimum noise.

4 Conclusions

This study aimed to assess the impacts of traffic characteristics on the generated traffic noise and to model the noise. Thus, the study analysed some negative implications of traffic on the noise level along an arterial road QRA Street in Amman city, Jordan. It presented an in-depth analysis of the main factors that affect traffic noise in urban areas, and modelled the noise level based on these factors. In addition, a noise map along the road was developed to help city planners to correctly understand the impact of traffic characteristics, traffic geometry and drivers' behaviours on the resultant noise. This study concluded that the percentage of heavy vehicles and traffic delays significantly affected the traffic noise. However, traffic management by organising the movement of heavy vehicles through the arterial road especially at rush hours will significantly reduce the noise. Meanwhile, the developed artificial inelegance model has demonstrated high capacity of predicting the noise level with an acceptable degree of error, and thus, it may help city planners to develop and implement further actions to minimize the traffic noise in urban areas.

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