Analysis of Urban Road Traffic Noise Exposure of Residential Buildings in Hong Kong Over the Past Decade

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Abstract

Introduction: With the development of transportation system and the economy, the rapidly increasing number of automobiles brings the associated problem of road traffic noise, especially in metropolitan and densely populated high-rise cities like Hong Kong. In Hong Kong, approximately one million people are affected by severe road traffic noise. Excessive noise exposure is hazardous to the health and wellbeing of people and therefore has drawn progressively more attention in Hong Kong. The Calculation of Road Traffic Noise (CRTN) has been adopted as the sole tool to evaluate road traffic noise in the form of descriptor LA10. The accuracy and suitability of the CRTN method for predicting road traffic noise in Hong Kong were evaluated in this study by comparing the prediction results and measured traffic noise levels. The results show that the CRTN method was able to provide adequate predictions with correlation coefficients of 0.8032 and 0.7626 between the predicted and measured LA10 for 2007 and 2017 respectively. The predicted traffic noise levels on different floors of seven selected residential buildings in 2017 were compared with those predictions for the same buildings in 2007. The worsening traffic noise exposure in these residential buildings was analysed and some suggestions and counter-measures to alleviate the traffic noise problems are put forward. Since the situation of Hong Kong is an example of what may happen in other cities, the present longitudinal study of the road traffic noise in Hong Kong hopes to contribute to a better urban acoustic environment worldwide. Context: Excessive noise exposure is hazardous to the health and wellbeing of people and therefore has drawn progressively more attention in Hong Kong. The urban road traffic noise exposure of residential buildings in Hong Kong over the past decade has been analysed. Aims: This study aims to assess the road traffic noise exposure of residential buildings over the past decade. Settings and Design: Measurements of traffic noise levels at some selected residential buildings were first conducted in 2007, and then repeated at the same buildings in 2017. Material and Methods: The CRTN was adopted to predict the traffic noise levels based on the recorded traffic flow data. Results: The exposure of these buildings to road traffic noise is higher in 2017 than in 2007. The study illustrates that the deterioration of the urban acoustic environment may not be caused by an increased total number of vehicles, but that heavy vehicles are dominantly responsible for the increased traffic noise levels. Restriction of vehicle velocity for urban street canyons is useless for road traffic noise control. Conclusions: This study shows the deterioration of traffic noise levels is mainly due to the increased heavy vehicles instead of the increased total number of vehicles. The alleviation of traffic noise levels by velocity restriction may not be obvious for urban street canyons and may only work with a certain velocity range.

Keywords: Calculation of road traffic noise, residential buildings, road traffic noise, urban noise

INTRODUCTION

As a result of rapid urbanization, the urban population proportion was estimated to be about 54% in 2014 and is expected to increase further in the next three decades. According to the United Nations Population Division, the world’s population is expected to increase from 7.4 billion in 2015 to 9.6 billion in 2050, while the urban population is expected to increase from 3.9 billion to 6.3 billion in the same period. It indicates that not only will almost all of the expected population growth be in urban areas but also that some of the rural population will be attracted to urban areas.
The increasing demands on all kinds of resources in cities will add pressure to the urban environment. Enhancing the habitability of cities will be a great challenge for authorities.\cite{2, 6} Urban road traffic noise is considered as one of the most severe issues among various environmental pollution problems in cities, especially for metropolitan and densely populated cities.\cite{9, 15} It affects a large number of inhabitants in physiological and psychological aspects and its effects can be cumulative.\cite{16-18}

Urban road traffic noise has been found to be related to people’s productivity, performance, and satisfaction.\cite{19-22} Some investigations illustrate that road traffic noise is harmful to human health and may cause some chronic diseases, for instance hypertension and ischemic heart disease.\cite{17, 23} The World Health Organization holds urban traffic noise responsible for adding a burden to the health of one million lives per annum in the European Union. More than 30% of the world population is suffering from exposure to excessive road traffic noise and the deteriorated situation is becoming increasingly apparent.\cite{24}

Being a major metropolitan city and one of the most densely populated high-rise cities in the world, Hong Kong has been confronting the immense road traffic noise problem for the past few decades. The road traffic noise problem in Hong Kong is due to a combination of factors including the scarcity of habitable land, a lack of concerns for the environment in previous planning, an ever-increasing population and the associated housing demand.\cite{25-28} The concentrated and large-scale road traffic network benefits the inhabitants with easy transportation and guaranteed logistics and support for the growth of the economy. However, limited land source constrains residential buildings to adjacent roads, bridges, and flyovers. As a consequence, it results in a serious noise pollution problem for residents. The Hong Kong Planning Standards and Guidelines highlight a road traffic noise benchmark of 70 dB(A), measured in the form of descriptor $L_{A10}$ (1 hour), according to the Calculation of Road Traffic Noise (CRTN) method.\cite{29} Approximately one million people in Hong Kong are exposed to excessive road traffic noise, labelling Hong Kong as one of the noisiest cities in the world.\cite{30} With the aim of fulfilling huge housing demand under the adversely limited land resources, the essential urban re-development of Hong Kong will lead to a more compact urban form with an increasing number of high-rise buildings, which will aggravate the urban acoustic environment and complicate counter-measures of road traffic noise abatement.\cite{31-33}

The Environmental Protection Department (EPD) of the Hong Kong Government, established in 1986, has been working hard to resolve the urban road traffic noise problem. As prevention is always better than cure, the effective planning and evaluation of roads and new residential developments in the early stages of design is the best method of protecting residents from excessive traffic noise in the future. Therefore, the EPD announced a guideline note, providing general criteria for preparation of a Road Traffic Noise Impact Assessment (RTNIA) under the Environment Assessment Ordinance (EIAO) in 2005.\cite{29} The guidance note highlights some possible traffic noise mitigation designs and measures and makes reference to the CRTN prediction method, a traffic noise prediction model that has been adopted by the EPD for years. The CRTN method was initially developed by Delany et al.\cite{34} for predicting traffic noise in the United Kingdom and then officially adopted by the Welsh Department of Transport in 1988 as well as authorities of Australia, New Zealand, and Hong Kong.\cite{35, 36} It is the sole tool recommended by the Hong Kong government for the assessment of road traffic noise. Since there are no simple answers to the road traffic noise problem in Hong Kong, the EPD published a comprehensive plan to track road traffic noise in 2006.\cite{30} Hong Kong has made tremendous efforts to improve the urban acoustic environment. Various noise measures have been implemented in Hong Kong in the past decades, including noise barriers, low noise material resurfacing, noise shielding walls, environmental impact assessment, pedestrianisation schemes, legislative control of individual vehicles and internal layout design. However, road traffic noise issues have still been raised by the Legislative Council, the district councils, and the media due to the public’s impatience of high traffic noise levels in Hong Kong.

The longitudinal studies of the road traffic noise over time may be the best means to determine temporal change in noise exposure. However, lack of resources and commonly accepted methodology results in very few longitudinal studies of the road traffic noise. This study aims to assess the road traffic noise exposure of residential buildings over the past decade. Measurements of traffic noise levels at some selected residential buildings were first conducted in 2007, and then repeated at the same buildings in 2017. The traffic flow data were recorded synchronously during each measurement. The accuracy and suitability of the CRTN method for predicting road traffic noise in Hong Kong were evaluated in the present study by comparing the prediction results and measured traffic noise levels. The predicted traffic noise levels on different floors of these residential buildings for 2017 were compared with those predictions (at the same buildings) for 2007. The measured traffic noise levels and the traffic flow data recorded for predictions may vary from day to day. Thus, the changes in road traffic noise exposure of residential buildings in Hong Kong over the past decade presented in this paper may not be accurate due to limited resources. However, the present investigation allows a glimpse of the temporal changes in urban road traffic noise over time. It is significant for prevention and mitigation of urban road traffic noise in Hong Kong as well as other cities. Since the situation of Hong Kong is an example of what may happen in other cities, the present study hopes to contribute to policies of urban road traffic noise control for better urban acoustic environment worldwide.
MATERIAL AND METHODS

Situation of Hong Kong over the past decade

With over 7.4 million people in a territory of 1108 square km, Hong Kong is the fourth-most densely populated region in the world as of the year 2017. The topography of Hong Kong is hilly to mountainous with steep slopes. Only about 24% of the land area (266 square km) has been developed, and 7% of the total land area is for residential purposes. About 40% of the land area is reserved as country parks and nature reserves. It is unsurprising that Hong Kong is the world’s most dense and vertical city with the largest number of skyscrapers and 36 of the world’s tallest residential buildings. A large-scale traffic network has been developed in Hong Kong and is among the most heavily used in the world. Although the large-scale road traffic network benefits the inhabitants and economy, insufficient land constrains residential buildings to adjacent road traffic and restricts the progress of the road traffic network. The development of traffic network has been sluggish in the past ten years. According to the Highways Department of the Hong Kong government, in 2007 there were 1984 km of road, of which 441 km were on Hong Kong Island, 452 km in Kowloon, and 1091 km in the New Territories. By December 2017, the total length of roads only increased to 2107 km (442 km on Hong Kong Island, 472 km in Kowloon and 1,193 km in the New Territories). Only 123 km of new roads have been built in the past decade (growth rate of 6.2%), and most of the newly-built roads are in the New Territories (generally considered as suburb area), as illustrated in Figure 1.

Nevertheless, the number of licensed vehicles in Hong Kong has increased rapidly from about 565,061 in 2007 to about 766,200 in December 2017. Licensed vehicles are categorized as ‘private cars’ and ‘others’. The category ‘others’ includes all types of buses, taxis, goods vehicles, special purpose vehicles and government vehicles. It can be observed from Figure 2 that the increased number of private cars account for nearly all of the total increased number of vehicles. Over this time, the total number of vehicles increased by 36.6%, and the number of private cars increased by 48.5%. The proportion of vehicles classed as private cars increased from 65.9% in 2007 to 72.1% in 2017. Considering the slow progress in the development of the road traffic network of Hong Kong over the past decade, the rapidly increasing number of vehicles will aggravate the immense pre-existing road traffic noise problem. Therefore, the analysis of temporal changes in road traffic noise of Hong Kong over the past decade is necessary and will be conducive to possible traffic noise mitigation designs and measures.

CRTN model

A road traffic noise prediction model that assesses the likely effects of traffic noise on people and the environment is required to aid in the early stages of design of roads and dwellings. A road traffic noise prediction model is also significant in the assessment of existing or envisaged changes to the traffic noise conditions. Six methods of road traffic noise prediction are commonly used around the world, including the FHWA method in the US, the CRTN method in UK, the RLS 90 method in Germany, the STL-86 method in Switzerland, the ASJ method in Japan and MITHRA method in France. Many alternative methods of road traffic noise prediction have been developed and adopted in different countries and areas, for example, in the Nordic countries, Mainland China, Taiwan, Italy and Iran. The mathematically-based CRTN method is among the first systematic schemes that consider certain physical conditions and the surrounding environmental characteristics of the traffic roadway when estimating road traffic noise. The CRTN method has been the sole tool for the assessment of road traffic noise by local authorities in Hong Kong. Therefore, this study will employ the CRTN method to evaluate...
and characterise the road traffic noise in Hong Kong over the past decade in the form of descriptor LA10. The descriptor LA10 in the CRTN model is one type of the A-weighted percentile levels LN, which are statistical parameters defined as the noise level exceeded for N% of the measurement time.

The CRTN method assumes the traffic noise source as a continuous line source with a constant speed (taking no account of vehicle acceleration) at a height of 0.5 m above the carriageway and 3.5 m from the nearside carriageway edge. At the reception point, with a reference distance of 10 m from the kerb (which is defined as the edge of the traffic lanes excluding the hard shoulders, hard strips and bus lay-bys), the CRTN method suggests the expression for the basic noise level LA10 as:

\[
LA10 = 10\log Q + 33\log (V + 40 + 500/V) + 10\log (1 + 5P/V) + 0.3G - 26.6
\]  

where \( Q \) is the total number of vehicles per hour, \( V \) represents the traffic speed, \( P \) is the percentage of heavy vehicles (weighting over 1525 kg) and \( G \) is the road gradient (expressed as a percentage).

The basic noise level LA10 considers the traffic flow, traffic speed, traffic composition, and road gradient. Additional corrections for the actual assessment point and other topographic data are taken into account in the CRTN model for the estimation of LA10. For the calculation of the predicted LA10 at different floor levels of a building, as illustrated in Figure 3, the distance correction of the CRTN method is based on the shortest distance \( d' \) between the reception point and the effective source point given by \( d' = \sqrt{(d + 3.5)^2 + h^2} \) (where \( d \) is the shortest horizontal distance and is assumed to be at least 4 m, \( h \) is the relative height of the reception point from the source line) and is expressed as:

\[
\Delta L_D = -10\log \left( \frac{d'}{13.5} \right)
\]  

Considering the compact form of the urban area, a correction for reflection from the opposite facade facing the reception point is a significant factor and is calculated by:

\[
\Delta L_F = 1.5 \left( \frac{\theta'}{\theta} \right) \]  

where \( \theta' \) is the sum of the angles subtended by all reflection facades on the opposite side of the road, and \( \theta \) is the total angle of the view at the reception point. More detailed calculation of additional corrections can be found in Ref. 36 and will not be presented here for simplification. Therefore, the predicted LA10 noise level can be obtained by combining the basic noise level given in Eq. (1) and corrections given in the CRTN method according to actual situation.

**RESULTS**

**Predicted and measured results of traffic noise levels at different floor levels of selected residential buildings in Hong Kong**

The accuracy and suitability of the CRTN method for predicting road traffic noise in Hong Kong has been evaluated by comparing the predicted values with measured traffic noise levels. Measurements of LA10 at different floor levels of some selected residential buildings in Hong Kong were first conducted in 2007, and then repeated at the same buildings in 2017. The measured traffic noise level LA10 and the traffic flow data for the predictions of LA10 using CRTN method were obtained in a one-hour period during the morning peak traffic. However, the measurements of LA10 and recorded traffic flow data may vary from day to day, especially between the working days and holidays. For
more common cases of road traffic noise, the working days were chosen to conduct measurements in this paper. The approximate locations of these selected buildings are shown in Figure 4. These are typical residential areas with concentrated dwellings and convenient road traffic conditions, and no new dwellings and roads are developed in these areas over the past decade. The residential buildings selected for prediction and measurement were chosen in order to avoid complicated traffic conditions such as multiple connected streets or roads in urban areas where there may
have been various non-traffic noise sources and traffic control signals. Other possible noise sources such as playgrounds, construction areas, railways, and noisy markets are distant from the selected residential buildings to ensure the accuracy of the traffic noise measurement. For traffic noise measurements of different floor levels of buildings, the measurement point was set to be a 1 meter from the exterior building facades. The sound analyser type B&K 2260 was used to obtain the traffic noise descriptor $L_{A10}$. A digital video camera was used to record the traffic flow in order to count the total traffic and the number of heavy and light vehicles synchronously during each measurement. Table 1 shows the predicted and measured noise levels $L_{A10}$ at different buildings in the years 2007 and 2017, as well as the traffic count for each measurement.

Comparisons of predicted traffic noise levels with measurements are illustrated in Figure 5. The predictions using the CRTN model correlate well with the $L_{A10}$ measured in both 2007 and 2017 (with a correlation coefficient ($R^2$) of 0.8032 and 0.7626 for 2007 and 2017, respectively). It should be noted that occasional strong winds and occasional noise from vehicle brakes and pedestrians were unavoidable throughout the measurements. Therefore, this indicates that traffic noise levels predicted by the CRTN method correlate closely with the measured levels despite the change of the traffic conditions over the years. The accuracy and suitability of the CRTN method presented here also generally agree with the previous study of Mak et al.\textsuperscript{[28,45]}

### Prediction of traffic noise LA10 at different floor levels of selected residential buildings in Hong Kong

Being a major metropolitan city and one of the most densely populated high-rise cities in the world, Hong Kong is also labelled as one of the noisiest cities in the world. The road traffic is considered as the dominant source for the noisy urban acoustic environment. Due to limited land source and rapid development in the past, the residential buildings in Hong Kong are constrained to be within short distance of existing roads. The lack of concern for the environment in previous planning and increased demand for traffic in the past decade have resulted in high levels of exposure to traffic noise in residential buildings with no immediate noise mitigation solutions. Hong Kong has made tremendous efforts to alleviate the traffic noise problem. This study aims to evaluate the urban traffic noise in Hong Kong over the past decade. All seven selected residential buildings directly face a road without any complicated traffic conditions or other possible noise sources. The approximate locations of these buildings are illustrated in Figure 4 and measured traffic data used for traffic noise level prediction is given in Table 1. Comparisons of predicted traffic noise levels at different floors of these residential buildings in 2007 and 2017 are shown in Figure 6.

It can be observed from Figure 6 that the predicted $L_{A10}$ values exceeded the benchmark of 70 dB(A) in both 2007 and 2017 at nearly all floor levels of all the residential buildings.

### Table 1: Traffic count during LA10 measurements and predictions based on the traffic conditions

| Site Traffic concerned | Building Building floor | Year | Traffic count per hour | Predicted $L_{A10}$ | Measurement |
|------------------------|-------------------------|------|------------------------|---------------------|-------------|
|                        |                         |      | Near lane Light (%)    | Far lane Light (%)  |
|                        |                         |      | $P$ (%)                | $V$ (km/h)         |
|                        |                         |      |                        | $P$ (%)            | $V$ (km/h) |

1. Tai Po Tai Wo Road  
   Tai Po Center Block X  
   1/F 2007 606 204 25.2 56.4 576 258 30.9 39.5 74.2 72.5  
   1/F 2017 538 372 40.9 56.6 440 272 38.2 60 76.2 73.1

2. Kam Ying Road  
   Saddle Ridge Garden Block 12  
   9/F 2007 92 72 43.9 52.2 72 56 43.8 48.1 67.8 67  
   9/F 2017 64 89 58.2 41.1 119 71 37.4 42.2 68.7 69.3

3. Tai Chung Kui Road  
   Belair Gardens Beverley  
   1/F 2007 694 516 42.6 49.9 516 232 31 45.1 73.8 73.4  
   1/F 2017 662 508 43.4 59.2 332 197 45.9 58.2 74.1 76.2

4. Kwai Chung Road  
   Kwai Fung House  
   11/F 2007 1612 204 11.2 48.5 1392 176 11.2 51 73.7 74.4  
   10/F 2017 935 717 43.4 53 1028 816 44.2 44.2 77.3 78.1

5. Lung Chuen Road  
   Chun Sing House  
   16/F 2007 2380 1592 40.1 58.7 2156 1394 39.3 55.4 78.6 77  
   13/F 2017 2111 1881 47.1 53.4 1973 1749 47 52.5 78.7 78.1

6. Prince Edward Road  
   Prince Edward Tower  
   12/F 2007 2301 705 23.5 37.8 2301 705 23.5 37.8 None 71.6 74  
   10/F 2017 1901 1681 34.6 34.6 None 74.2 75

7. Island Eastern Corridor  
   Tai On Building  
   19/F 2007 2113 493 18.9 82 1800 533 22.8 80 76 74.5  
   23/F 2017 1671 951 36.3 65.8 1303 972 42.7 67.8 78.1 79.7

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except site 2. For the investigated residential buildings, the traffic noise levels of 2017 were greater than those of 2007. This indicates that it is not easy to achieve the benchmark of 70 dB(A) at all floor levels of existing buildings and that the road traffic noise problems are getting more serious, despite the great efforts of the government. As illustrated in Figure 6, it can be generally considered that there has been no increase of traffic noise levels at site 3. A slight increase in traffic noise levels can be found at sites 1, 2, 5 and 7. However, rapid increases of 4 dB(A) and 3 dB(A) in traffic noise levels can be observed at site 4 and site 6 respectively. Considering the traffic noise levels at site 4 and site 6 were already exceeding the benchmark in 2007, the traffic noise levels of these two sites in 2017 were terrified. The different changes in traffic noise levels of these residential buildings motivate us to seek the reasons and possible solutions.

Analysis of the change of the traffic noise levels
The comparisons of traffic conditions between the years 2007 and 2017 at sites 4 and 6 are illustrated in Table 2. For site 6, the total number of vehicles increased by 20% between 2007 and 2017. The mean velocity of vehicles decreased slightly from 37.8 km/h to 34.6 km/h. Generally, the flow of the traffic is unimpeded despite of the increased number of vehicles. However, the increased number of vehicles has caused the road traffic noise exposure of the building to deteriorate. The average traffic noise levels at different floors within the building on site 6 (Prince Edward Road) increased by over 3 dB(A). The total number of vehicles classed as heavy vehicles increased from 705 to 1681, and the percentage of heavy vehicles increased from 23.5% to 34.6%. Figure 7 compares the predicted L_{A10} of year 2007 and 2017 with predicted values based on two different hypotheses. Hypothesis 1 assumes that the number of heavy vehicles and the mean velocity in 2017 remains the same as it was in 2007 without altering the total number of vehicles in 2017. Hypothesis 2 changes the mean velocity of the Hypothesis 1 into the level in 2017. It can be observed from Figure 7 that the heavy vehicles account for almost all of the increased traffic noise levels, and the mean velocity nearly has no effects on the noise levels.
traffic noise levels. Although the total number of vehicles increased by 20%, there would have been almost no increase in traffic noise levels with restricted heavy vehicles.

The effects of the number of heavy vehicles on the traffic noise levels are more obvious at site 4. As shown in Table 2, the total number of vehicles and their mean velocity recorded at site 4 have remained almost the same over the past decade. The increased heavy vehicles result in the additional 4 dB(A) of traffic noise at all floor levels. This indicates that the deterioration of the urban acoustic environment may not be caused by an increased total number of vehicles, but that heavy vehicles are dominantly responsible for the excessive traffic noise levels. In order to investigate the effects of the mean velocity on the traffic noise levels, two hypotheses consider different mean velocities based on the traffic conditions at site 4 in 2017. Figure 8 indicates that the mean velocity has little effect on the traffic noise levels at site 4.

The traffic noise levels at site 3 remain the same in 2017 as it was in 2007. Although the percentage of vehicles classified as heavy vehicles increased from 38.2% to 41.5%, as shown in Table 3, the number of heavy vehicles decreased as did the total number of vehicles. However, the mean vehicle velocity increased from 48.1 km/h to 58.9 km/h. The beneficial effects of a decreased number of heavy vehicles and total vehicles have been counteracted by this increase in mean velocity. Figure 9 compares the predicted $L_{A10}$ values for 2007 and 2017 with predicted values based on two different hypotheses. Hypothesis 1 and Hypothesis 2 assume a change of mean velocity to 50 km/h and 45 km/h respectively by 2017. Unlike the situation of sites 4 and 6, a distinct decrease in traffic noise levels can be observed between predicted $L_{A10}$ for 2017 and both of these two hypotheses. However, the difference in traffic noise levels between Hypothesis 1 and Hypothesis 2 are not obvious. Therefore, it indicates that a reasonable restriction of vehicle velocity can alleviate the noisy of urban acoustic environment without effects on the smooth flow of traffic.

The effects of mean velocity on the traffic noise levels are different among sites 3, 4 and 6. Reduction of mean velocity contributes to the mitigation of traffic noise levels at site 3, however, it has little effects on the traffic noise levels at sites 4 and 6. Figure 10 shows the plan view of selected buildings at sites 3, 4 and 6 respectively. Site 4 and site 6 are located in typical urban street canyons flanked by high-rise buildings, while there is no reflection facade opposite site 3. It indicates that the urban street canyons are not sensitive to variation of the mean velocity. Restriction of mean velocity for

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**Table 2: Comparisons of traffic conditions across different years for sites 4 and 6**

| Site | Traffic concerned | Year | Traffic flow summary (per hour) | Mean velocity |
|------|------------------|------|---------------------------------|---------------|
|      |                  |      | Light | Heavy | $P$ (%) | Total |               |
| 4    | Kwai Chung Road  | 2007 | 3004  | 380   | 11.2    | 3384  | 49.7           |
|      |                  | 2017 | 1963  | 1533  | 43.8    | 3496  | 48.4           |
|      |                  |      | 1963  | 1533  | 43.8    | 3496  | 58             |
|      |                  |      | 1963  | 1533  | 43.8    | 3496  | 38             |
| 6    | Prince Edward Road | 2007 | 2301  | 705   | 23.5    | 3006  | 37.8           |
|      |                  | 2017 | 1901  | 1681  | 34.6    | 3582  | 34.6           |
|      |                  |      | 2877  | 705   | 19.7    | 3582  | 37.8           |
|      |                  |      | 2877  | 705   | 19.7    | 3582  | 34.6           |

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**Figure 7:** Comparisons of predicted $L_{A10}$ at site 6 in 2007 and 2017 and predictions based on hypotheses.
urban street canyons is useless for road traffic noise control. On the contrary, it will obstruct traffic flow and may generate additional noise due to vehicle brakes and engine start.

The slight increase in traffic noise levels can be found at sites 1, 2, 5 and 7. For site 1, both the increased number of heavy vehicles and increased mean velocity account for the increase in traffic noise levels. The respective effects of increased number of heavy vehicles and increased mean velocity on the traffic noise levels at site 1 are demonstrated in Figure 11. The two hypotheses for site 1 are given in Table 4. The increased number of heavy vehicles has a far worsen impact on the road traffic noise than the increased mean velocity. Nevertheless, the combination of reduction in mean velocity and modest growth in heavy vehicle numbers makes a slight increase in traffic noise levels at sites 2 and 5. It should be noted that the

![Figure 8: Comparisons of predicted LA10 at site 4 in 2007 and 2017 and predictions based on hypotheses.](image_url)

| Site | Traffic concerned | Year | Traffic flow summary (per hour) |
|------|-------------------|------|---------------------------------|
|      |                   |      | Light | Heavy | P (%) | Total | Mean velocity |
| 3    | Tai Chung Kui Road| 2007 | 1210  | 748   | 38.2  | 1958  | 48.1          |
|      |                   | 2017 | 954   | 705   | 41.5  | 1699  | 58.9          |
|      | Hypothesis 1      |      | 954   | 705   | 41.5  | 1699  | 50            |
|      | Hypothesis 2      |      | 954   | 705   | 41.5  | 1699  | 45            |

![Figure 9: Comparisons of the predicted LA10 of different floor levels located at site 3.](image_url)
The number of heavy vehicles at site 7 rose sharply, as shown in Table 4. Fortunately, the increased traffic noise levels are not as severe as at sites 4 and 6 due to the large reduction of mean velocity. This may be the reason that the speed limit of the Island Eastern Corridor (site 7) is 70 km/h rather than 80 km/h as it is for other roads of the same route, especially considering that the Island Eastern Corridor is the only expressway on Hong Kong Island. However, as shown in Figure 6, the traffic noise levels at all floors at site 7 exceeded 76 dB(A) in 2017. Effective measures should be taken to eliminate the immense traffic noise problem. Restriction of heavy vehicles is a proven and effective method, as illustrated above. Considering the significant role of the Island Eastern Corridor in Hong Kong Island, we propose a hypothesis in which the heavy vehicles increase by 50% at site 7 between 2007 and 2017 (without changing of the total number of vehicles in 2017), then the total number of heavy vehicles would be 1057 in 2017 instead of 1923. With this hypothesis, the traffic noise levels of 2017 are almost the same as those in 2007, as illustrates in Figure 12. Although the traffic noise problem at site 7 is still severe according to the hypothesis, it indicates that the acoustic environment will not deteriorate.
with time through some appropriate measures. The traffic conditions at site 7 shows that an appropriate decrease in mean traffic velocity will not prevent the smooth flow of traffic and will contribute to the elimination of traffic noise levels.

### Suggestions

According to aforementioned cases in this study, the urban road traffic exposure of residential buildings in Hong Kong seems to deteriorate over the past decade. The deterioration of the urban acoustic environment may not be caused by an increased total number of vehicles. The increased number of heavy vehicles is dominantly responsible for increased traffic noise levels, especially for street canyons, such as at sites 4 and 6 of this study. Reasonable limitations of vehicle velocity can contribute to the elimination of traffic noise levels without effects on the traffic flow at some sites. To prevent worsening of road traffic noise and improve the urban acoustic environment, some suggestions are given:

1. Despite the requirement of authorities to evaluate the effects of traffic noise for newly-built roads and residential buildings, noise may not be a primary factor in the early planning stage compared with engineering feasibility and cost of construction. The worsening of road traffic noise in the future is not taken into full consideration. Thus, mitigation measures such as roadside barriers or covers have to be taken in order to alleviate the excessive road traffic noise. However, lack of reservation places is problematic to retrofit existing roads with these measures. Although noise barrier is a kind of effective and economical method to reduce traffic noise, only about 3 kilometres of noise barriers have been built in Hong Kong over the past decade, including installations on newly-built roads. Therefore, noise mitigation measures for worsening traffic noise in the future should be emphasized in the planning stage.

2. Traffic management schemes should be more restricted in residential areas so that heavy vehicles or vehicles that do not need to go into residential areas or urban street canyons would be banned from doing so during sensitive hours. The effects of mean velocity on the road traffic noise are related to the structure of street. Reasonable limitations of vehicle velocity should be
explored where practicable on a case-by-case basis. An appropriate decrease in mean traffic velocity will not prevent the smooth flow of traffic and will contribute to the elimination of traffic noise levels.

(3) Vehicles with a weight greater than 1525 kg are qualified as heavy vehicles in the CRTN method. With growth of the economy and the development of the automobile industry, private vehicles increasingly tend to be heavy vehicles. However, heavy vehicles have adverse effects on a satisfactory acoustic environment that would protect people against excessive road traffic noise and provide a better quality of life to the public. The increased number of heavy vehicles rather than the increased number of total vehicles is dominantly responsible for increased traffic noise levels. Therefore, legislative control of private heavy vehicles is needed.

CONCLUSION

This study aims to assess the road traffic noise exposure of residential buildings in Hong Kong over the past decade. The accuracy and suitability of the CRTN method are evaluated first by comparing prediction results and measured traffic noise levels. The results show that the CRTN method could provide adequate predictions with correlation coefficients (R2) of 0.8032 and 0.7626 between the predictions and measurements of L_10 for 2007 and 2017 respectively. It indicates that the CRTN method is still reliable although it was released about 30 years ago. Based on the traffic flow data recorded synchronously during each measurement, the predicted traffic noise levels on different floors of seven selected residential buildings in 2017 are compared with those predictions in 2007. The exposure of these building to road traffic noise is higher in 2017 than in 2007. The study illustrates that the deterioration of the urban acoustic environment may not be caused by an increased total number of vehicles, but that heavy vehicles are dominantly responsible for the increased traffic noise levels. However, heavy vehicle numbers have increased quickly over the past decade due to the growth of the economy and development of the automobile industry. A decreased vehicle velocity can contribute to the elimination of traffic noise levels. However, the alleviation of traffic noise levels by velocity restriction may not be obvious for urban street canyons and may only work with a certain velocity range. Meanwhile, velocity restriction may act against the smooth flow of traffic. Therefore, a reasonable limitation of vehicle velocity should be explored where practicable on a case-by-case basis. Since the situation of Hong Kong is an example of what may happen in other cities, the present longitudinal study of the road traffic noise in Hong Kong hopes to contribute to policies of urban road traffic noise control for better urban acoustic environment worldwide.

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Conflicts of interest

There are no conflicts of interest.

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