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Effective traffic noise policy of urban development projects in South Korea

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Table of Contents

Executive Summary

In 1980, South Korean government built a large scale apartment complex in the Seoul metropolitan area because of consecutive urbanization and rapid industrialization. However, in late 1980, as the housing market surged rapidly, the government constructed several huge new towns. These new towns and urban development projects contributed to stabilizing the housing market, but residents in new towns began to suffer from traffic noise and this became social problems.

Traffic noise is caused by tire friction and also influenced by various factors such as vehicle volume and traffic speed. There are two primary measures to mitigate the traffic noise; reducing noise at their source and using anti-propagation measures. Even though at-source measures are preferable to anti-propagation measures, noise barriers representing anti-propagation measure are the most common measure to be applied.

In this paper, I used traffic noise level data to assess the factors that affect traffic noise. I examined the effectiveness of each type of noise reduction measures, which are at-source and anti-propagation, by the magnitude of noise-factors and the cost-effectiveness. I also identified noise reduction effectiveness of noise barriers.

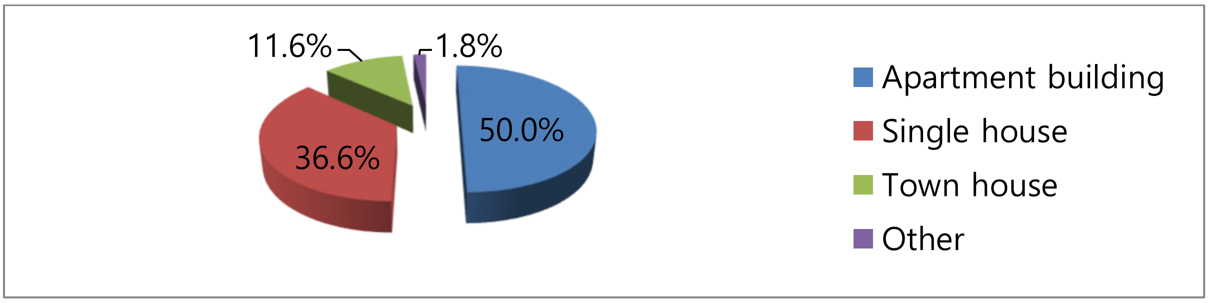
I found that some noise-factors have significant relationship with traffic noise statistically. These factors are vehicle volume, traffic speed, road pavement, apartment floors, and noise barrier application status. The magnitude of the factors is vehicle volume, traffic speed, and apartment floors in order from largest to smallest. At-source measures are more effective than anti-propagation measures based on the magnitude of the noise factors and the cost-effectiveness. Noise barriers are only effective on the lower floors of apartment buildings.

Introduction

In 1980, South Korean government built a large scale apartment complex in the Seoul metropolitan area because of consecutive urbanization and rapid industrialization. However, in late 1980, as housing market surged rapidly, the government decided to construct several huge new towns to stabilize housing prices near Seoul (Oh, 2008). This was called first new town development project. Based on the successful result of the first new town project, the government planned and implemented many urban development projects including the second new town project.

These new towns and urban development projects contributed to stabilizing the housing market and increasing quality of life. However, residents in new towns have been suffering from traffic noise problems. This is because predominantly provided housing types are apartment buildings, which are very vulnerable to traffic noise (Park, 2015). According to the 2015 Census of Korea, 50.0 percent of people live in apartment buildings and 11.6 percent live in townhouses (see chart 1), which means that more than half of the Korean population suffers from the daily influence of traffic noise.

Chart 1. Residential type per household in 2015



Source: Statistics Korea

Traffic noise is one of the largest negative externalities from urban development projects. Long-term exposure to noise pollution can lead to chronic annoyance and sleep disturbances, resulting in physiological changes in the body and certain diseases (Stansfeld et al., 2000; Bsbisch, 2002). Traffic noise also lowers the value of property as well as the quality of life of residents (M. Kim, Kim, & Kim, 2015; Taylor, Breston, & Hall, 1982). Therefore, traffic noise has been severe a social problem and controversial issue in urban development projects.

Traffic noise is basically caused by tire friction and also influenced by various urban factors such as traffic volume, average speed, vehicle type, and road surface. There are two primary measures to mitigate the noise emission. The first is to reduce noise at their source. The second is to mitigate noise by using anti-propagation (end of pipe) methods like noise barriers (Boer & Schroten, 2007). At-source measures are considered to be the first priority approach to reduce traffic noise (B. Kim, 2010). This is because the at-source measures reduce the overall noise generated and the anti-propagation measures are focused on reducing the noise emission in local level (Popp, 2002; Klooster, 2005). Generally at-source measures limit traffic speed and vehicle volume, and use low noise pavement. Noise barriers and tunnels are typical methods of anti-propagation measures.

However, among the noise abatement measures, noise barriers, which represent anti-propagation measure, are the most common measures applied in reality. They are a little easy to apply and quite effective on noise reduction (C. Kim, 2014; H. Kim, 1998). Considering the domestic land use situation of South Korea, noise barriers are the most appropriate measures (Yang, 2012). Thus, according to the Ministry of Environment report of South Korea, 5,107 noise barriers (1,373km) were installed by 2013. More than 50km noise barriers are being constructed every year. As the noise barriers are widely applied as a noise reduction measure, the installation of noise barriers will be increasing.

Studies and papers, which are relevant to traffic noise mitigation measures, explain that at-source measures are considered as the most effective measures to achieve overall noise reduction, but ironically noise barriers are applied most. That is, anti-propagation measures are being used more often than at-source measures to manage noise problems.

In this paper, I use traffic noise level data from urban development projects in South Korea to assess the factors that affect traffic noise. Some factors are related to the at-source measures and others are related to the anti-propagation measures. I examine which types of noise reduction measures, at-source or anti-propagation, are more effective to reduce traffic noise based on the magnitude of each factors affecting noise and the cost-effectiveness. I also identify whether noise barriers, which are widely applied now, are effective on noise reduction and suggest what type of noise policy is necessary for effective noise measures.

Literature Review

Traffic noise is mainly caused by engine noise, noise generated by the surface of the car and the flow of air, and tire friction noise. Researcher indicates that the tire friction noise generated from road surface is the predominant cause of traffic noise (Lee, 2004). Traffic noise is also influenced by various external factors such as traffic management (speed and flow), surrounding structure, density of traffic, type of vehicle, and road surface (H. Kim, 1998). On the basis of noise emission cause, there are basically two methods to mitigate traffic noise. The first is to reduce traffic noise at their sources, which manage vehicle speed, volumes, and road types and surfaces. The second is to minimize noise exposure by means of anti-propagation such as noise barriers, tunnels, or buffer zone and by limiting the number of floors in apartment (Boer & Schroten, 2007; Zagvozda, 2015).

The literature indicates that limiting traffic speed and volume definitely have positive effect on traffic noise level (see Table 1). Boer & Schroten (2007) shows that limiting speed has a noise reduction of 0.7 ~ 2.1 dB(A). In particular, when the vehicle speed is decreased from 60km/h to 50km/h, the noise reduction is the greatest at 2.1 dB(A). They also explained that there is positive correlation between traffic volume and traffic noise. That is, the less traffic on the roads, the lower noise emission is generated. For example, if traffic volume is reduced by 50%, there will be a noise mitigation of about 3 dB(A) (Boer & Schroten, 2007).

Table 1. Effects of speed limit changes and traffic reduction on noise mitigation

Speed reduction (10% heavy traffic)				***Traffic reduction***	
From 110 to 100 km/h	*0.7 dB(A)*	*From 70 to 60 km/h*	*1.8 dB(A)*	*10%*	*0.5 dB(A)*
From 100 to 90 km/h	*0.7 dB(A)*	*From 60 to 50 km/h*	*2.1 dB(A)*	*30%*	*1.6 dB(A)*
From 90 to 80 km/h	*1.3 dB(A)*	*From 50 to 40 km/h*	*1.4 dB(A)*	*50%*	*3.0 dB(A)*
From 80 to 70 km/h	*1.7 dB(A)*	*From 40 to 30 km/h*	*0 dB(A)*	*75%*	*6.0 dB(A)*

Source: A study of traffic noise reduction in Europe (Boer & Schroten, 2007)

Boer & Schroten (2007) added that traffic management measures will be advantageous in reducing the traffic noise level by up to 4.0 dB(A), when controlling for traffic flow and speed. Typical measures are traffic calming, roundabouts and speed humps. Speed cameras, which regulate high speed traffic, also help to reduce noise levels. Installing a speed camera on the expressway reduces noise effect around to 1dB(A) (C. Kim, Choi, Chang, & Kim, 2014).

Porous pavements, which partially absorb noises into the air void, are an additional traffic noise measure. These pavements reduce noise level relative to nonporous pavements (Rochat & Donavan, 2013). Asphalt pavements have a 3.0 dB(A) noise reduction effect compared to concrete pavements (C. Kim, 2014).

Road types are also a critical factor affecting noise level. Expressways which are penetrating or passing by adjacent to a city create relatively louder noise than city roads. High speed and volume roads induce many noise complaints from residents (Ahn, Ryu, Kim, Kim, & Chang, 2014). Therefore, it is necessary to plan bypass roads or to keep expressways far enough away from residential areas in urban development projects (Jang, 1997).

In cities, traffic noise varies depending on the floor of the apartment (see below Table 2). In the case of 15-floor apartment buildings, noise levels increase up to the middle floor (7th) by 2.6 dB(A), and then noise levels gradually decreases to the top floor by 0.5 dB(A) (Park, 2005).

Table 2. Noise level adjustment coefficient by floors

Floor	***Adjusted***	***Floor***	***Adjusted***	***Floor***	***Adjusted***
1	-	*6*	*2.6dB(A)*	*11*	*1.4dB(A)*
2	*1.1dB(A)*	*7*	*2.6dB(A)*	*12*	*0.9dB(A)*
3	*1.9dB(A)*	*8*	*2.4dB(A)*	*13*	*0.6dB(A)*
4	*2.4dB(A)*	*9*	*2.2dB(A)*	*14*	*0.4dB(A)*
5	*2.6dB(A)*	*10*	*2.0dB(A)*	*15*	*0.5dB(A)*

Source: A study on road noise reduction plan in urban development such Housing Complex and land

However, in Park's other recent study, the noise level steadily increases as the floors rise in apartment buildings over 20 floors. Noise level has a positive correlation with apartment building floor levels. Thus, it is necessary to take noise measures against higher floors in apartments (Park, 2014).

To relieve traffic noise, noise barriers are quite helpful (Yang, 2012). They can reduce noise level to 10~20 dB(A), at most, in actual application. In order to maximize the reduction effect, noise barriers of adequate height and length need to be installed (H. Kim, 1998; H. Kim, Ju, & Ju, 2004).

However, noise barriers have some negative impacts; specifically, they disrupt the urban landscape and block the view and wind's stream. Sun & Park (2007) insist that noise barriers and tunnels do not harmonize with urban landscapes, but rather interfere with the positive living environment. According to government data[1] on noise barriers installment during 2001~2010, noise barriers higher than 10 meters have increased from 2007. On the

[1] Noise barrier design guideline (Ministry of Land, Infrastructure and Transport)

other hand, noise barriers of more common 3~5 meters have decreased since 2005. It can be assumed that negative impacts of noise barriers are increasing.

Moreover, noise barriers have a limited effect on reducing traffic noise. The anti-propagation effect is only valid in situations in which noise-receiving points are directly blocked by noise barriers. Thus, other approaches are needed to manage noise problems for high floor apartments (H. Kim et al., 2004).

Keeping a certain degree of distance between the noise source (road) and receiving point is another noise reduction method. According to the result of the noise reduction effect by distance, the noise reduction amount of about 2.5 ~ 4.0 dB(A) was obtained for every doubling of the distance. The minimum distance not to be disturbed by traffic noise in urban development projects is eight meters (H. Kim et al., 2004).

At-source measures are generally more cost-effective than anti-propagation measures (Ohm, 2006; Larsen, 2005). The Danish national traffic noise research demonstrates that anti-propagation measures such as noise barriers are the least cost-effective methods among noise measures (Danish, 2003). When comparing to anti-propagation measures, at-source measures like low pavements and speed cameras are far more cost-effective (Larsen, 2005; J. Kim & Park, 2008).

Methodology

Data collection

The data used in this study is from two noise research studies: Park, 2014, 2015. Park studied the road noise prediction model application guidelines for environmental impact assessment in 2014 and studied the road noise policy and improvement of indoor noise measurement method in 2015. In his research, he found some apartment buildings in urban development projects which had noise problems. Then, he measured traffic noise levels of those apartment buildings every a couple of floors. While he was measuring the noise level, he recorded vehicle volume, speed and crucial relevant noise factors at the same time. His goal of the studies was to make guidelines for the noise prediction model of environmental impact assessment and for the indoor noise measurement method.

In order to examine the effectiveness of two types of noise reduction measures in this study, I extracted measurement data from his studies. The data are critical factors affecting traffic noise such as vehicle speed and volume, apartment building floors (height of noise heard), pavement type, and noise barrier application status etc. The unit of analysis is noise level in response to traffic noise. I made 236 observations through data cleaning. Table 3 shows the descriptive statistics of the data.

Table 3. Descriptive statistics of the data

Variable	***Obs***	***Mean***	***Std. Dev.***	***Min***	***Max***
Noise level (dB(A))	*236*	*63.59*	*5.408*	*51.7*	*76.5*
Average traffic speed (km/h)	*236*	*57.44*	*18.653*	*30.4*	*100.5*
Vehicle volume (total)	*236*	*4,778.55*	*3,170.286*	*108*	*17,220*
Large Vehicle volume	*236*	*502,85*	*684.801*	*0*	*3,660*
Small Vehicle volume	*236*	*4,275.70*	*3,199.115*	*96*	*13,560*
Floors (measurement height)	*236*	*10.07*	*6.283*	*1*	*27*
Number of road lanes	*236*	*9.11*	*3.857*	*4*	*18*
Distance to noise source (m)	*236*	*53.58*	*34.846*	*5*	*160*
RT dummy 1 (city road)	*236*	*0.470*	*0.500*	*0*	*1*
RT dummy 2 (expressway)	*236*	*0.326*	*0.470*	*0*	*1*
RT dummy 3 (national highway)	*236*	*0.204*	*0.403*	*0*	*1*
RP dummy 1 (asphalt)	*236*	*0.915*	*0.279*	*0*	*1*
RP dummy 2 (asphalt&concrete)	*236*	*0.059*	*0.237*	*0*	*1*
RP dummy 3 (concrete)	*236*	*0.026*	*0.158*	*0*	*1*
NW dummy1 (noise barrier not applied)	*236*	*0.483*	*0.501*	*0*	*1*
NW dummy2 (noise barrier applied)	*236*	*0.517*	*0.501*	*0*	*1*

Dependent variable

Noise level generated by traffic on the road is the dependent variable.

Independent variable

When measuring traffic noise level, all factors influencing noise measurement are independent variables. Among various noise-affecting factors, I used eight factors as independent variables. These independent variables are divided into two categories, which are at-source and anti-propagation. Table 4 explains the categorization of the independent variables.

Table 4. Independent variables

	Category	
	At-source factors	***Anti-propagation factors***
Independent variable	*Traffic speed,* *Vehicle volume,* *Road type,* *Pavement type*	*Apartment floors(Height of noise-heard)* *Noise barrier application status,* *Distance between noise source and receiving location,* *Number of road lanes*

At-source variables are traffic speed, traffic volume, road type, and pavement type. Regarding vehicle speed, I used the average vehicle speed for measuring the time of noise level to minimize the measuring errors. Traffic volume was divided into two subcategories: large vehicles and small vehicles. Both road and pavement type factors are dummy variables. Road types are city roads, national highways, and expressways, whereas pavement types are asphalt, concrete, and the combined type of asphalt and concrete. National highways are intermediate level roads between city roads and highways.

Anti-propagation variables are apartment floors (height of noise-heard), noise barrier application status, distance between noise source and receiving location, and number of road lanes. Apartment floors are the vertical noise measurement and indicate how much noise level changes from height. Noise barriers application status is a dummy variable which tells whether it is installed or not. Distance between noise source and noise-heard point means the effect on the noise level on the horizontal as it decreases or increases. The number of road lanes is related to vehicle volume and distance.

Analysis model

I attempt to analyze the magnitude of each factor affecting noise with regression models. The equation I use to run my regressions is: $y = ß_0 + ß_1x_1 + \epsilon$. Specifically, $y = ß_0 + \text{averagespeed}x_1 + \text{trafficvolume}x_1 + \text{roadtype}x_1 + \text{pavementtype}x_1 + \text{floors}x_1 + \text{noisebarriers}x_1 + \text{distance}x_1 + \text{roadlane}x_1 + \epsilon$.

Findings and Analysis

Impact of noise-affecting factors

After running the regressions, I found that the variables of traffic speed, traffic volume, road pavement, apartment floors, and noise barriers application status have an effect on traffic noise level. Their coefficients are significant at a 90~99% confidence level. Table 5 shows the regression result of each variable. Since the units of each variable are different, I compared how much the variables affect the noise level by multiplying the coefficient of each variable by the mean value of the data.

Table 5. Regression result

Variable	*Coef*	*Robust Std. Err.*	*t*	*P>|t|*
Average traffic speed (km/h)	*0.0634754*	*0.0225872*	*2.81*	*0.005****
Large vehicle volume	*0.0018972*	*0.0007207*	*2.63*	*0.009****
Small vehicle volume	*0.0007043*	*0.0002326*	*3.03*	*0.003****
RT dummy 1 (city road)	*-1.785474*	*1.294468*	*-1.38*	*0.169*
RT dummy 2 (expressway)	*-4.445714*	*1.449229*	*-3.07*	*0.002****
RP dummy 1 (asphalt)	*-5.838516*	*1.935576*	*-3.02*	*0.003****
RP dummy 2 (asphalt&concrete)	*-7.972295*	*2.063812*	*-3.86*	*0.000****
Floors (measurement height)	*0.330554*	*0.0459392*	*7.20*	*0.000****
NW dummy1 (noise barrier not applied)	*-1.436473*	*0.8304329*	*-1.73*	*0.085**
Distance to noise source (m)	*-0.0191004*	*0.0151271*	*-1.26*	*0.208*

Number of load lane	*0.0132349*	*0.0845287*	*0.16*	*0.876*

***P≤0.01, **P≤0.05, *P≤0.1

First of all, the coefficient of the average traffic speed is significant. Its coefficient is 0.063 which means as traffic speed goes up 10 km/h, the noise level increases by 0.63 dB(A). When multiplying the mean value of the traffic speed (57 km/h) by the coefficient, it shows that it generates 3.6 dB(A).

The coefficient of traffic volumes is also significant. When comparing each unit by vehicle type, large vehicles are relatively noisier than smaller ones. In the multiplication of the mean value and the coefficients, it generates 3.94 dB(A) in total: 0.95 dB(A) for large vehicles and 2.99 dB(A) for small vehicles.

It seems that road type does not affect noise level statistically. Whereas the coefficient of city roads (RT dummy1) is not significant, expressways (RT dummy2) show significance. Expressways generate less noise by as much as 4.4 dB(A) compared to national highways (RT dummy3).

The regression shows that road pavement type affects traffic noise statistically. Asphalt pavement (RP dummy1) takes advantage of reducing noise level by as much as 5.8 dB(A) compared to concrete. The combined pavement (RP dummy2) also creates less traffic noise than concrete. It seems that asphalt or mixed pavement have a greater effect on noise reduction than concrete pavement.

Apartment floors have a significant relationship with noise level. As one floor goes up, noise level increases by 0.33 dB(A). Noise level is 3.3 dB(A) for the mean value (10 floors) of apartment floors. It shows that the residents of the higher floors of the apartment buildings are greatly affected by the traffic noise.

The noise level in areas without noise barriers (NW dummy1) is lower than that of areas with noise barriers (NW dummy2). That is, noise level is 1.4 dB(A) higher when there are noise barriers. This is an unusual result. It seems that noise barriers have limited effect on mitigating traffic noise level.

Since distance from noise source is inversely proportional to noise level, noise level decreases. However, the coefficients of the variables of the distance and the number of roads are not statistically significant.

Effective noise abatement measures

As a result of regression, the traffic speed, traffic volume, and road pavement variables show that they have an effect on noise level. These factors belong to at-source measures group. On the other hand, in the anti-propagation measures group, apartment floors and noise barrier application status variables affect traffic noise statistically. Table 6 indicates each variable’s impact on traffic noise when multiplying each factor's coefficient by the mean value of the data.

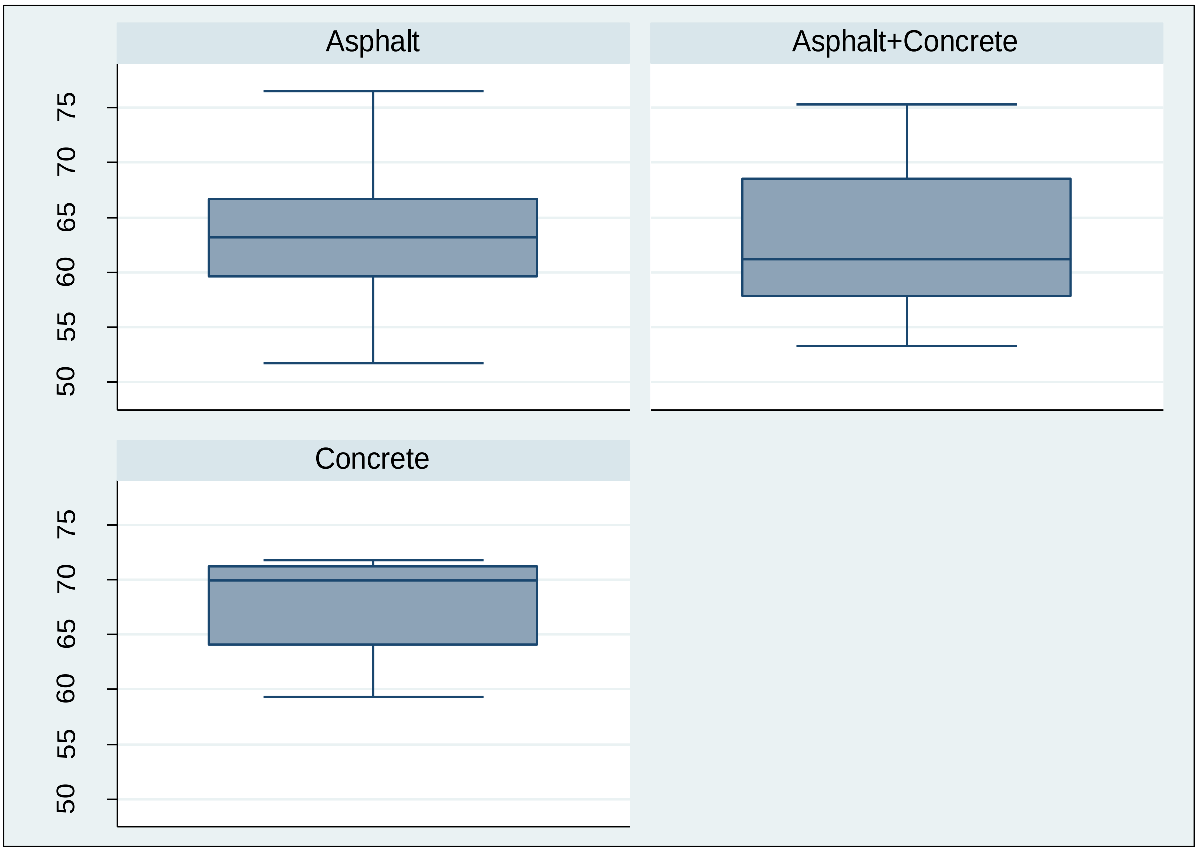
Table 6. Impact of each factor on noise level

Independent Variable		***Impact on noise level in the means***
At-source measures	*Traffic speed*	*3.6dB(A)*
	Vehicle volume	*3.9dB(A)*
	Road pavement(asphalt, combined)	*-5.8~-8.0dB(A)(compared to concrete)*
Anti-propagation measures	*Apartment floors*	*3.3dB(A)*
	Noise barrier installation	*1.4dB(A)(compared to non-installation)*

Based on the above analysis, vehicle volume and traffic speed are the major factors affecting traffic noise when various noise factors influence noise level simultaneously. This means that the effectiveness of noise reduction measures will be maximized when establishing noise policies with a focus on vehicle volume and traffic speed. Thus, if policy planner manages those factors in a more effective way, the goal of noise mitigation can be achieved with ease.

Kim (2014) insists that asphalt pavements have an around 3.0 dB(A) noise reduction effect compared to concrete pavement, but the regression result shows that asphalt pavements have a larger noise reduction effectiveness. This can be explained with the graph 1 as well (see below).

Graph 1. Noise level by road pavement type

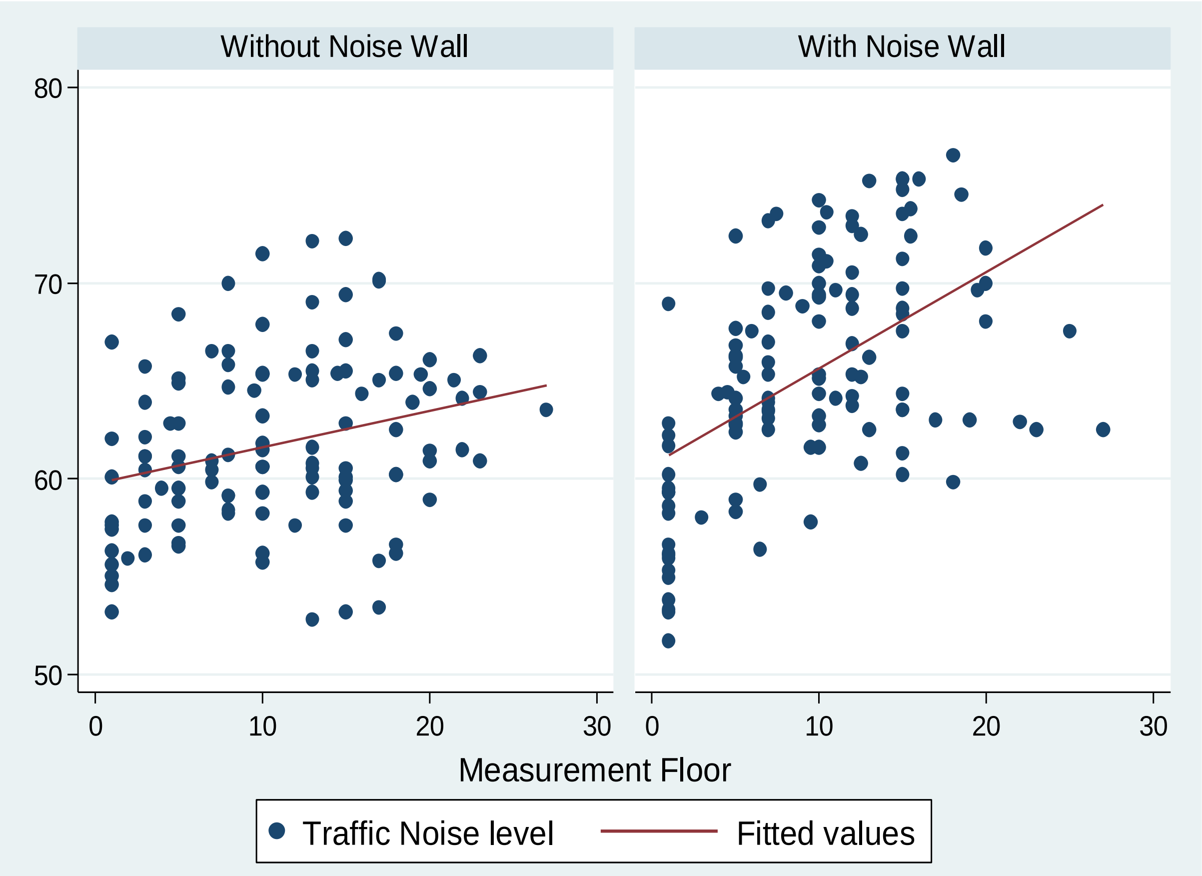


Restricting the number of apartment floors is a noise measure that can be applied during the initial planning stage. The regression results show that residents in higher floors of apartment buildings hear higher traffic noise. If the buildings adjacent to the road are limited to a certain number of floors, the impact of traffic noise will be greatly reduced. Adjusting the number of apartment floors in the planning stage has a substantial effect in dealing with noise level, so it can be a useful anti-propagation measure.

On the other hand, noise barriers, which are the most widely used as an anti-propagation measure, have practically no effect on noise reduction at least for the higher floors. The regression results indicates that the noise level of areas with noise barriers is 1.4 dB(A) higher than the noise level of areas without noise barriers. This could be caused by improper installation or limited effectiveness on higher floors, or both.

Graph 2 shows the correlation between noise barriers and apartment floors in the data. In areas with noise barriers, the level of noise reduction is effective below the 10th floor, but noise levels increase sharply above the 10th floor. Thus, we can assume that noise barriers have a limited effect on higher floors, even though they are effective on the lower floors of apartment buildings.

Graph 2. Correlation between noise barriers and floor height



In conclusion, at-source measures are more effective than anti-propagation measures based on the magnitude of the noise factors. Managing vehicle speed and traffic volume, which is at-source measure, is definitely the most effective to mitigate noise level. Asphalt pavements have a larger noise reduction effectiveness compared to concrete. Among the anti-propagation measures, adjusting the number of apartment floors in the initial planning stage is advantageous in noise countermeasures. Noise barriers are only effective on the lower floors of apartment buildings, and noise reduction effectiveness is limited in high-rise apartments.

The cost-effectiveness of noise measures

Measures of reducing the noise at the source are generally more cost-effective than those of anti-propagation measures (Ohm, 2006; Larsen, 2005). Cost-effectiveness of the above two types of noise measures can be demonstrated through the cost-benefit analysis of pavement measures and noise barriers.

The case study of Larsen (2005) indicates that porous asphalt is much more cost effective than anti-propagation measures such as noise barriers. Noise barriers are 3-10 times more expensive than porous asphalt. The Dutch Noise Innovation Programme (IPG) found that every decibel of noise mitigation at the source will save 100 million euros compared to noise barriers (Boer & Schroten, 2007).

A similar result was found in the Jo & Son (2001) study. They researched the cost-benefit analysis of noise barriers and low noise pavement for apartments adjacent to the highway. When estimating unit cost of the basic noise measures required to satisfy the noise limit (68 dB(A)) of the target site, the noise barrier was $9,495/dB(A)·㎡·year and the low noise pavement was $6,551/dB(A)·㎡·year. This study also demonstrates that low noise pavement, which is one of the at-source measures, is more cost-effective than noise barriers.

At-source measures related to vehicle speed and traffic volume, which have the greatest impact on traffic noise, are not easy to calculate in the cost, because these are preliminary countermeasures that are mainly applied in the initial planning stage. However, the costs for these measures are a tiny part of the total project budget. Bypassing large roads, constructing roundabouts, traffic calming, and speed humps are examples of countermeasures. The installation of speed cameras, which limit traffic speed, also reduces traffic noise at a relatively low cost. They cost only about 50,000 dollars for 2 units (J. Kim & Park, 2008). Therefore, the cost-effectiveness of at-source measures generally exceeds that of anti-propagation measures. That is, at-source measures are more advantageous in cost saving.

Effective traffic noise policy for urban development projects

It is found that factors related to the at-source measures have more effect on traffic noise than those of anti-propagation measures. This means that if these factors are managed to mitigate noise in an efficient way, the goal of noise reduction can be more easily achieved. As mentioned in the above analysis, noise barriers representing anti-propagation measures do not lead to effective outcomes. Their effectiveness is limited to the lower floors of an apartment building, and they also have social problems, such as the disruption of the urban landscape and the obstruction of the wind. Therefore, noise barriers are not adequate noise mitigation measures in urban development projects, which are responsible for many high-rise apartment buildings.

Thus, it is recommended that various at-source measures need to be developed and applied for urban development projects. As the vehicle volume and traffic speed have the greatest impact on traffic noise, the noise mitigation measures focused on these two factors need to be used broadly. For example, the vehicle speed can be controlled by utilizing various transportation systems and devices. Traffic volume can be also managed in the early planning stage of development projects in a way that bypasses large volumes of roads or stays away residential areas from the main roads. Application of traffic calming, roundabouts and speed humps which control the traffic speed and flow is also a useful strategy in traffic noise policy. On top of that, since restricting the number of apartment floors in the anti-propagation measures shows a substantial effectiveness, if applied together with noise-source measures, it will bring tremendous advantages in minimizing traffic noise.

Conclusion

I found that some noise-factors have a significant relationship with traffic noise statistically. These factors are vehicle volume, traffic speed, road pavement, apartment floors, and noise barrier application status. Other factors like road type distance to noise source, and number of road lanes do not affect traffic noise. Except for the dummy variable, the magnitude of the factors affecting the noise is vehicle volume, traffic speed, and apartment floor in order from largest to smallest. The first two factors are related to the at-source measures, and the last one is related to anti-propagation measures. Based on the magnitude of the noise factors, at-source measures are more effective than anti-propagation measures in noise reduction.

Moreover, at-source measures are also more cost-effective than anti-propagation measures overall. Specifically, when comparing representative measures of each type, which are pavement measures and noise barriers, pavement measures are far more advantageous in cost-effectiveness.

Noise barriers are effective below the 10th floor, but effectiveness will not last any longer above the 10th floor. That is, even though noise barriers have effectiveness in lower floors of apartment buildings, they have limited effectiveness in higher floors. In anti-propagation measures, limiting the number of apartment floors is a useful noise measure. However, this measure needs to be applied during the initial planning stage.

In conclusion, at-source measures, especially managing vehicle volume and traffic speed, are the most effective method to reduce noise. Thus, a variety of at-source measures need to be developed and applied in urban development projects.

The implication and limitations

In this study, I identified which factors have the greatest impact on traffic noise when various noise-factors are simultaneously affecting. I also found the limitation of noise barriers which are being widely applied at present. In particular, it has been indicated that noise barrier is only effective on the lower floors of an apartment, and its noise reduction effectiveness is limited in high-rise apartments. In order to establish more effective noise mitigation measures, it is necessary to take significant measures at the source, which focuses on managing vehicle volume and traffic speed. Finally, I suggested that at-source measures should be widely utilized in urban development projects.

However, since there are not many observations used in this study, there is a limitation to identify the precise correlation between noise-factors (independent variables) and noise level (dependent variable). More observations will provide more concrete results. For example, the coefficient of road type did not show any significance statistically, but generally, expressways and national highways have higher noise levels than city roads because of higher traffic volume and speed.

There are many explanatory variables which are related to generate noise level, but I could not identify all those independent variables in this study. I used eight factors affecting noise level. Even though those variables which are not applied in this study do not have a strong relationship or causation with noise level, they might affect the results somehow. More explanatory variables will deliver clearer outcomes.

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