The Formation Mechanisms of Road Traffic Noise in Urban Historic Districts: A Case Study of Grand Tang Dynasty Ever-Bright Block in Xi’an, China

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Abstract. The formation mechanisms of road traffic noise in urban historic districts are comprehensively studied through analyzing the superposition of influencing factors with the characteristics of historical districts. Then both the gray related theory and spatial syntax theory are used to construct the screening method of road traffic noise causes which can combine accurate quantitative data and spatial structure selection probability, while the empirical study of Grand Tang Dynasty Ever-bright block in Xi’an is conducted then. The research indicates that the formation mechanisms of road traffic noise in urban historical districts are due to complex stratification in which the traffic flow of motor vehicles, non-motor vehicles and pedestrians affect the noise formation by individual or as a whole under different conditions, as well as the disturbances of landscape nodes and road attributes. Moreover, it is believed that accurate identification of non-quantitative factors is the key to design road traffic noise screening method in historical districts rather than motor vehicle traffic flows.

Keywords. Historic districts, road traffic noise, formation mechanism, screening method, Grand Tang Dynasty Ever-bright block in Xi’an.

1. Introduction
With the development of social and economic undertakings and the improvement of environmental protection consciousness, more and more attention has been paid to the sound environment [1], and the related research results are increasing progressively [2-3]. In recent years, the tranquil urban historical districts also begin to face more complex acoustic environment under the influence of rapid growth of tourism and the rapid expansion of motor vehicles. Although some researches have been done about the acoustic environment quality of urban historical districts [4-5], scholars has not yet systematically proposed the formation mechanism of road traffic noise in urban historic districts, and the corresponding empirical measures are also limited to the effects of traffic volume on the acoustic environment. Therefore, this paper comprehensively discusses the formation mechanisms of road traffic noise in urban historic districts with multiple factors superimposed, and a systematic evaluation method for the formation mechanism of road traffic noise in historical districts is constructed then by introducing the corresponding technical means. To providing theoretical guidance and working methods for improving the acoustic environment quality of urban historical districts, the empirical test of Xi’an Grand Tang Dynasty Ever-bright block is conducted.
2. Forming Mechanisms and Evaluating Methods

2.1. Analysis on the Influencing Factors of Road Traffic Noise in Urban Historic Districts
In general, motor vehicles are considered to be the main source of road traffic noise [6-7]. However, the adoption of public transport development strategies intertwined with the rise and promotion of Bicycle-sharing [8] makes the pedestrian traffic flows and non-motor vehicle traffic flows significantly higher than that of ordinary urban roads in the urban historic districts.

During holidays, the important cultural landscape nodes around the districts will attract a large number of tourists and a variety of mobile businesses and performances. There will be not only revival and prosperity in historical districts [9] but also breaking of the balance between the generation and attraction of existing local road traffic system in the districts, which may lead to road traffic noise a sharp increase near the landscape nodes. In addition, in order to meet the needs of the special cultural tourism function of the historic districts, the attributes of internal roads in districts often make adaptable adjustments, such as road constructions (using quartzite and other special pavement materials) and traffic managements (permitting pedestrians crossing the road randomly). All of them will interfere with the formation mechanisms of road traffic noise to a certain extent.

In summary, the factors affecting the formation of road traffic noise in urban historic districts mainly include: the traffic flows of motor vehicles, non-motor vehicles and pedestrians on the road, the important human landscape nodes around the districts and disturbances caused by the special attributes of internal roads in districts.

2.2. The Formation Mechanisms of Road Traffic Noise in Urban Historic Districts
According to above analysis, the corresponding traffic noise formation mechanisms can be explained according to classification of road traffic function characteristics in historic districts. For motor vehicle accessible roads within the districts, the source of traffic noise will mainly be traffic flows of motor vehicles superimposing the function of non-motor vehicle and pedestrian traffic flows simultaneously.

For motor vehicle inaccessible roads within the districts, the source of traffic noise will be mainly the traffic flows of non-motor vehicles and pedestrians. When the two types of roads are close to important scenic areas, disturbance factors of landscape nodes should be added. When special constructions and managements of internal roads are used so as to create an archaic building style around historic districts, the road attributes disturbances should be added too. The formation mechanism of road traffic noise in urban historic districts is concluded as shown in figure 1.

Figure 1. The formation mechanisms of road traffic noise in historic districts.

2.3. The Method of Screening the Causes of Road Traffic Noise in Urban Historic Districts
Through the method of combining the quantitative data to the spatial structure recognition, this paper discusses the causes of road traffic noise of each motor vehicle accessible roads in the districts by three steps.

2.3.1. Screening the Causes of Road Traffic Noise Based on Gray Relational Analysis. Gray relational analysis is a kind of classical research method for quantitative analysis of the interrelations and interactions between complex factors. It doesn't require much data and can be used in small volume sample studies under incomplete information for a wide range [10]. So gray correlation analysis is employed to determine whether the variation trend of the measured road traffic noise and the motor
vehicle traffic flows of its corresponding sections is consistent or not so that the effect of vehicle traffic flows on the road traffic noise in historical blocks can be detected. If the calculated correlation results of the two is at a high level of degree, the motor vehicle traffic flows is proved the main cause of the traffic noise of the corresponding road section. If correlation degree between the two is not at a high level, the process goes to the second screening step.

2.3.2. Screening the Causes of Road Traffic Noise Based on Spatial Syntax Theory. In this following step, this paper analyzes the effect of non-motor vehicle traffic flows on traffic noise in historical districts by using the relevant algorithm of spatial syntax theory, as well as the effect of pedestrian traffic flows and the disturbances from the generation and attraction in cultural landscape nodes. Thus, both the randomness of non-motor vehicles and pedestrians traffic behavior and the uncertainty of traffic disturbance of important cultural landscape nodes on its adjacent road sections can be settled. In recent years, spatial syntax theory, which means a series of elements abstract models detecting the laws between space structure and human activities, has been more and more widely applied [11-12]. It has been believed that the spatial texture of historic districts has obvious linear network characteristics, while the spatial syntax is especially applicable to these complex linear networks [13].

The axis model of spatial syntax theory [14] quantifying the spatial structure based on relational diagram and expressing the topological relation among the network nodes is used as researching methodology in this paper. Firstly, internal roads of the historic district and external roads connected to its boundary are decomposed into several straight lines (for the elimination of the boundary effect), and they are regarded as the basic elements of the model - the axes. Secondly, because one of the describing parameters of axis model - choice represents the frequency of a node serving as the shortest topological distance between any other two nodes in space, it is effective to conclude the advantages of any one spatial element serving as the shortest travel path [15]. Therefore, choice calculating is suitable for detecting the road sections where non-motor vehicle flows and pedestrian traffic flows are centrally distributed in historic districts. Obvious effects of non-motor vehicle flows and pedestrian flows on road traffic noise also occurs on these road sections. Thirdly, another describing parameter of axis model - topology refers to the minimum number of connections between two nodes in a space network (i.e., topological convenience) [16]. So, topology calculating is suitable for detecting the road sections where remarkable disturbances by landscape nodes to traffic noise happened in historic districts on condition that the important cultural landscape nodes around the historic districts are taken as the traffic generations and attractions and the setting of topology range and length are identified before.

2.3.3. Screening the Causes of Road Traffic Noise Based on Qualitative Analysis. In the last step, since there are still a few roads whose traffic noise is not attributable to the causes discussed above in the historical districts, it is necessary to investigate them on spots and identify the causes of road traffic noise qualitatively according to the features of archaic building style on both sides of the road, as well as the distribution of commercial forms.

3. An Empirical Study of Xi'an Grand Tang Dynasty Ever-Bright Block

3.1. A Brief Introduction to Research Object and Data Acquisition

Grand Tang Dynasty Ever-bright block, constructed by Xi'an Qujiang New District, locates in the world famous historical city - Xi'an, China. It is an antique historic district with diversified functions, such as tourism, shopping, catering, entertainment and so on [17]. Tang Paradise & Great Wild Goose Pagoda cultural relics, included in the "World Heritage List", are adjacent to this block too. This paper studies the traffic noise formation mechanism of motor vehicle accessible roads in Xi'an Grand Tang Dynasty Ever-bright block. The researching scope is north to Ci 'en Road, south to Yannan 2nd Road, west to Ci 'en West Road, east to Ci 'en East Road. In the researching scope, 16 observation points are set beside motor vehicle accessible roads. As shown in figure 2. A non-working day (Saturday, March
16, 2019) was chosen as the survey day, while the traffic volume and road traffic noise of 16 observation points were respectively measured in 3 periods of noon peak (11:30-12:30), evening peak (17:30-18:30) and night (20:30-21:30).

For the road traffic noise measuring, the position of the decibel meter is adjusted to extend the effective coverage of noise observation points as far as possible in terms of noise test basic requirements of "Environmental quality standard for noise GB 3096-2008". Meanwhile the traffic continuity and stability should be ensured during traffic noise measuring and two decibel meter devices are arranged on both sides of each observation point. After the noise reading of the device tends to be stable, count once every 1min. Then, root mean square of five consecutive counts is recorded as one measuring value and the final measuring value of this observation point is the mean value of two devices at the same point.

For the motor vehicle traffic flows monitoring, the camera recording device is placed close to the position of either decibel meter device of each observation point so as to continuously monitor the motor vehicle traffic flow of the road section in corresponding noise counting period. Moreover, the standard Passenger Car Unit outcome of motor vehicle traffic flows is conversed and obtained for each observation point in each period by above monitoring process.

3.2. Causes Analysis Based on Grey Relational Theory
The obtained noise measuring data in Grand Tang Dynasty Ever-bright block is calculated through gray correlation analysis to verify the influence of motor vehicle traffic flows on road traffic noise. The standard motor vehicle traffic flows at different time is set as the parameter series and the equivalent sound pressure level of measuring noise at the same time is set as comparison series. Then, both the initial image processing of these two series and their gray correlation degree are calculated.

The results of gray correlation degrees between traffic noise and motor vehicle traffic flows in different periods of each observation point are shown in table 1.
Table 1. Gray correlation degrees between traffic noise and traffic flows.

| Points             | Gray correlation degrees at different period | On average |
|--------------------|---------------------------------------------|------------|
|                    | Noon peak 11:30-12:30 | Evening peak 17:30-18:30 | Night 20:30-21:30 |
| Ci ‘en East Road 1 | 0.697                        | 0.646               | 0.442               | 0.595               |
| Ci 'en East Road 2 | 0.723                        | 0.662               | 0.508               | 0.631               |
| Ci ‘en Road 1      | 0.824                        | 0.744               | 0.543               | 0.704               |
| Ci ‘en Road 2      | 0.621                        | 0.714               | 0.672               | 0.669               |
| Ci 'en West Road 1 | 0.768                        | 0.476               | 0.585               | 0.610               |
| Ci ‘en West Road 2 | 0.499                        | 0.639               | 0.474               | 0.538               |
| Yannan 1st Road 1  | 0.629                        | 0.803               | 0.724               | 0.719               |
| Yannan 1st Road 2  | 0.929                        | 0.842               | 0.734               | 0.835               |
| Yannan 2nd Road 1  | 0.849                        | 0.665               | 0.777               | 0.764               |
| Yannan 2nd Road 2  | 0.744                        | 0.593               | 0.558               | 0.632               |
| Yanta South Road 1 | 0.645                        | 0.723               | 0.618               | 0.662               |
| Yanta South Road 2 | 0.635                        | 0.668               | 0.620               | 0.641               |
| Mean               | 0.704                        | 0.680               | 0.590               | 0.658               |

*a* Two observation points are arranged for some long road section and their average value is reported.

It can be seen from table 1 that the gray correlation degrees of each road section are all greater than 0.5 and the mean correlation degree is 0.658 < 0.7, which indicates that there is a clear but not significant positive correlation between road traffic noise and motor vehicle traffic flows in Grand Tang Dynasty Ever-bright block. Part of the gray correlation degrees are greater than 0.7 among all road sections, including Yannan 1st Road 1, Yannan 1st Road 2, Yannan 2nd Road 1, Ci ‘en Road 1. Thus, it is believed that motor vehicle traffic flows are not only strongly related to but also main reason for traffic noise causing of these road sections.

By comparing the gray correlation degrees of different periods, the mean degree of each observation point from high to low are the noon peak (0.704), the evening peak (0.680) and the night peak (0.590). The reason for this changing features is adaptive to tourism traffic attraction of Grand Tang Dynasty Ever-bright block on non-working day. At noon, less tourists visit the block for catering or shopping and its traffic noise is mainly caused by passing motor vehicles. However, lots of tourists go to the block for entertainment in the afternoon and evening when they finish visiting to Tang Paradise & Great Wild Goose Pagoda and other scenic. So sound environment of connecting roads in the block becomes complex due to more increasing traffic flows of pedestrians and non-motor vehicle. At this period, a variety of influencing factors contribute to traffic noise causing of the whole block together rather than motor vehicles only.

3.3. Causes Analysis Based on Spatial Syntax Theory
This paper analyzes the roads spatial structures of Grand Tang Dynasty Ever-bright block with the help of axis model in spatial syntax theory in order to further study the influence of non-motor vehicle and pedestrian traffic flows on road traffic noise in the block, as well as the disturbance of landscape nodes. At first, the research scope is expanded to reduce the impact of boundary effects. It is north to Xiaozhai East Road and Xiying Road, south to Yannan 4th Road and Yanzhan Road, west to Cuihua Road, east to Furong West Road and Furong East Road, as shown in figure 3. Then, 118 axes for non-motor vehicles and pedestrians passing are extracted from the expended research scope to constitute the axis model of street network of the block.
3.3.1. Choice Calculating for Non-motor Vehicle and Pedestrian Flows Analysis. The choice detection of axis model measures the potential of an element to attract through traffic. Although the actual travel path selection may not be the shortest topology path, this path is still selected with the maximum probability. Therefore, this paper detects spatial distribution of mixed traffic flows of non-motor vehicle and pedestrian in the expanded research scope with choice detection tools.

It is assumed that the mixed traffic flows are evenly distributed in the expanded scope and selectively move to other locations (axes). When the axes drawn in AutoCAD are input into Depthmap software for analysis, the choice in the spatial syntax is detected through the weights determined by the length of each axis, and the results are shown in figure 4. The grayscale from shallow to deep in it shows the choice values changing from small to large, while the road sections with high choice include Yannan 1st Road 2, Ci’en East Road 1, Ci’en East Road 2 and Yanta South Road 1 from the detecting results. According to the gray correlation degrees discussed above (shown in Tab.1), the traffic noise of these road sections hasn’t significantly affected by motor vehicle traffic flows except Yannan 1st Road 2. So the traffic flows of the non-motor vehicles and pedestrians are considered underlying cause of road traffic noise for them instead.

**Figure 3.** Expanded research scope of Grand Tang Dynasty Ever-bright block

**Figure 4.** Test results of choice detection.

**Figure 5.** Test results of topology detection.
3.3.2. Topology Calculating for Disturbance of Landscape Node Analysis. Tang Paradise & Great Wild Goose Pagoda cultural relics (World Heritage) are the two most important landscape nodes around Grand Tang Dynasty Ever-bright block, while they are also the main traffic generations and attractions of domestic and oversea tourists to the block. Therefore, this paper uses the topology detection of axis model to calculate topological distance from these two landscape nodes as starting point. Because the area of research scope is not big enough, it is believed that free moving distance of most tourists is short and limited within 2 steps of axis model near landscape nodes in the block. On this basis, the topological distances nodes less than or equal to 2 from the two landscape can be detected in the axis model. As shown in figure 5. Ci ’en Road 1, Ci ’en Road 2 and Yannan 1st Road 2 within the block are classified as the road sections cluster with topological distance less than or equal to 2 based on the topology detection results in figure 5. Due to the road traffic noise of Ci ’en Road 1 and Yannan 1st Road 2 has been proved to be closely related to motor vehicle traffic flows before, the disturbance of landscape nodes are considered underlying cause of road traffic noise for Ci ’en Road 2.

3.4. Causes Analysis Based on Qualitative Investigation to Road Attributes

For the road sections whose traffic noise causing are still not found by gray correlation analysis and space syntax analysis, some other thinking ought to be done through on spots investigations and qualitative analysis as follows.

Yanta South Road 2 uses quartzite paving form for archaic building style. However, this pavement kind is different from commonly used asphalt concrete structure in urban road pavement with a large hardness but low flatness between connecting quartzite. Meanwhile, more driving vibration and noise will be produced on this road section. Ci ’en West Road 1 is one-way traffic from north to south, but Ci ’en West Road 2 and Yannan 1st Road both are two-way traffic. Not well matching traffic organization makes the queuing period of intersection between Ci ’en West Road and Yannan 1st Road become long, while both traffic congestion and road traffic noise may increase on connecting road sections to this intersection. There are public green lands on both sides of Ci ’en West Road 2 and Yannan 2nd Road 2, and there is no physical separation facility in the middle of these road. The opening recreation spaces are considered underlying cause of road traffic noise for these two sections. So does passing through behaviors of pedestrians and non-motor vehicles.

4. Conclusion and Prospect

Firstly, the formation mechanism of road traffic noise in urban historic districts is complex. The passing traffic flows of the motor vehicles, non-motor vehicles and pedestrians are respectively considered underlying cause of road traffic noise under specific situations, as well as the disturbances of landscape nodes around historic districts. By the way, road sections attributes may also be cause of road traffic noise due to special constructions and managements for an archaic building and commercial development in districts.

Secondly, gray relational analysis, spatial syntax theory and qualitative analysis are employed together to design a screening method of road traffic noise in historic districts. With an empirical study of Grand Tang Dynasty Ever-bright block in Xi’an, it is discovered that accurate identification of other factors besides motor vehicle traffic flows is the key to road traffic noise screening in historic districts. By introducing the spatial syntax theory, the effect of traffic flows of non-motor vehicles and pedestrians and disturbances of landscape nodes on road traffic noise can be detected respectively from the choice and the topology tools of axis model, and qualitative analysis of road sections construction and management is sometimes indispensable.

In the future, the formation mechanism of traffic noise in urban historic districts should be combined with the development of traffic big data technology. With the spreading of satellite positioning and navigation technology to individual mobile terminals, the future trajectories of non-motor vehicles and pedestrians will be accurately quantified. This technology revolution will make
more use of detailed travel path data to identify road traffic noise in historic districts rather than probabilistic selection represented by spatial structures.

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