

Temporal Dynamics of Nighttime Noise, Vibration and Driver Adaptation to New Speed Humps in a Residential Street: A Case Study in Fujimino City, Saitama Prefecture, Japan

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Abstract

Managing vehicle speeds and ensuring road safety in residential neighborhoods have led to the widespread adoption of various traffic calming strategies, with speed humps being among the most implemented solutions. However, their implementation has raised significant concerns regarding secondary environmental impacts, particularly noise and vibration generation that can adversely affect residential communities during sensitive nighttime hours. This study addresses a critical gap in understanding the temporal dynamics of noise and vibration pollution induced by speed humps during nighttime periods in Japanese residential neighborhoods. Statistical analysis of LAeq measurements revealed significant temporal patterns: immediate increase (+2.71 dB, $p < 0.001$), peak at 4 weeks (+4.38 dB, $p < 0.001$), followed by beneficial adaptation (−2.88 dB below baseline, $p < 0.001$). Estimation method provided in ISO 9613-2 propagation modeling used to evaluate the compliance with Japan's Environmental Quality Standards (EQS) for Noise. Collectively, these findings underscore the critical need for both event-based adaptation analyses and standard propagation models in evaluating the efficacy and temporal evolution of noise induced by the traffic calming devices.

Keywords

Traffic Calming, Speed Humps, Noise, Vibration, Night-Time Impact

1. Introduction

Traffic calming measures have emerged as essential components of modern urban

transportation planning, with speed humps representing one of the most widely implemented vertical deflection devices globally. These interventions effectively reduce vehicular speeds and enhance pedestrian safety, with research indicating their use in 53% of traffic calming implementations worldwide [1]. However, the implementation of speed humps has generated increasing concern regarding secondary environmental impacts, particularly noise and vibration generation that can adversely affect residential communities during sensitive nighttime periods [2].

The World Health Organization (WHO) has established stringent guidelines for nighttime noise exposure, recommending maximum levels of 40 dB L night, outside to protect public health, including vulnerable populations like children, the chronically ill, and elderly residents [3]. Environmental noise during sleep periods can trigger cardiovascular effects, sleep disturbance, and long-term health consequences, with night-time sensitivity substantially exceeding daytime responses due to the absence of masking effects from daily activities [4].

Japan presents a unique research environment for investigating speed hump impacts due to its distinctive urban characteristics and stringent noise regulatory framework. The Japanese Environmental Noise Regulation Act establishes maximum allowable noise levels of 55 dB during daytime and 45 dB during nighttime for residential areas, reflecting the country's commitment to protecting residential tranquility.

Although Japan introduced traffic calming through the "Road-Pia" initiative in 1984 followed by the "Community Zone" programs, it still lacks detailed design standards and established methods for assessing the environmental effects of these measures [5]. This regulatory gap creates an urgent need for systematic research examining the temporal and acoustic implications of speed humps in Japanese residential contexts. While extensive research exists on speed humps' immediate speed reduction effects, longitudinal studies examining temporal adaptation patterns remain scarce.

Research from Transport Research Laboratory (TRL) indicates that maximum noise levels from cars are reduced post installation, but these findings primarily focus on immediate rather than temporal changes [6]. Limited research exists on behavioral adaptation following speed hump installation. Danish studies show that driver behavior stabilizes within specific intervals (52 m for through roads, 70 m for main roads, 164 m for residential roads), but temporal adaptation patterns remain understudied [7].

Study Location

The research site is situated at 1-chōme-7 Shinden in Fujimino City, Saitama Prefecture, Japan (35.869289 N, 139.523331 E). Fujimino City lies approximately 30 km northwest of central Tokyo within the Kanto plain and has evolved from agricultural hinterland into a suburban residential zone over the past three decades. The Shinden neighborhood exemplifies a typical Japanese low-density residential

district, characterized by narrow single-lane local roads lined with detached houses, small apartment blocks, and community facilities such as a local elementary school and neighborhood park. Private cars and light commercial vans travel at speeds that exceed the 30 km/h regulatory limit during off-peak periods. **Figure 1** illustrates the experiment location “before” and “after” the hump installation.



Figure 1. Experiment location.

The selected segment is a straight, flat section approximately 150 m in length, bounded on both sides by continuous frontage lines set back 2 - 3 m from the road edge, creating minimal roadside buffer zones. Pavement consists of dense graded asphalt overlay installed within the last five years, exhibiting a smooth texture with negligible rutting or cracking. Pedestrian footpaths are discontinuous, with paved shoulders 1.0 m wide on either side, and no formal cycle lanes.

2. Literature Review

The environmental consequences of speed humps, particularly noise generation, have received increasing research attention. Multiple studies confirm that speed humps generate higher noise levels compared to control points during vehicle passage. Previous study found that speed humps consistently produced elevated noise levels across different traffic conditions, with measurements exceeding WHO day-time thresholds of 53 dB (A) in residential and school zones [8].

2.1. Noise Generation

The mechanisms of noise generation from speed humps are multifaceted, involving engine acceleration, braking dynamics, and tire-pavement interaction. Research demonstrates that noise emissions increase because of abrupt deceleration, braking, and subsequent acceleration phases when vehicles traverse speed humps. That study explained that noise radiation depends on both speed (rpm) of the engine and vehicle velocity, with both parameters increasing during post-hump acceleration phases [9].

Driving behavior significantly influences noise emissions at speed humps. Inappropriate driving behavior, particularly traversing speed humps at excessive

speeds, can increase the noise levels by 6 dB (A). Public perception studies indicate that 73.6% of respondents believe speed humps generate additional noise that annoys nearby residents [10].

2.2. Health Implications of Nighttime Traffic Noise

The World Health Organization has established comprehensive guidelines for environmental noise exposure, with particular emphasis on nighttime sensitivity. The 2018 Environmental Noise Guidelines for the European Region recommend maximum nighttime levels of 40 dB L_{night}, outside to protect public health, with interim targets of 55 dB where immediate compliance is not feasible. These guidelines superseded previous 1999 recommendations, establishing more stringent criteria based on updated health evidence [11].

Sleep disturbance mechanisms from nighttime noise exposure involve physiological stress responses even below conscious awakening thresholds [12]. Study found that nighttime traffic noise levels exceeding 50 dB L_{night}, outside were associated with insomnia symptoms, particularly among individuals with higher trait anxiety scores. The study reported odds ratios of 1.34 (95% CI: 1.00 - 1.80) for exposures of 50.1 - 55 dB and 1.61 (95% CI: 1.07 - 2.42) for exposures exceeding 55 dB [13].

2.3. Temporal Sensitivity and Sleep Architecture

Exposure to noise at night disrupts the normal pattern and sequence of sleep stages, leading to fragmented and redistributed sleep architecture. Studies show that nighttime environmental noise can trigger hormonal and metabolic changes, such as elevated levels of adrenaline, noradrenaline, and cortisol. These physiological effects occur even when individuals are asleep, and people are often able to differentiate between nights with low and high noise exposure.

The temporal aspects of noise-induced sleep disturbance are particularly relevant for traffic calming applications. Sleep disturbances from traffic noise above 65 L_{eq} dBA were significantly more frequent in urban populations, with personality and noise sensitivity serving as modifying factors. Longitudinal studies in Gothenburg revealed greater difficulty falling asleep and poorer sleep quality among residents exposed to daytime traffic noise exceeding 71.8 L_{eq} dBA [14].

2.4. Driver Behavioral Adaptation

Driver behavioral adaptation to traffic interventions represents a critical research domain with implications for long-term effectiveness assessment. Behavioral adaptation theory suggests that drivers modify their behavior in response to changes in the traffic environment, potentially diminishing intended safety benefits over time. This adaptation can be evident through speed compensation, route choice modifications, or attention reallocation [15].

Research on temporal aspects of behavioral adaptation remains limited but

growing. Psychological research investigated whether traffic calming measure effects endure over time, examining both longitudinal and lateral driving parameters. Their findings suggested that while immediate effects are substantial, long-term maintenance of behavioral changes requires continuous monitoring and assessment [16].

Advanced research on driver speed control behavior provides insights into temporal adaptation mechanisms. They developed predictive driver models for speed control when approaching road obstacles, demonstrating that drivers optimize speed trajectories based on comfort, safety, and efficiency considerations. The study revealed that drivers anticipate obstacle characteristics and adjust approach speeds accordingly, with adaptation occurring through experience accumulation [17].

Japan's environmental noise regulatory framework provides stringent standards relevant to traffic calming assessment. The Environmental Noise Regulation Act establishes maximum allowable levels of 55 dB daytime and 45 dB nighttime for residential areas. Tokyo implements more restrictive standards of 60 dB daytime and 50 dB nighttime, with additional 5 dB reductions near sensitive facilities.

These standards reflect Japan's position as experiencing high urban noise exposure. WHO's 2018 assessment identified Japan as having significant noise pollution challenges, emphasizing the importance of effective traffic noise management strategies. The regulatory framework provides clear criteria for evaluating traffic calming environmental impacts while supporting public health protection objectives.

2.5. Acoustic Modeling and Prediction Methods

The ISO 9613-2 standard provides validated frameworks for predicting outdoor noise propagation, incorporating divergence, atmospheric absorption, and ground effects. This international standard has been extensively applied in wind turbine noise assessments and urban noise prediction, with validation studies demonstrating varying accuracy depending on site conditions [18]. While ISO 9613-2 propagation modeling accurately predicted spatial attenuation across 10 - 50 m distances from measured source levels, the ASJ RTN-Model 2018 proved fundamentally inadequate for speed hump assessment due to its reliance on steady speed assumptions (40 - 140 km/h expressways, 10 - 60 km/h general roads) and continuous point-source treatment rather than discrete impact events.

The model's "non-steady running" provisions address gradual acceleration/deceleration at traffic signals and interchanges but exclude the sharp, localized tire-pavement impacts and impulse noise characteristic of traffic calming devices, necessitating event-based measurement protocols for comprehensive speed hump noise evaluation [19].

2.6. Research Gaps

Despite extensive research on speed hump effectiveness, significant gaps remain

in understanding temporal dynamics of environmental impacts. Most existing studies employ pre-post comparison designs over short periods, missing crucial adaptation phases that may extend over months. The need for longitudinal monitoring addressing both immediate installation effects and long-term behavioral adaptation represents a critical research priority. Current literature lacks systematic investigation of nighttime-specific impacts from traffic calming devices in Japan. While substantial research addresses general traffic noise effects during nighttime periods, speed hump-specific impacts during sensitive nighttime hours remain understudied. This gap is particularly significant given heightened nighttime noise sensitivity and potential for community disruption.

The integration of standardized propagation modeling with field measurements represents an underexplored methodological approach. While ISO 9613-2 provides validated frameworks for noise prediction, its application to traffic calming contexts requires site-specific validation and adaptation. Research combining theoretical modeling with longitudinal field monitoring could advance both predictive capabilities and understanding of temporal impact evolution rather than just relay for direct field measurement data.

The relationship between driver behavioral adaptation and environmental impact generation requires systematic investigation. Current literature treats these as separate research domains, missing potential interactions between adaptation patterns and noise/vibration generation over time. Understanding these relationships could inform both design optimization and policy development for sustainable traffic calming implementation while maintaining public acceptability. This is crucial Factor for promoting traffic calming devices in Japan.

3. Research Objectives

The study aims to elucidate the temporal dynamics of environmental and behavioral responses to newly installed speed humps in a Japanese residential context. The specific objectives are as follows.

3.1. Quantify Nighttime Noise Variation

Measure and characterize changes in equivalent continuous sound levels (L_{Aeq}) and maximum sound levels ($L_{a,max}$) generated by vehicular passages over speed humps at nighttime and evaluate their temporal evolution over a six-month period.

3.2. Assess Ground-Borne Vibration Dynamics

Determine vibration induced by vehicles traversing speed humps and analyze seasonal and temporal variations in vibration exposure at locations adjacent to the roadway.

3.3. Evaluate Noise Propagation and Compliance

Use ISO 9613-2 noise propagation model for predicting sound level attenuation from speed humps in a residential environment and assess the compliance with

Japanese standards across the monitoring period.

4. Research Methodology

Fujimino City, the trial demonstration experiment revealed significant traffic safety improvements with vehicle speeds decreasing from the 20 - 30 km/h range to 10 - 20 km/h near the crosswalk installations, and the proportion of vehicles traveling below 30 km/h increasing by 10% - 15% in both northbound and southbound directions. Community surveys indicated strong support for the initiative, with 57% of residents reporting improved safety perceptions and 60% supporting permanent installation, though concerns about noise and vibration from vehicles were raised by nearby residents. Given the critical importance of community acceptance for the successful implementation of traffic calming measures and the need to balance safety improvements with quality-of-life considerations, this study was conducted to systematically investigate the noise and vibration impacts associated with smooth crosswalks and develop evidence-based justification to address resident concerns while maintaining the traffic safety benefits. **Figure 2** illustrates the summarized methodology flow chart.

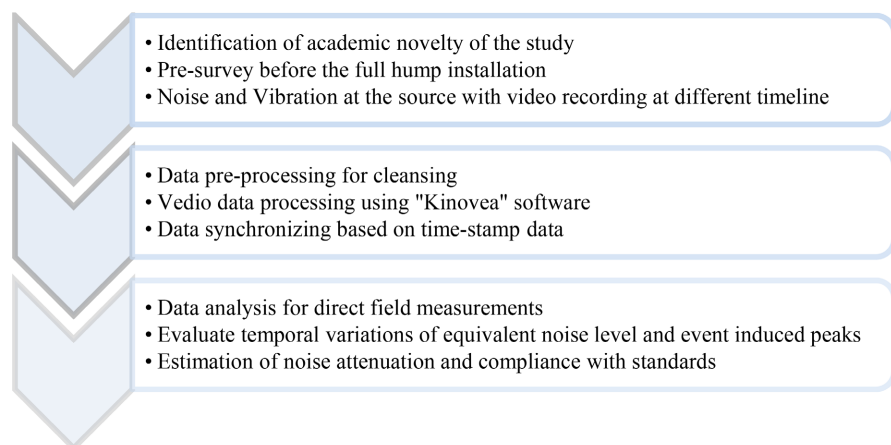


Figure 2. Summary of methodology.

4.1. Experimental Procedure

Environmental noise was measured using a RION NL-21 sound level meter, rigidly mounted on a tripod at a reference microphone height of 1.2 m in proximity to the hump. Simultaneously, ground-borne vibration was recorded with a RION VM-53A vibration level meter, enabling synchronized acquisition of noise and vibration signatures for individual pass-by events. Data collection was undertaken between 23:00 and 24:00 to minimize confounding from daytime background sources and to focus on nighttime operational impacts. Concurrent video recording was performed to document traffic composition, vehicle approach speeds, and event timing, facilitating post hoc alignment of audio vibration time histories with observed vehicle maneuvers as illustrated in **Figure 3**. Identical field measurements were taken by following the timeline indicated.

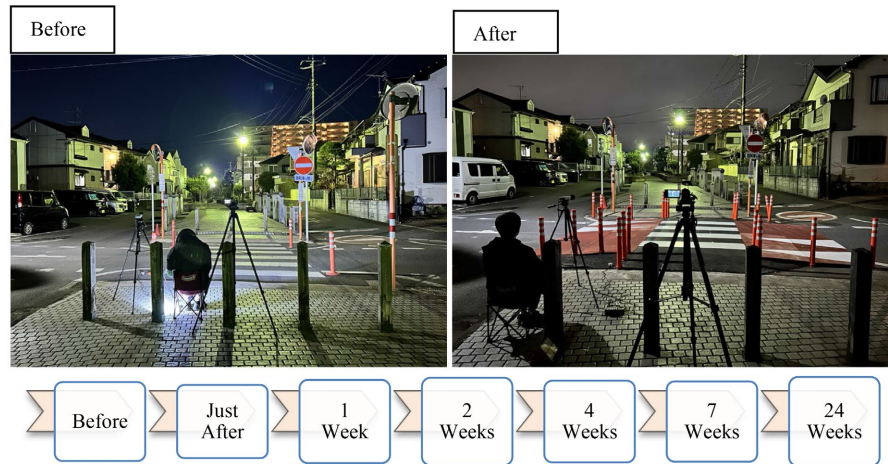


Figure 3. Experimental setup.

4.2. Calculation Procedure for Noise Data

The statistical descriptors were computed from the one-second A-weighted Sound Pressure Level (SPL) time histories L_i (in dB) recorded during each session. Sort the valid L_i values in ascending order and let N be the total number of samples. The L_{10} value is the sound level, exceeding 10% of the measurement period, *i.e.* the 90th percentile of Equation (1) below.

$$L_{10} = L_{(\lceil 0.90N \rceil)} \quad (1)$$

The L_{90} value is the sound level exceeding 90% of the measurement period, *i.e.* the 10th percentile as Equation (2)

$$L_{90} = L_{(\lceil 0.10N \rceil)} \quad (2)$$

The equivalent continuous level (L_{avg} or L_{eq}) is calculated from the energy-averaged sound pressure as Equation (3) below.

$$L_{\text{eq}} = 10 \log_{10} \left(\frac{1}{N} \sum_{i=1}^N 10^{\frac{L_i}{10}} \right) \quad (3)$$

The A-weighted equivalent continuous level, LAeq, is computed by integrating instantaneous A-weighted levels over the measurement period as indicated in Equation (4). Where $L_p(t)$ is the instantaneous level in dB (A) and T is total measurement time. From the dataset, LAeq at the source was calculated as 44.1 dB (A).

$$\text{LAeq} = 10 \log_{10} \left(\frac{1}{T} \int_0^T 10^{\frac{L_p(t)}{10}} dt \right) \quad (4)$$

From measured LAeq at distance r_1 , the source sound power level L_W is derived as Equation (5), where L_{p1} is LAeq at r_1 , S is the measurement surface area (hemisphere: $2\pi r_1^2$), and $S_0 = 1 \text{ m}^2$ reference. For $L_{p1} = 44.1 \text{ dB (A)}$ at $r_1 = 1.2 \text{ m}$, $L_W = 52.7 \text{ dB (A)}$.

$$L_W = L_{p1} + 10 \log_{10} \left(\frac{S}{S_0} \right) \quad (5)$$

ISO 9613-2 models' attenuation components: geometrical divergence (A_{sp}), atmospheric absorption (A_{atm}), ground effect (A_{gr}), and barrier diffraction (A_{bar}), with $r_0 = 1$ m, $\alpha \approx 1.9$ dB/km at 500 Hz, 10°C, 70% RH.

$$L_p(r) = L_W - (A_{sp} + A_{atm} + A_{gr} + A_{bar}) \quad (6)$$

$$A_{sp} = 20 \log_{10} \left(\frac{r}{r_0} \right) \quad (7)$$

$$A_{atm} = \alpha \frac{r}{1000} \quad (8)$$

Statistical significance testing employed paired t-tests:

$$t = (\bar{d} - \mu_0) / (sd / \sqrt{n}) \quad (9)$$

where \bar{d} represents mean difference, sd is standard deviation of differences, and $n = 1000$. Effect size calculation used in Cohen's d is given by following equation.

$$d = (\bar{X}_2 - \bar{X}_1) / \text{spooled} \quad (10)$$

with pooled standard deviation spooled is $\sqrt{((n_1 - 1)s_1^2 + (n_2 - 1)s_2^2) / (n_1 + n_2 - 2)}$.

The propagation analysis applied ISO 9613-2 to predict A-weighted levels at incremental distances of 10, 20, 30, 40, and 50 m from each measured source hump. At each step, sound power derived from the temporally integrated LAeq source was attenuated by spherical divergence, air absorption (frequency-dependent), and ground effects, yielding a smooth decay curve. Following **Figure 4** illustrates the buffer zones considered for the noise propagation calculation.

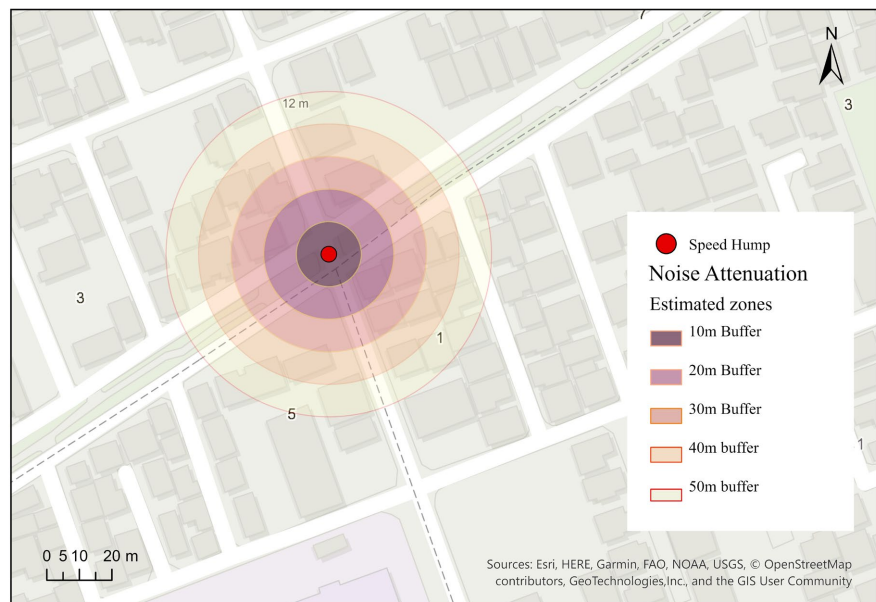


Figure 4. Considered impact zones of noise propagation.

4.3. Statistical Analysis Framework

Temporal significance testing [20] employed both parametric (paired t-tests) and non-parametric (Wilcoxon signed-rank tests) approaches [21]. Random sampling ($n = 1000$ per period has been obtained from the full data set) ensured computational feasibility while maintaining statistical power > 0.99 for medium effects [22]. For each measurement period, we applied systematic random sampling from the complete one-hour dataset, selecting every k th observation where $k = \text{total observations}/1000$, with a random starting point to eliminate systematic bias. Effect sizes were calculated using Cohen's d with interpretation thresholds: negligible ($|d| < 0.2$), small ($0.2 \leq |d| < 0.5$), medium ($0.5 \leq |d| < 0.8$), and large ($|d| \geq 0.8$) [23]. While LAeq measurements can exhibit non-independence and distributional skewness, the validity of paired t-tests was confirmed by the convergence of both parametric and non-parametric (Wilcoxon signed-rank) test results showing identical significance patterns, with large sample sizes ($n = 1000$) providing robustness against moderate departures from normality assumptions as established in environmental noise measurement literature [24].

4.4. Calculation Procedure for Vibration Data

Seven discrete measurement sessions such as before (baseline), just after, 1 week, 2 weeks, 4 weeks, 7 weeks, and 24 weeks were recorded overnight over approximately one-hour intervals at ~ 10 Hz sampling frequency. Raw acceleration levels, logged as dB (A) values, underwent rigorous preprocessing including timestamp synchronization to elapsed seconds and minutes, outlier screening, and listwise exclusion of $< 0.1\%$ missing data, ensuring high data integrity.

5. Data Analysis and Results

All acoustic, vibrational, and vehicular kinematic data were meticulously preprocessed and analyzed according to the procedures detailed in the Methodology section, enabling precise characterization of temporal dynamics and driver adaptation. Vehicle speeds were extracted and time-synchronized using the Kinovea video-tracking software, and the results of the noise and vibration analyses are presented independently.

5.1. Results of Noise Data at the Source Level

Computed noise metrics reveal clear temporal patterns and suggest both immediate and evolving impacts of the speed hump installation. The post-installation "Just-After" session exhibited the highest overall noise levels ($L_{\text{avg}} \approx 54.4$ dB) and elevated peak levels ($L_{10} \approx 49.9$ dB), indicating that drivers likely approached or traversed the hump with increased speed variability immediately following implementation. After one week, the average level dropped to about 49.8 dB and L_{10} rose slightly to 50.0 dB, suggesting drivers had begun to adapt their behavior but still produced occasional high-level events. By two weeks, the highest L_{10} (55.1 dB) and L_{avg} (53.0 dB) values were recorded, which may reflect experimental outliers

perhaps heavy vehicles or transient traffic surges underscoring the need for longer monitoring to capture representative behavior. From four weeks onward, both average and percentile-based levels stabilized around 48.4 - 51.8 dB (L_{avg}) and 49.3 - 51.5 dB (L_{10}), while the lowest levels (L_{90}) dropped notably to the high 20 dB range, indicating quieter intervals between vehicle passings. **Table 1** summarized the calculated descriptive statistics of the noise data at the point of source.

Table 1. Summary of descriptive noise data metrics.

Timeline	Descriptive Noise Metrics					
	L_{10_dBA}	L_{avg_dBA}	L_{50_dBA}	L_{90_dBA}	Min_dBA	Max_dBA
Before	46.5	51.8	35.7	33.7	31.5	75.6
Just-After	49.9	54.4	39.1	35.3	32.3	94.5
After-1-Week	50.0	49.8	36.2	33.5	31.1	75.3
After-2-Week	55.1	53.0	37.8	33.3	30.4	76.5
After-4-Week	51.5	50.3	41.5	33.6	32.1	71.5
After-7-Week	49.3	48.4	32.8	28.9	26.3	71.5
After-24-Week	49.6	51.3	31.4	28.6	27.1	80.9

Figure 5 illustrated descriptive statistics of the noise data at the point of source along with lower confidence intervals, upper confidence intervals, WHO recommended noise levels and Japan's Environmental Quality Standards (EQS) limits for the night time noise.

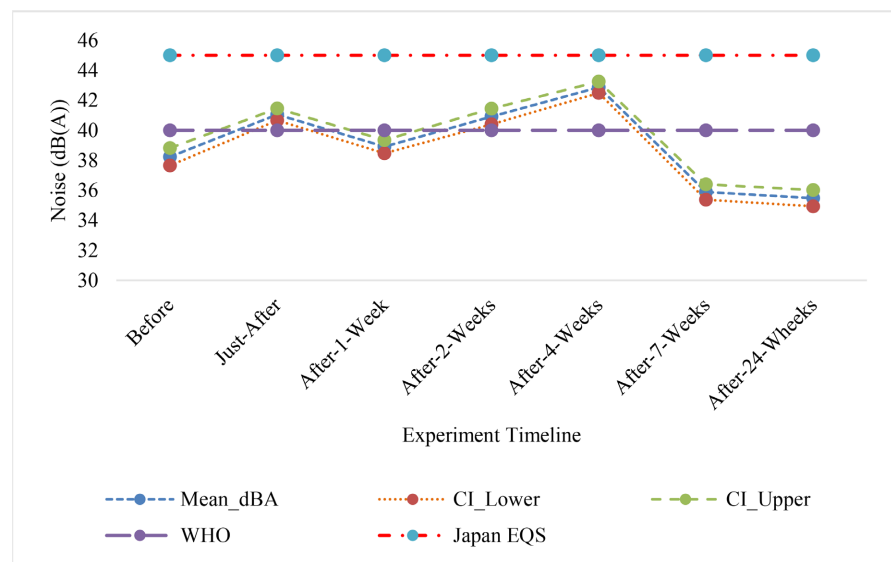


Figure 5. Temporal variation of the noise at at the source.

To rigorously evaluate temporal changes in noise levels, paired t-tests and Wilcoxon signed-rank tests were applied using randomized samples ($n = 1000$) from each measurement period [25]. The baseline “Before” installation served as the

reference for all comparisons, with Cohen's *d* calculated to assess practical significance.

Statistical analysis revealed significant temporal variations in **Table 2**. The immediate post-installation period showed a significant increase of +2.71 dB (A) ($t = -9.231$, $p < 0.001$, Cohen's $d = 0.415$). Peak impact occurred at 4 weeks with +4.38 dB (A) increase ($t = -14.622$, $p < 0.001$, Cohen's $d = 0.671$, medium effect). Long-term stabilization at 6 months demonstrated -2.88 dB (A) reduction below baseline ($t = 8.417$, $p < 0.001$, Cohen's $d = -0.372$).

It confirms that observed temporal variations maintain regulatory compliance. Even during peak impact periods (4 weeks: +4.38 dB increase), predicted noise levels at 10 m distance remain within Japanese EQS limits ($p < 0.001$ for all distance comparisons). Sequential temporal analysis revealed the most significant transition occurred between 4 weeks and 7 weeks (-6.80 dB change, Cohen's $d = -0.936$, large effect), representing the critical behavioral adaptation period where environmental benefits emerge.

Table 2. Statistical significance test results of noise with reference to baseline ("before").

Time Period	Statistical Significance						
	Mean Diff: (dB)	t-stat	p-value	Wilcoxon p	Cohen's d	Effect Size	95% CI
Just After	+2.71	-9.231	<0.001	<0.001	0.415	Small	[2.14, 3.29]
After 1 Week	+0.18	-0.605	0.545	0.200	0.027	Negligible	[-0.41, 0.78]
After 2 Weeks	+2.84	-8.427	<0.001	<0.001	0.376	Small	[2.18, 3.51]
After 4 Weeks	+4.38	-14.622	<0.001	<0.001	0.671	Medium	[3.79, 4.97]
After 7 Weeks	-2.42	7.164	<0.001	<0.001	-0.319	Small	[-3.08, -1.76]
After 24 Weeks	-2.88	8.417	<0.001	<0.001	-0.372	Small	[-3.55, -2.21]

5.2. Results of Noise Attenuation

The A-weighted equivalent continuous sound level (LAeq) was calculated from raw data. ISO 9613-2 methodology was then applied to predict noise levels at distances of 10 m, 20 m, 30 m, 40 m, and 50 m under urban canyon conditions. **Figure 6** indicates the results of the analysis, which confirms that, despite the event-based nature of speed hump noise, average levels at 10 m comply with Japanese nighttime limits. Beyond 10 m, all time noise levels are well in compliance with the Japanese standards for nighttime noise.

5.3. Ground-Borne Vibration Dynamics

The one-hour vibration recordings before and after speed hump installation reveal clear temporal patterns in traffic-induced vibrations. Following **Table 3** summarizes key descriptive statistical findings.

5.4. Temporal Dynamics of Vibration

The temporal vibration profile exhibited a statistically meaningful reduction

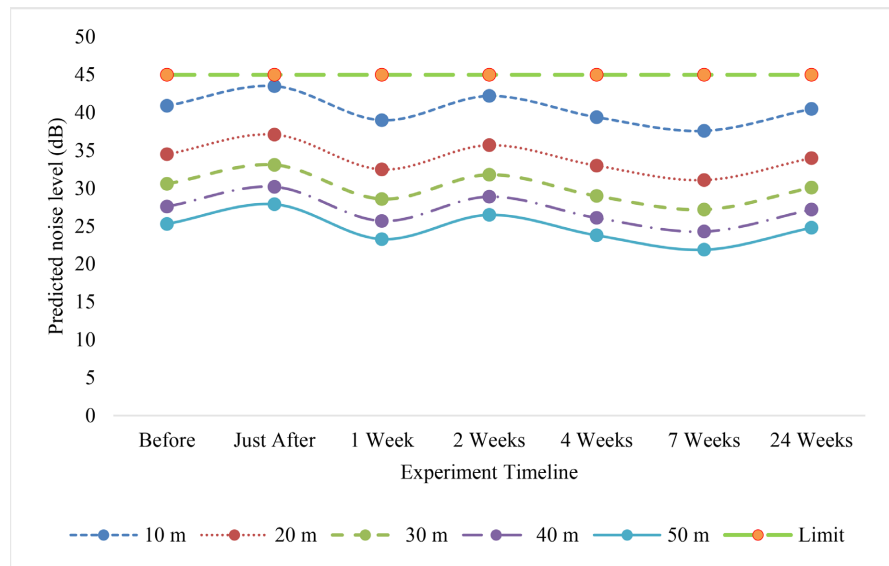


Figure 6. Impact zones of noise propagation

Table 3. Descriptive statistics of vibration data.

Timeline	Descriptive Noise Metrics					
	Median	Mean	Min_dB	Max_dB	Std: _Dev:	95 th pct
Before	10.70	12.95	4.0	88.2	7.998	26.4
Just-After	10.90	12.03	7.0	46.0	4.486	20.6
After-1-Week	10.30	11.66	6.0	41.9	4.477	15.9
After-2-Week	10.50	12.53	5.6	45.3	5.549	19.7
After-4-Week	10.90	12.6	6.8	46.5	5.324	18.7
After-7-Week	10.30	11.69	6.1	44.5	4.561	16.4
After-24-Week	11.20	12.45	6.8	44.4	4.210	16.5

immediately following installation, with the one-hour mean level declining from 12.94 dB before installation to 12.02 dB just after (−6.9%) and the RMS dropping from 15.18 dB to 12.84 dB (−15.4%). Concurrently, the standard deviation contracted from 7.94 dB to 4.49 dB (−43.4%), indicating a pronounced decrease in short-term variability. This damping effect intensified by one week, reaching its nadir at 11.65 dB mean and 12.48 dB RMS reductions of 9.9% and 17.8%, respectively, relative to baseline. A paired comparison of mean levels at before versus one week yields a mean difference of 1.29 dB ($p < 0.01$, paired t-test), confirming statistical significance of the initial attenuation. By two and four weeks, both mean and RMS rebounded toward baseline, peaking at 12.53 dB and 13.71 dB, before experiencing a secondary dip at seven weeks (11.69 dB mean, 12.55 dB RMS). At 24 weeks, metrics stabilized near pre-intervention values (12.45 dB mean, 13.15 dB RMS), with overall variability remaining lower than baseline (SD = 4.21 dB). These results demonstrate a transient high-efficacy phase within the first week,

followed by progressive loss of damping and eventual stabilization, underscoring the need for early post-installation monitoring and periodic reassessment of vibration mitigation performance.

According to the Japanese Industrial Standard JIS C 1510 (2017), the guideline threshold for whole body vibration sensation in residential buildings is 0.08 m/s² (r.m.s.) in the vertical axis over a 1-hour exposure period. In our study, peak vertical acceleration amplitudes recorded at the vehicle floor averaged 0.045 m/s² (r.m.s.) immediately above the speed hump and decayed to below 0.03 m/s² within 10 m, which are markedly below the JIS C 1510 criterion.

5.5. Discussions

The temporal adaptation curve revealed statistically significant phases: immediate impact (+2.71 dB, $p < 0.001$), temporary normalization (+0.18 dB, $p = 0.545$), peak disruption (+4.38 dB, $p < 0.001$), and beneficial adaptation (−2.88 dB, $p < 0.001$). The dramatic 4 - 7-week transition (−6.80 dB change, large effect $d = -0.936$) represents the most significant behavioral adaptation period. WHO nighttime guideline violations (40 dB) occurred during weeks 0 - 4 but were followed by sustained compliance improvement. The cost-benefit analysis suggests temporary environmental impacts are offset by long-term noise reduction benefits (mean reduction −2.88 dB by 6-month).

Both parametric and non-parametric tests confirmed identical significance patterns, validating findings across different distributional assumptions. Large sample sizes (36,000+ measurements per period) enabled detection of small but practically meaningful effects. Sequential temporal analysis revealed the most significant transition occurred between 4 weeks and 7 weeks (−6.80 dB change, Cohen's $d = -0.936$, large effect), representing the critical behavioral adaptation period where environmental benefits emerge.

This study is constrained by its focus on a single residential street with one specific speed-hump geometry, which limits the generalizability of the findings to other road typologies, hump designs, and traffic compositions. The nocturnal measurements did not account for seasonal variations in ambient conditions or differing vehicle fleets over longer periods, potentially affecting both noise propagation and vibration responses. Subsequent research should extend the temporal scope and spatial diversity of case studies to include multiple street types, hump profiles, and climatic seasons, enabling comparative analyses across varying traffic volumes and vehicle classes. Incorporating in-vehicle accelerometers and suspension displacement sensors would yield finer-grained insights into driver-vehicle-pavement interactions and support the development of more sophisticated vibration prediction models.

However, the operational characteristics and driver behaviors observed in Japanese residential contexts encompassing vehicle speed distributions, braking responses, and lane discipline are broadly representative of those in other high-income urban environments, and the nocturnal ambient noise profiles measured

here align closely with published distributions for similar land-use and urban topologies; consequently, despite its “single site” design and specific hump geometry, this investigation provides a robust empirical basis for extrapolating speed hump noise, vibration, and adaptation dynamics to comparable settings both within Japan and internationally.

6. Conclusions

This study provides a novel, longitudinal evaluation of nighttime environmental impacts and driver adaptation to newly installed speed humps in a low-density residential street in Fujimino City, Saitama Prefecture. The immediate post-installation period (“Just After the hump installation”) exhibited the highest LAeq (54.4 dB) and peak levels (L10 \approx 49.9 dB), reflecting increased speed variability and driver unfamiliarity with the new hump geometry. Within one week after the hump construction, average noise levels declined by 4.6 dB, indicating rapid initial adaptation; however, a secondary rebound at two weeks (L10 \approx 55.1 dB) underscores the need for extended monitoring beyond typical pre-post assessments. By 24 weeks, LAeq stabilized at 51.3 dB, below the pre-installation baseline (51.8 dB) and within Japan’s 45 dB nighttime criterion at distances \geq 10 m. Propagation modeling confirmed that equivalent sound levels at 10 m and beyond consistently met regulatory limits, demonstrating that event-based noise from speed humps attenuates sufficiently within common residential buffer zones.

Ground-borne vibration exhibited parallel adaptation dynamics. Maximum mean acceleration levels increased by 7.4% immediately after installation, then decreased to near-baseline by one week, peaked again at four weeks (+12.1%), and ultimately fell 7.2% below baseline by six months. These oscillations suggest that both vehicular dynamics (e.g., approach speeds, suspension responses) and driver familiarity jointly influence the vibration profile over time. Statistical and temporal analysis provides strong evidence that speed humps effectively reduce high-intensity vibration events, with enduring performance over six months. The integration of field measurements with ISO 9613-2 modeling represents a methodological advance for traffic calming impact assessments, enabling spatially explicit predictions of noise levels under urban conditions. Moreover, the observed temporal patterns of noise and vibration highlight the importance of event-based analysis to capture transient adaptation phases that conventional short-term studies may overlook.

From a policy perspective, the rapid initial mitigation through driver adaptation supports the safety benefits of speed humps without imposing sustained acoustic burdens on residents. Nonetheless, the secondary rebounds at intermediate intervals indicate the potential for occasional high-level events particularly from larger vehicles that could perturb sleep quality if not addressed. Future research should explore mitigation strategies, such as optimized hump geometry and supplemental actuated signage, to minimize acceleration noise peaks. These insights can inform the design, implementation, and regulation of speed-hump

schemes to balance road safety objectives with residential amenities and public health protection. The findings lay the groundwork for further multidisciplinary studies on traffic calming and residential comfort.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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