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Environmental Effects of Traffic Calming Devices on Residential Area using SUMO

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Abstract: *Recently, the number of traffic accidents on trunk roads tends to decrease due to the performance improvement of passenger vehicles. In the commuter rush hour of morning and evening, vehicles via residential road increases without going along trunk roads. Therefore, there are many traffic accidents of pedestrians (or bicycles) and vehicles on residential roads. In order to safeguard residents against traffic accidents, traffic calming devices (TCD), such as chicane, speed hump, and school zone, etc. have been introduced. Investigating these effects repeatedly is not easy since many times and efforts are required, such as observed at the place actually. In this paper, the effects of TCDs in residential areas, such as noise, speed, and emission of a vehicle, using Simulation of Urban Mobility (SUMO) are examined. As a result, it is found that it is possible to reduce the speed of the vehicle by TCD, and the level of noise at the location behind TCD becomes higher than the level of noise at the location of TCD implemented.*

Keywords: Traffic Calming Devices; Simulation of Urban Mobility; Noise; Emission; Residential Area

1. Introduction

Because vehicles passing residential roads do not often keep a speed limit, pedestrians and bicycles are risked. On residential roads co-existing many pedestrians and bicycles, there are many traffic accidents [1]. In order to reduce the speed of these vehicles and keep residents safe from traffic accidents, traffic calming devices (TCD) have been introduced to residential vehicle roads. TCDs are, in general, classified into four categories such as vertical deflections (e.g. hump or bump, speed table, raised intersection), horizontal shift (e.g. neighborhood traffic circle, chicane), roadway narrowing (e.g. choker, center island narrowing), and closure [2]. An example of a hump is shown in Fig. 1 [3]. In 1997, the UK has been launching the program of 'Traffic Management Schemes and Vehicle Emissions' including traffic calming schemes on vehicle emissions [4]. The common feature of those TCDs is that the speed of vehicles has decreased at just before TCDs and vehicles are speeding up after that. This behavior of vehicles results in the noise of acceleration and more pollutant exhaust gases, making residents in unhealthy conditions.

Figure 1. Example of a hump implemented in Saga-city [3]

In this paper, we investigate the effects of TCD on residential areas, from the points of noise, speed, and emissions of vehicles by using the Simulation of Urban Mobility (SUMO) [5]. SUMO is the road traffic simulation that was designed so that it might be possible to deal with a large-scale transportation network. Fig. 2 shows the parts of trunk roads (yellow line) and residential roads (orange line) in Saga-city. We pay attention to residential roads (i.e., orange dashed line in Fig. 2), in case of TCD such as a speed hump of 6m-long dimension.

2. Simulation Model

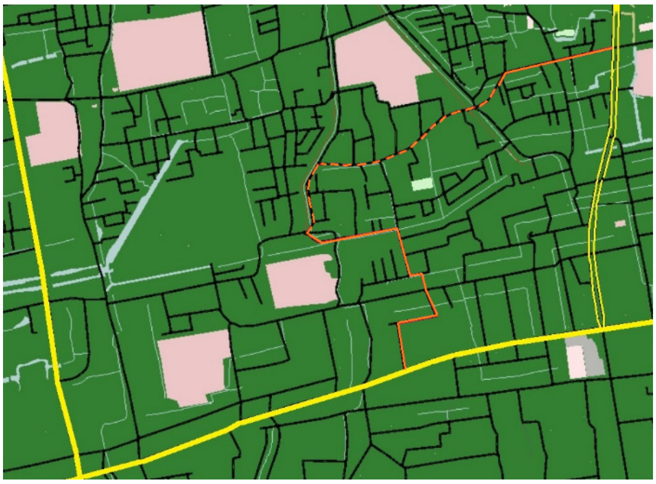

Figure 2. Selecting analytical residential road (orange) from trunk (yellow) and residential (black) roads in Saga-city

Selecting residential roads in Saga-city models TCD as a small zone like speed hump (or bump) of 6 meter-long. The effects of TCDs are analyzed by SUMO (Ver. 0.28.0), comparing its mobility characteristics without TCDs. The following are assumed: the maximum speed of gasoline-powered vehicles is 30 [km/h]. Passenger vehicles travel with speed of passing TCD limits 10 [km/h], acceleration and deceleration are 2.9 [m/s^2] and 7.5 [m/s^2], respectively. The length and width of the vehicle are 4.8 [m] and 1.8 [m], respectively. Furthermore, a vehicle supports EU emission standards for light-duty vehicles, Euro 4 [6]. The map data which is exhibited by the purpose used in SUMO is used [7]. A vehicle travel from P*start* point to P*end* point. Speed of vehicle is 0 [km/h] at P*start* point and 30 [km/h] at P*end* point. From P*start* point to P*end*, four TCDs are implemented as shown in Fig. 3.

Figure 3. Simulated residential road section with four TCDs

3. Noise and Speed of Vehicle Passing Through TCD

3.1 Noise level and speed of traveling vehicle

Fig. 4 shows the level of noise of vehicle generated when a vehicle travel from P*start* point to P*end* point on the lane of the road.

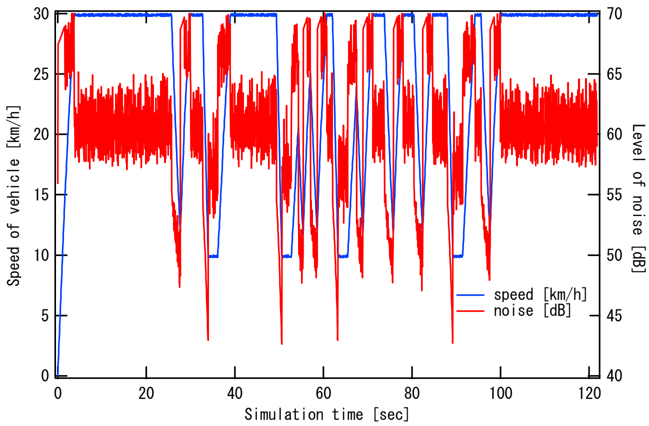

Figure 4. Noise level vehicle generated

From Fig. 4, it is found that vehicle speed decreases in the neighborhood of four places of TCD, and simultaneously prevent noise. The part where noise decreases besides that is because the vehicle is decelerating at an intersection. So, to investigate the noise and speed of the vehicle in detail, we pay attention to part of the residential road including TCD1 as shown in Fig. 5. Vehicle travels from P*st* to P*en* and TCD1 is implemented ahead of 27.74 [m] apart from P*st*.

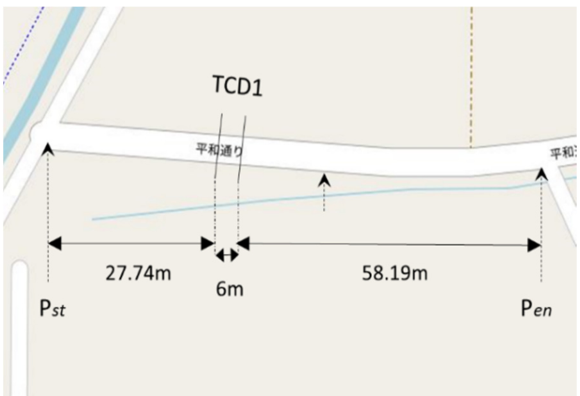

Figure 5. Simulation model of the residential road with TCD1

A level of noise from a vehicle, N, is attenuated by the following factors: the distance between observer and vehicle, A_{div}, absorption by the atmosphere, A_{atm}, influence of a ground level, Aground, absorption by a wall and the building, A_{screen}, and absorption by other factors, A_{misc}. Real noise of vehicle that observers of TCDs neighborhood hears, N_{real}, is given by

$$N_{real} = N - (\ A_{div} + A_{atm} + A_{ground} + A_{screen} + A_{misc}) \qquad [dB] \qquad (1)$$

In this paper, only A_{div} and A_{atm} are considered because it's complicated to consider the situation of the road surface and influence between the buildings. A_{div} is given by

$$A_{div} = 20 \cdot log\left(\frac{d}{d_0}\right) \qquad [dB] \qquad (2)$$

Where d [m] denotes the distance between observer and vehicle (d_0=1). A_{atm} is given by

$$A_{atm} = \frac{\alpha \cdot d}{1000} \qquad [dB] \qquad (3)$$

Where α [dB/km] denotes attenuation coefficient and set to 4.8 (in environment of 1 [kHz], temperature=20 degrees, and humidity 60%) [8].

Fig. 6 shows the level of noise of vehicle generated and speed when a vehicle travel from P*st* point to P*en* point on the lane of the road. The level of noise [dB] is set on the left-hand axis and the speed [km/h] is set on the right-hand axis, respectively, and the location of the vehicle from P*st* point is set on the axis of abscissa. From Fig. 6, it is found that the case of TCD1 is not implemented, the level of noise is about 60 [dB] because of vehicle travel at a constant speed of 30 [km/h] (*(a)→(f)→(e)*). On the other hand, the case of TCD1 implemented, the level of noise changes to *(a)→(b)→(c) →(d) →(e)* because the vehicle slows down before TCD1 and accelerates after having passed through TCD1 [9].

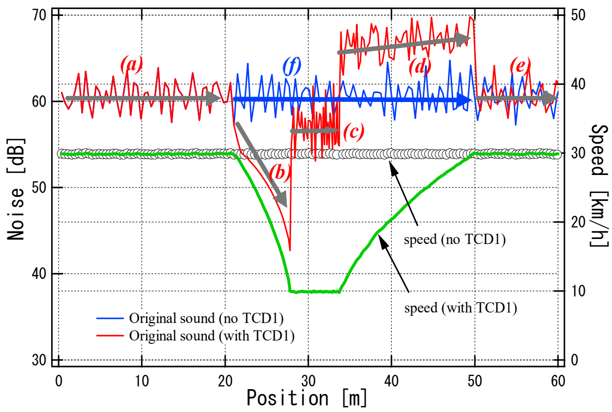

Figure 6. Noise and speed on a residential road with TCD1

3.2 Level of noise at the location of observing resident

Fig. 7 shows the level of noise that a resident observed at a point of 30.7 [m] away from P*st* point, i.e., in the middle of TCD1. Simulation time is set on the axis of abscissa. It is found that vehicle passes to the points of 30.74 [m] at about 35 sec. In addition, the vehicle passes the start and end points of TCD1 at about 34 sec. and 36.3 sec. respectively. The maximum level of noise is about 60 [dB] at point of 30.7 [m]. To investigate the effects of TCD1 in detail, we assume four observation points, a point of 27.7 [m] (i.e., at the start of TCD1), a point of 30.7 [m] (i.e., at the middle of TCD1), a point of 33.7 [m] (i.e., at the end of TCD1) and a point of 48.7 [m] (i.e., at the after of TCD1). The elapsed time in the simulation is classified into the range of three, times until a vehicle reaches TCD1, (A), time when a vehicle passes in TCD1, (B) and time after a vehicle passed TCD1, (C).

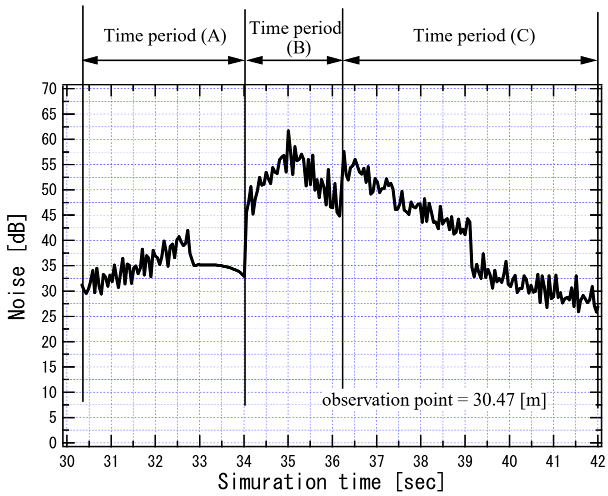

Figure 7. Noise level a resident observed at the middle of TCD1

3.2.1 The noise of vehicle observed in the time period (A)

Fig. 8 shows the level of noise that a resident observed at each four points in time period (A). The attenuation in Fig. 8 denotes $A_{div} + A_{atm}$. The level of noise is the value that deducted attenuation from the noise that the vehicle generates. Attenuation becomes small so as to approach the observation point, i.e., the level of noise increases. On the other hand, noise decreases because the vehicle begins to slow down in front of TCD1 (refer to (*b*) in Fig. 6). In addition, the noise level in an observation point will be so small that the distance between the vehicle and the observation point becomes long.

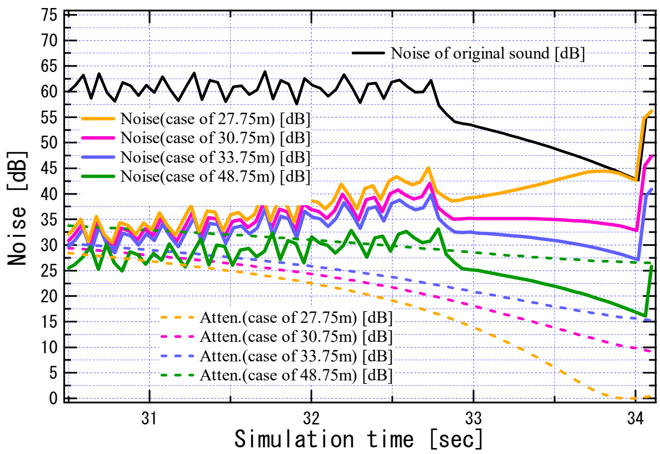

Figure 8. Noise level a resident observed in the time period (A)

3.2.2 The noise of vehicle observed in the time period (B)

Fig. 9 shows the level of noise that a resident observed at each four points in time period (B). In this period, the level of noise generated by vehicle is constant because vehicle travels at a constant speed of 10 [km/h]. The quantity of attenuation is minimized at the observation point. After the observation point, attenuation gradually increases. Therefore, in an observation point of 30.75 [m], noise becomes maximizes at 35 sec. and gradually decreases afterward. In an observation point of 27.75 [m], noise decreases gradually because the vehicle continues going away. On the other hand, in an observation point of 33.75 [m] and 48.75 [m], noise increases gradually because the vehicle comes close. The maximum level of noise is about 60 [dB] at point of 30.75 [m].

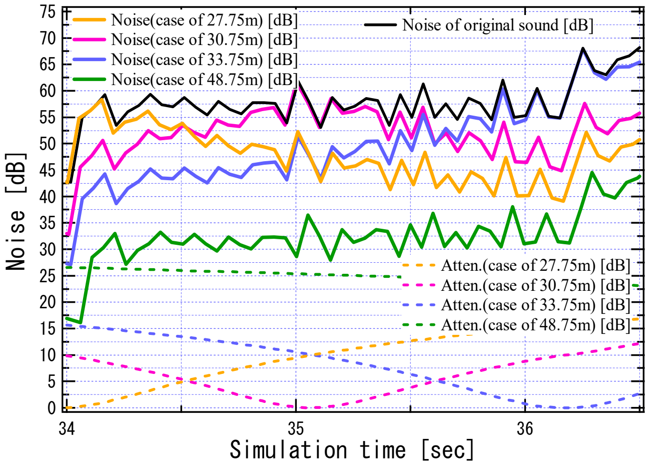

Figure 9. Noise level a resident observed in the time period (B)

3.2.3 The noise of vehicle observed in the time period (C)

Fig. 10 shows the level of noise that a resident observed at each four points in time period (C). From Fig. 10, it is found that vehicle passes to the points of 48.7 [m] at about 39 sec. Noise that a resident observed at each four points decreases suddenly at about 39 sec. because the acceleration of the vehicle ends. After that noise is decreasing gradually. In this period, the maximum level of noise is about 70 [dB] at point of about 49 [m]. Vehicle accelerates to 30 [km/h] from 10 [km/h] after passed TCD1. Therefore, the vehicle generates a higher noise (refer to (*d*) on Fig. 6). 70 [dB] is maximum noise at all of the time periods.

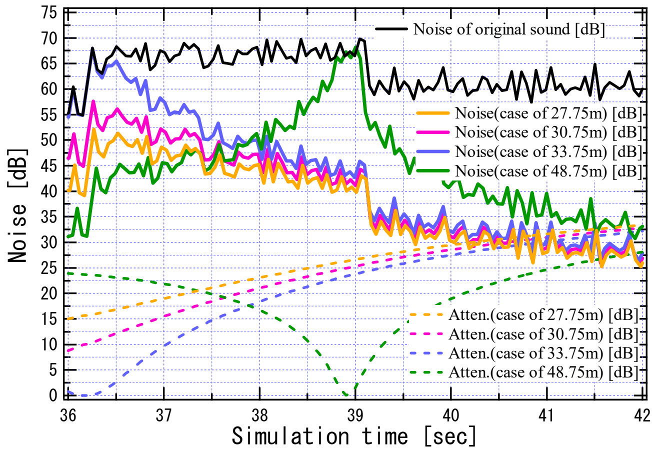

Figure 10. Noise level a resident observed in the time period (C)

3.2.4 The total times by which an observer hears a noise beyond fixation

Fig. 11 shows the total time when the level of noise of specified levels (e.g., 66 [dB], 68 [dB], 70 [dB], etc.) was observed with the average of 20 vehicles. From Fig. 11, it is found that the level of noise becomes small at around 25 [m] because the vehicle is decelerating and the place where less than 64 [dB] of noise is observed long is about 37 [m]. On the other hand, the place where more than 66 [dB] of noise is observed long is about between 43 [m] to 49 [m]. Fig. 12 expanded noise of more than 66 [dB] in Fig. 11. From Fig. 12, it is found that the level of noise at the interval of (*g*) about 10 [m] away from the end of TCD1 becomes higher than the level of noise at the TCD1 location (i.e. around 30 [m]).

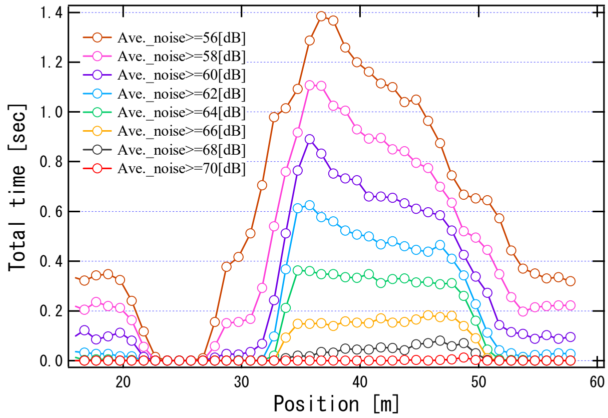

Figure 11. The total time when the noise more than 56dB was observed

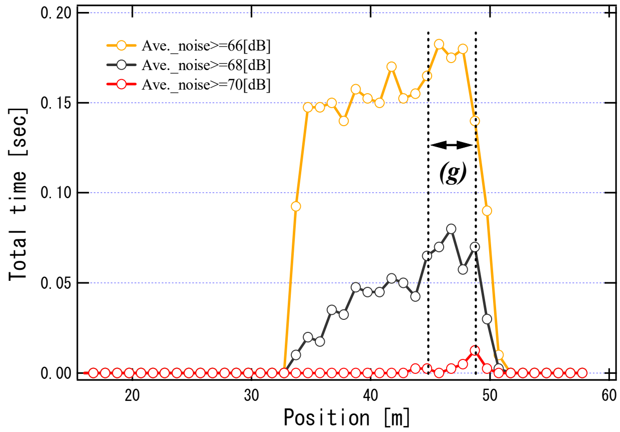

Figure 12. The total time when the noise more than 66dB was observed

4. Exhaust Gasses from Vehicle

Table 1, 2, and 3 show the gross volumes of gases exhausted for one second when vehicle travel in time periods (A), (B), and (C), respectively [10].

Table 1. Exhaust gases from the vehicle at the time period (A)

	CO2 [mg/sec]	CO [mg/sec]	HC [mg/sec]	NOx [mg/sec]	PMx [mg/sec]	fuel [ml/sec]
No TCD1	1616.45	29.38	0.170	0.624	0.022	0.695
With TCD1	1164.77	21.08	0.122	0.447	0.015	0.500

Table 2. Exhaust gases from the vehicle at the time period (B)

	CO2 [mg/sec]	CO [mg/sec]	HC [mg/sec]	NOx [mg/sec]	PMx [mg/sec]	fuel [ml/sec]
No TCD1	1598.10	28.99	0.169	0.617	0.021	0.687
With TCD1	1245.04	56.75	0.287	0.535	0.024	0.535

Table 3. Exhaust gases from the vehicle at the time period (C)

	CO2 [mg/sec]	CO [mg/sec]	HC [mg/sec]	NOx [mg/sec]	PMx [mg/sec]	fuel [ml/sec]
No TCD1	1480.30	26.91	0.156	0.572	0.020	0.636
With TCD1	2683.65	62.36	0.346	1.125	0.049	1.154

In time period (A), the initial speed of vehicle is 30 [km/h] and the final speed is 10 [km/h]. In time period (C), the initial speed of vehicle is 10 [km/h] and the final speed is 30 [km/h]. From Table 1, it is found that in the case of TCD1 is unimplemented, more quantity of the gases are exhausted and more fuel is consumed than the case of implemented TCD1. This is because the speed of vehicle decreases in case of with TCD1 while vehicle travel at a constant speed in case of without TCD1. On the other hand, from Table 3, it is found that in the case of TCD1 is implemented, more quantity of the gases are exhausted and more fuel is consumed than the case of unimplemented TCD1. This is because the vehicle accelerates to go back up at original speed (i.e., 30 [km/h]) in case of with TCD1. Table 2 shows that CO, HC, and PMx become a lot when the vehicle travels at low speed (i.e. 10 [km/h]). Considering the whole period of A, B, and C, it is found that in case with TCD1, the quantity of the exhaust gas increases in comparison with a case without TCD1 because the exhaust gas has a bigger influence by the acceleration than influence by the slowdown of vehicle.

5. Conclusion

In this paper, we simulated the effects of TCD in residential area using SUMO. After investigating attenuation of the generated noise of a vehicle at observation points, we considered about noise that an observer hears. As a result, it was shown that 1) it is possible to reduce the speed of a vehicle by TCD, 2) in case of TCD, the quantity of the exhaust gas and fuel consumption increase in comparison with a case without TCD, and 3) the level of noise at the location behind TCD about 10 [m] becomes higher than the level of noise at the location of TCD implemented. The data provided by this study depend on the simulation. The examination of the comparison by the actual values will be performed in the near future.

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Conflicts of Interest: The authors declare no conflict of interest.

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