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NOISE ABATEMENT THROUGH RED WAVE IN URBAN AREA: CASE STUDY

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ABSTRACT

A case study of forced speed limitation by reducing traffic light cycles (red wave) during the nighttime period, the opposite approach to green wave, is presented. The experiment was conducted on a section of urban road with high traffic flow regulated by traffic lights. Speed decrease led to a significant reduction in noise levels both at the center of the road section and at the intersection. The report presents the acoustic benefits in terms of $L_{Aeq\ (22\text{-}06)}$ up to 3 dB(A) and other traffic noise indicator such: L_{Amax}, TNI, NPL, IR, EVT, $G_{50\text{-}10kHz}$, L_{Zeq}-L_{Aeq}. This type of traffic management solution is low cost and permanent over time, compared to other types of noise mitigation in urban area, and brings potential improvements in road safety. Open questions, possible answers, and contraindications to the introduction of the red wave are discussed.

Keywords: *red-wave, traffic-calming, traffic-management, noise-indicators, noise-abatement.*

1. INTRODUCTION

In Italy, unlike in other countries, structural traffic calming techniques, such as speed bumps, structured paving, chicanes, narrowing, are rarely applied. Alternatively, traffic management is one of the main tools for reducing noise in cities, such as the green wave.
Several studies have shown good results in terms of reducing noise by green waves or actively adjusting traffic lights up to 2 dB(A), as collected in [1], while other studies are limited to numerical simulations, as in [2].
A completely opposite approach is that of red waves, the purpose of which is the forced reduction of vehicle speed. Conceptually, speed reduction reduces vehicle emissions, but the resulting accelerations and decelerations can cause an increase in noise emissions, for this reason there are no specific studies or tests on this issue. This contribution presents the encouraging results of a red wave field experiment applied on a high-traffic urban road section regulated by traffic lights. The study shows how in fact the institution of the red wave has discouraged deceleration/acceleration near the road intersection. The benefits in terms of speed reduction with consequent potential road safety benefits, acoustic benefits, and some critical issues will be discussed.

2. CASE STUDY

2.1 Red wave concept

Centralised traffic light systems are now common in large cities. In the City of Turin, there are 650 traffic lights, 40% of which are regulated by Swarco UTOPIA (Urban Traffic Control System) operated by 5T Telematic Technologies Transport Traffic Turin s.r.l. (Italy).
The concept of the red wave is designed to discourage drivers from assuming high speeds or performing sudden accelerations/decelerations to cross intersections regulated by traffic lights. This involves giving a green restart signal with the visual presence for the driver of the red signal for the next intersection, see video [3]. The red wave condition is only applicable during the nighttime period due to lower vehicular flow. Additionally, an initial evaluation was conducted to optimally set the red wave and set the noise measurements, which was essential for the success of the experiment.

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2.2 Experimental site and condition traffic light cycles

Aerial view of the experimental site for the traffic light synchronization study in the City of Turin is showing in Fig.1.

The survey measured vehicular flows, speeds, and sound levels for different traffic light timings, red wave option 1-2, compared to the ordinary configuration during the nighttime reference period (22-06), see Tab.1. Furthermore, for technical reasons, the traffic light configuration with flashing signal was not evaluated in this experiment. The traffic light cycles times in the various configurations analysed were set remotely.

The experimental site, *c.so Principe Oddone* (R01-R02), is approximately 215 meters long and located between *st. del Fortino* (R1) and *c.so Ciriè* (R2), in the direction of *p.zza Statuto* (D1).

The infrastructure consists of three lanes in each direction with separate carriageways, and a speed limit of 50 km/h. Two traffic light systems (TL1-TL2) regulate the two intersections along the road. The road pavement was built in 2016 and is in good condition.

It is important to mention that during the night period (22-06), the traffic flow on *c.so Principe Oddone* (R01) towards *p.zza Statuto* (D1) is around 2,000 vehicles, while the flows on *c.so Ciriè* (R1) and *st. del Fortino* (R2) are significantly lower. Therefore, it is not necessary to quantify the latter flows for the purposes of this assessment. It was necessary to optimise field measurements such as of the red wave.

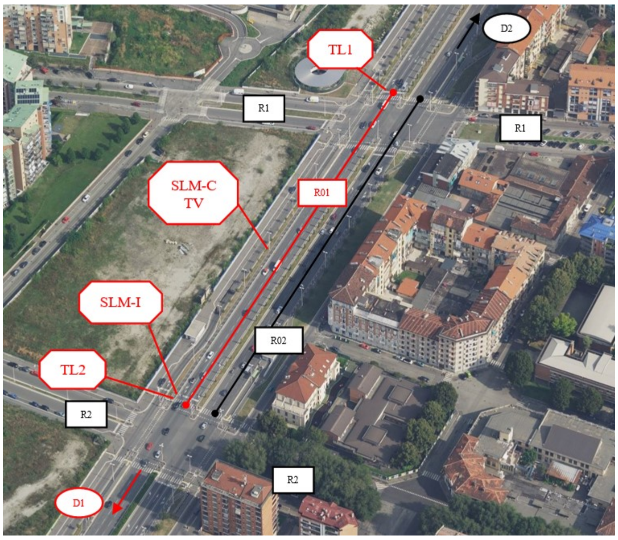

Figure 1. Experimental site and measurement configuration.

Table 1. Traffic light cycles configurations at night period (22-06).

Traffic Light Cycles	Description
Ordinary Cycle	Coordinate TL1-TL2 (39 sec for R01)
Red Wave (option 1)	Counterphase TL1-TL2 (39 sec for R01)
Red Wave (option 2)	Counterphase TL1-TL2 (24 sec for R01)

2.2.1 Initial assessment session

To determine if there were any changes in noise levels, a preliminary evaluation was conducted in May and June 2022. During this evaluation, sound levels, vehicle flows, and speeds were measured simultaneously for the three different traffic light cycle configurations, see Tab. 1. To collect the data, a class I sound level meter (SLM-C) and a radar traffic and velocity detector (TV) were installed on a public lighting pole in the center of the road section being studied, see left of Fig. 2. The traffic and speed measurements only concerned carriageway R01; however, this did not influence the acoustic evaluations in the present experiment. The sound measurements were taken by recording the A-weighted equivalent continuous level L_{Aeq} at 5-minute intervals for the entire measurement period.

Figure 3 shows the speed distributions for the three traffic light configurations analysed. A significant decrease in speeds is observed for the two red wave configurations, particularly for option 2. In addition, a reduction of 1.5 dB(A) is noted in the $L_{Aeq\ (22\text{-}06)}$. It should be noted, however, that the acoustic evaluation may not be accurate due to the limited 5-minute sampling interval and the lack of audio and spectral recordings on post-processing refinement.

Figure 2. Left: SLM-C and TV, right: SLM-I.

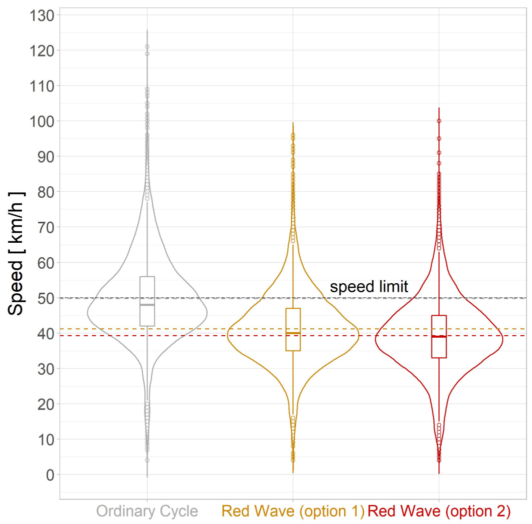

Figure 3. Violin plot of speed in the different traffic light configurations: initial assessment session.

2.2.2 Final assessment session

Following the promising results obtained, in terms of speed reduction (see 2.2.1), the experiment was further refined with a second measurement session in September 2022, limited to the red wave comparison only option 2, which provides the best speed reduction as it is more restrictive.
The new session was conducted by adding a second class I sound level meter (SLM-I) at the *c.so Cirié* (R1) intersection to assess any noise increases caused by acceleration/deceleration near the stop line, acquiring data every second, in addition to the audio signal and spectrum to better detect any anomalous events not attributable to vehicular traffic, see right of Fig. 2.
The two measurement sessions (initial and final) for each traffic light configuration lasted between 5 and 10 days. During the monitoring sessions, meteorological conditions were suitable for most of the measurement time. Any periods of bad weather (wind > 5 m/s and atmospheric precipitation) were subsequently excluded from data processing. The air temperature measured by the Arpa meteorological station 1 km from the experimental site was also acquired.
In addition, to minimise measurement uncertainties, the same detectors, the same acoustic calibrator, and the same measurement point (x, y, z) were used for all measurement performed.
The final assessment confirmed the speed reductions reported in the first session. Slight deviations in the average speed between the two evaluations were observed: 0.8 km/h for the ordinary cycle and 0.3 km/h for the red wave (option 2). This demonstrates an excellent degree of repeatability of the method.

3. RESULTS AND DISCUSSION

3.1 Results

The results of the final assessment session, ordinary cycle vs red wave (option 2), are presented below.
The reduction in speed is substantial, with 87% of vehicles below the speed limit of 50 km/h compared to the previous 62%, Tab.2 and Fig.4. The result is substantiated by Wilcoxon's statistical test, rejects the null hypothesis, with a 99% confidence level, that the two samples (*Ordinary Cycles* vs *Red Wave*) are from to the same population.

Table 2. Speed at night - ordinary cycle vs red wave

Parameter	Unit	Ordinary Cycle	Red Wave
Mean	km/h	49.1	39.6
Median	km/h	47.0	39.0
Q1	km/h	42.0	33.0
Q3	km/h	55.0	45.0
σ	km/h	12.2	10.3
> 30 km/h	%	96	84
> 50 km/h	%	38	13
> 70 km/h	%	5	1
> 90 km/h	%	0.6	0.05

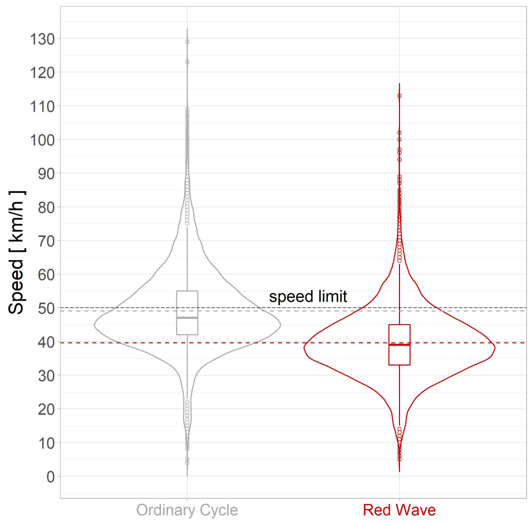

Figure 4. Violin plot of velocity - ordinary cycle vs red wave: final assessment session.

For the acoustic assessments, data collected with samples per second after exclusion of anomalous events were analysed using the open source software R. Figure 5 shows the distribution of the samples per second of L_{Aeq}. The Wilcoxon's statistical test rejects the null hypothesis, with a 99% confidence level, that the two samples (*Ordinary Cycles* vs. *Red Wave*) are from the same population.

For the estimation of the reduction in terms of $L_{Aeq\ (22\text{-}06)}$ the data were normalised for the variation in vehicular flows and air temperature recorded to account for possible variations in the different traffic light configurations that could modify vehicular emissions, beyond speed. The normalisation for vehicular flows and air temperature was carried out using formula 2.2.1 and 2.2.10 respectively, as reported by the CNOSSOS-EU calculation model [4-5]. This normalisation resulted in a shift of 0.0 dB(A) for the acoustic measurements at the center of the section and 0.2 dB(A) for the intersection. Taking this small shift into account, other noise indicators were calculated, such as:

- TNI - Traffic Noise Index as defined in [6]
- NPL - Noise Pollution Level as defined in [7]
- IR - Intermittency Ratio as defined in [8]
- EVT - Event Component as defined in [9]
- $G_{50\text{-}10kHz}$ - center of mass of the spectrum
- L_{Zeq}-L_{Aeq} - low frequency components

In addition, the L_{Amax} parameter recorded at 5-minute intervals was evaluated. Table 3 shows the average variations obtained from the hourly calculation of TNI, NPL, IR, EVT, see Fig. 6 and Fig.7. For spectral indicators as well as L_{Amax}, the average over the entire night period (06-22) was assumed.

The decrease in indicators such as IR and EVT, which describe events emerging from the background noise, is a consequence of a symmetrical distribution and smaller interquartile range of $L_{Aeq,1s}$ for the red wave compared to a positive symmetry of ordinary cycles, see Fig. 5. The anomalous events in terms of speed (Fig.4) and sound levels for red wave (Fig.5) are attributed to crossing violations in red signals (approx. 3%). The distribution of levels below 40 dB(A) are comparable, indicating that the background noise remained unchanged during the different measurement sessions.

Sound signals with a low-frequency predominance are found to have greater sound propagation and intrusiveness in building interiors. There is a minimal and insignificant shift towards the low frequencies of the spectral components at the intersection, $G_{50\text{-}10kHz}$ and L_{Zeq}-L_{Aeq}, see Tab. 3. The reduction in noise indicators is also evident at the intersection.

This last positive and partly unexpected result can be explained in two ways: vehicles equipped with a start and stop system reduce noise emissions when stopped at the intersection and at the same time cars nearing the intersection (TL2) in a red wave configuration are not in the condition of approaching the intersection with a traffic light signal of yellow. This avoids accelerations to evacuate the crossroads as quickly as possible or decelerations to stop the vehicle in time.

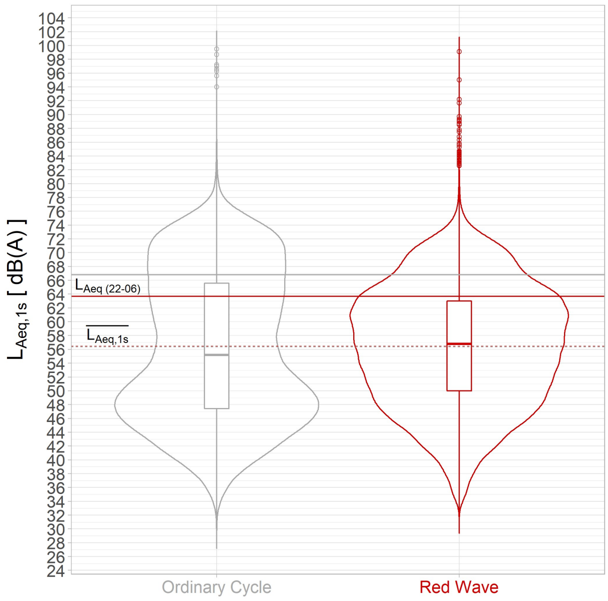

Figure 5. Violin plot of $L_{Aeq,1s}$ - ordinary cycle vs red wave: in center section, final assessment session. Dashed lines show arithmetic mean (0.2 dB different), solid $L_{Aeq\ (22\text{-}06)}$.

Table 3. Variation of noise indicators.

Noise Indicator	Unit	Red Wave minus Ordinary Cycles	
		Center Section	Intersection
$L_{Aeq\ (22\text{-}06)}$	dB(A)	-3.1	-2.5
L_{Amax}	dB(A)	-3.8	-3.2
TNI	dB(A)	-22.5	-21.7
NPL	dB(A)	-9.6	-8.7
IR	%	-7.0	-6.0
EVT	scale of 0 to 10	-1.4	-1.2
$G_{50\text{-}10kHz}$	Hz	0.0	-20
L_{Zeq}-L_{Aeq}	dB	0.0	+1.7

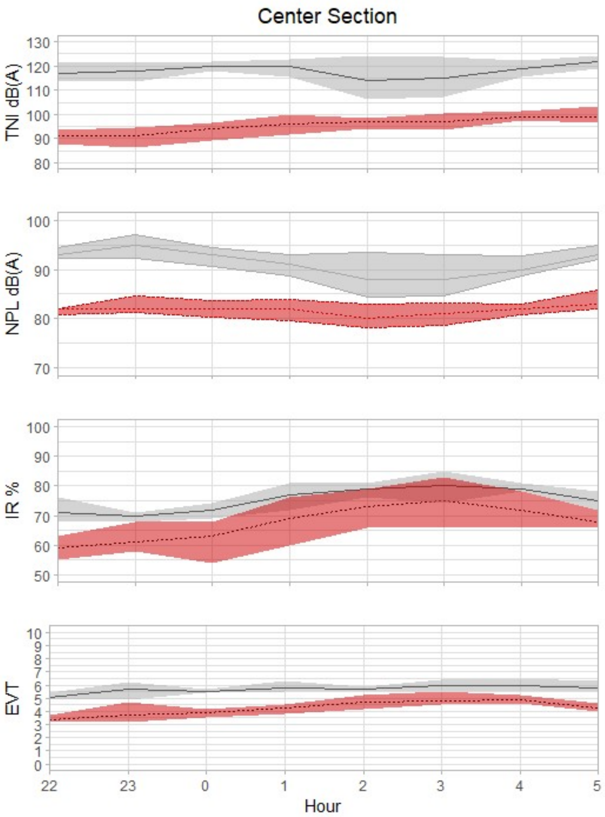

Figure 6. Noise indicator: min, max, mean for each hour for ordinary cycles and red wave at center section. Red wave in red color.

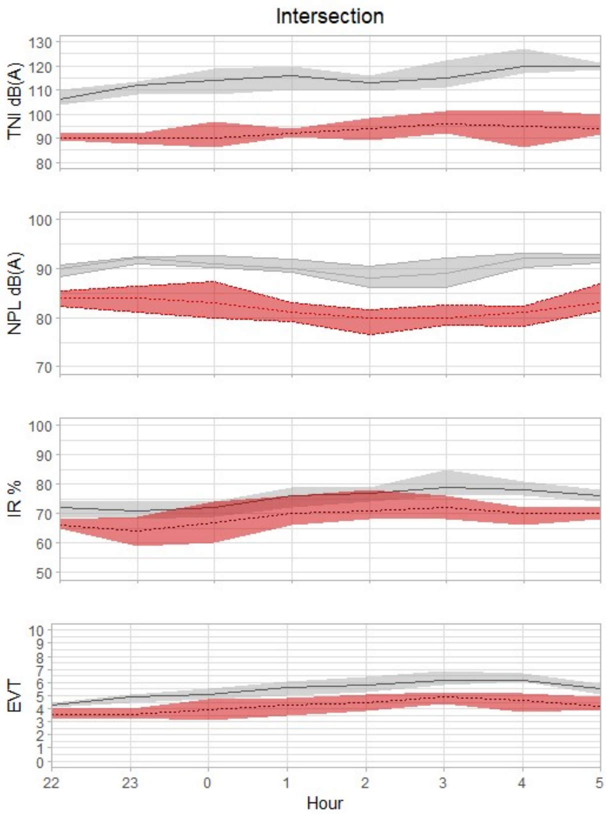

Figure 7. Noise indicator: min, max, mean for each hour for ordinary cycles and red wave at intersection. Red wave in red color.

3.2 Discussion

The experimentation of the red wave during the nighttime period showed excellent results in terms of acoustic benefits both in the center of the road section and at the intersection (deceleration/acceleration phase near the stop line), with considerable benefits related to the decrease in vehicle speeds and the consequent improvement in road safety. In this regard, it should be noted that to date no complaints have been received by the Municipality of Turin from road users.

Advantages, contraindications to the introduction of the red wave and open questions are discussed below with possible answers.

Road safety? The Highway Safety Manual reports that a 1 mph (1.6 km/h) reduction in operating speeds can result in a 17% decrease in fatal crashes. A separate study found that a 10% reduction in the average speed resulted in 19% fewer injury crashes, 27% fewer severe crashes, and 34% fewer fatal crashes [10]. In this study, the average speed was reduced by 10 km/h, 20% reduction.

The costs of noise mitigation? The costs are already present in the network system of the traffic light installations. The only costs relate to the optimisation of the traffic light timings and any field tests.

Duration of noise mitigation? It is unlimited with only the routine maintenance of the traffic light systems, which are already in place due to their functionality anyway.

What would happen in the near future with a predominance of electric vehicles? Following the study proposed in [11], a theoretical assessment of road noise emissions was carried out by considering the totality of electric vehicles with a reduction in average driving speed from 50 to 40 km/h as obtained in the present study. Reductions of L_{Aeq} 2.2 dB(A) would be achieved. This result is due to the substantial contribution of rolling noise that will remain with the introduction of EVs. Even in a more distant future of self-driving car the red wave may be a good solution to reduce noise.

Could drivers be encouraged to change roads? It is believed that this type of speed calming could only be introduced on main road that by their nature are predominantly used. Any disincentive to their use would in any case constitute a redistribution of traffic over the entire road network with a consequent reduction in the noise impact on people in hot spots.

Increased travel time? It is assumed that during the night period the impact on road users is less due to low traffic volumes.

What happens when a red wave is established on consecutive crossings? At present, this aspect has not been analysed.

Emissions in atmosphere and cost for drivers? This must be taken into account in view of the increase in vehicle restarts and the possible increase in fuel consumption [12].

4. CONCLUSION

The presented case study highlights the positive outcomes of implementing a red wave at night on a high-traffic urban road section regulated by traffic lights. The results showed encouraging noise reduction benefits in center section, with a decrease of up to 3 dB(A) in $L_{Aeq\,(22\text{-}06)}$, and over 3 dB(A) in L_{Amax}. Additionally, noise indicators such as IR and EVT decreased by 7 and 1.4 points respectively, indicating a reduction in emergent noise events. Importantly, there were no adverse effects observed in the low-frequency spectral components, which are typically considered critical in noise assessment. Unexpectedly, almost similar results were obtained at the road intersection.

Implementation of the red wave at night resulted in a significant reduction in average speed, with a 10 km/h decrease. This led to 87% of vehicles operating below the speed limit, compared to the previous 62%. The improved compliance with speed limits contributes to road safety enhancements. The reduction in speeds indicates an estimated decrease of more than 2 dB(A), even with the total introduction of electric vehicles.

Considering the cost-effectiveness and long-term sustainability of this traffic management solution, it is regarded as a low-cost and permanent measure compared to other noise mitigation approaches in urban areas. Many large cities already employ centralized traffic light systems, which are inherent in the existing network infrastructure. Therefore, optimizing the traffic light cycles to implement the red wave strategy can be achieved without significant additional costs.

The trial's success has prompted plans for replication at other sites to validate the positive outcomes. However, one aspect that requires further evaluation is the potential impact on air emissions. As the trial did not address this aspect explicitly, it remains to be assessed whether there are any notable increases in air pollutant emissions associated with the red wave implementation.

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