

Waze to Beat the System: A Real-World Evaluation of Crowdsourced Enforcement Alerts on Driver Speed

Levi Anderson

l.anderson@usc.edu.au

University of the Sunshine Coast <https://orcid.org/0000-0003-4234-1842>

Research Article

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Abstract

Crowdsourced navigation applications such as Waze allow users to report speed enforcement locations in real time, alerting nearby drivers to the presence of police or speed cameras. Despite the widespread adoption of these platforms, no empirical research has examined whether such alerts influence actual driver speed. This study addresses that gap using a real-world, quasi-experimental pre–post design to assess the impact of crowdsourced enforcement alerts on vehicle speed across multiple road environments in Queensland, Australia. Vehicle speeds were measured using a ProLaser 4 speed detection device at 33 sites spanning various speed zones (40–100 km/h) and multiple road types including arterial, residential, commercial, highway, mixed, and active school zone environments. At each site, speeds were recorded during a baseline period before an enforcement alert appeared on Waze, and during a matched post-alert period of equal duration. Analysis of 9052 speed observations across 33 sites found a statistically significant reduction in mean speed occurred following the appearance of enforcement alerts on the navigation apps (Before: $M = 1.23$ km/h, $SD = 8.34$; After: $M = -3.92$ km/h, $SD = 7.77$). These findings highlight that crowdsourced enforcement alerts are a contemporary mechanism of technology-facilitated punishment avoidance and while suppressing speed at the point of detection, may erode the perceived certainty of apprehension and embolden offending across the wider road network over time. The practical implications of this study suggest that road policing in a digitally connected environment may benefit from shorter, more geographically dispersed deployments, with the appearance of an enforcement alert leveraged as a trigger to reposition enforcement, acting as a force multiplier for a finite enforcement resource.

Introduction

Speeding remains one of the most significant contributors to road trauma globally, with excess speed linked to a substantial proportion of serious injuries and fatalities (World Health Organization, 2023). In Queensland, Australia, speeding contributes to approximately one-third of fatal road crashes, making it a persistent priority for road safety policy and enforcement (Queensland Government, 2024). The relationship between speed and crash severity is well established: as vehicle speeds increase, both the likelihood and severity of crashes rise exponentially, a relationship often described as the power model of speed and crash risk (Nilsson, 2004; Elvik et al., 2019).

The primary mechanism through which police seek to reduce speeding is enforcement, both overt and covert. Deterrence theory, which underpins most speed enforcement strategies, posits that the perceived certainty, severity, and swiftness of punishment discourage individuals from engaging in prohibited behaviour (Beccaria, 1764/2009; Becker, 1968). In the context of road policing, this translates to the proposition that drivers who believe they are likely to be detected and sanctioned for speeding will reduce their speed (Fleiter & Watson, 2006; Ritchey & Nicholson-Crotty, 2011). Research consistently demonstrates that the certainty of detection, that is, the perceived probability of being caught, exerts a stronger deterrent effect than the severity of the penalty (Barnum et al., 2021; Nagin, 2013). As deterrence operates through perceived risk rather than objective risk, the certainty of apprehension is largely influenced by what drivers believe, rather than the police resources that are actually deployed (Paternoster & Bachman, 2012). Crowdsourced enforcement alerts can therefore be posited as a mechanism that manipulates perceived certainty in real time.

A well-documented feature of speed enforcement is the “halo effect” which is where speed reductions are observed not only at the precise area where enforcement is occurring but also in the surrounding area and for a period of time or distance after enforcement activity ceases (Fu & Liu, 2023; Hauer et al., 1982; Vaa, 1997). This spatial and temporal generalisation of deterrence is a cornerstone of enforcement strategy, as it implies that visible enforcement can produce broader compliance effects beyond the immediate enforcement zone (Cohn et al., 2020). The extent or operative ‘halo’ effect of speed enforcement, however, depends on drivers perceiving that enforcement is both present and unpredictable (Simpson et al., 2020).

In recent years, a technological development has emerged that may fundamentally alter the dynamics of speed enforcement deterrence: navigation applications that incorporate crowdsourced information on hazards and enforcement. Platforms such as Waze (a Google subsidiary with over 150 million monthly active users worldwide) enable drivers to report in real time the presence of police, speed cameras, and other enforcement activities (Buganza et al., 2015). Within Australia, it is reported that approximately 33.5% of drivers are using Waze or similar navigation apps while driving (Australian Automobile Association, 2020). When a Waze user reports an enforcement location, the information is immediately shared with other app users in the vicinity through an in-app alert, effectively providing advanced warning to drivers of enforcement presence ahead of drivers on their journey. Google Maps

(which acquired Waze in 2013) and Apple Maps have since incorporated similar features, further expanding the reach of crowdsourced enforcement notifications. Google Maps relies on crowdsourced information from not only their own user, but also pull in enforcement location information from Waze users that have reported the police location within the Waze app.

The practical implications of this technology for road policing are substantial yet empirically under-examined. On one hand, crowdsourced enforcement alerts could be viewed as extending the deterrence halo, that is, if drivers receive advanced warning of enforcement and subsequently reduce their speed, the alert functions similarly to an enforcement warning sign, which research has demonstrated to be effective in reducing speeds (Holland & Conner, 1996; Simpson et al., 2020). In line with this interpretation, apps like Waze might inadvertently support traffic enforcement objectives by broadening the spatial reach of enforcement presence on the road beyond a visual line of sight. Conversely, these crowdsourced alerts may undermine deterrence (Oviedo-Trespalacios & Watson, 2021) or operational enforcement strategy by enabling drivers to reduce speed only in the immediate vicinity of known enforcement, resuming higher speeds once the perceived threat has passed; a pattern analogous to the “kangaroo effect” observed near speed cameras (De Pauw et al., 2014). Point-to-point (or average speed) enforcement systems were developed in part to address this limitation, measuring mean speed across a road segment rather than at a single detection point, and have been shown to reduce not only mean speed but speed variance and the proportion of high-end speeders (Soole et al., 2013). However, with navigation applications such as Waze that alert drivers to both the entry and exit points of average speed zones and displays a continuous countdown of the remaining distance within the monitored zone, this potentially enables drivers to modulate speeding behaviour strategically across the segment rather than maintaining consistent compliance throughout, thereby partially undermining the core mechanism by which point-to-point systems reduce speed variance and non-compliance.

From a policing perspective, the uptake of navigation apps which provide enforcement raises important operational and strategic questions. If enforcement locations are being reported and shared in real time, the element of unpredictability that underpins effective deterrence may be compromised. Alternatively, if these alerts produce genuine speed reductions, even if localised or temporary, they may represent a previously unrecognised mechanism through which technology supplements enforcement capacity. For frontline police, understanding the impact of these alerts on driver behaviour is essential for informed deployment decisions, resource allocation, and the development of enforcement strategies that account for the technological landscape in which modern road policing operates.

Despite the clear relevance of crowdsourced enforcement alerts to road policing practice, there is limited empirical research that has examined the direct impact on individual driver speed. While a study out of the Netherlands (Liu & Feng, 2023) and a Belgian field study (Dons, 2024) provide initial evidence that crowdsourced alerts are associated with modest speed reductions of 1–3 km/h, both relied on aggregate sensor data or passive camera deployments rather than individual vehicle measurements. Further studies have explored the role of navigation apps in traffic management and route optimisation (Buganza et al., 2015) and have noted that some drivers use apps like Waze to detect police presence (Barnum et al., 2021; Truelove, Stefanidis, et al., 2023). The present study addresses the current limitations and gaps within the literature, offering a more direct test of the behavioural response to crowdsourced enforcement alerts using individual laser-measured speeds across a quasi-experimental design replicating a real-world enforcement context.

The present study aims to address an identified gap in the literature by providing the first quasi-experimental, real-world examination of the impact of crowdsourced speed enforcement alerts on driver speed at the site of the enforcement alert specifically. Using a quasi-experimental pre–post design, we measured vehicle speeds at multiple sites across Queensland, Australia, were measured before and after the appearance of a Waze enforcement alert. Specifically, this study addresses three research questions:

Aim 1. Do crowdsourced speed enforcement alerts reduce mean vehicle speed and the proportion of vehicles exceeding the posted speed limit?

Aim 2. How quickly do enforcement alerts appear on Waze following the commencement of data collection, and how long do they persist after the research team departs?

Aim 3. Does the impact of crowdsourced enforcement alerts on driver speed vary across road environments and speed zones?

Literature Review

Speed, Enforcement, and Deterrence

The relationship between vehicle speed and road trauma is among the most well-established findings in road safety research. The power model developed by Nilsson (2004) and subsequently refined by Elvik et al. (2019) demonstrates that even modest changes in mean speed produce disproportionately large changes in crash risk and severity. A 5% reduction in mean speed, for example, has been estimated to produce approximately a 20% reduction in fatal crashes (Elvik, 2009). This evidence base has driven policy efforts across jurisdictions to reduce speed through a combination of engineering, education, and enforcement measures.

Speed enforcement, whether through police-operated speed detection devices, fixed and mobile speed cameras, or automated average-speed systems, is grounded in classical deterrence theory. The theory proposes that rational actors weigh the expected costs and benefits of offending behaviour, with the costs determined by the perceived certainty, severity, and swiftness of sanctions associated with such offending behaviour (Beccaria, 1764/2009; Becker, 1968). In the speed enforcement context, Ritchey and Nicholson-Crotty (2011) demonstrated that estimates of the effect of speed limits on traffic fatalities in the United States were significantly distorted when enforcement and penalty variables were not considered in the calculations. These findings from Ritchey and Nicholson-Crotty (2011) reinforce that posted speed limits alone are insufficient controls on a road network, without drivers having certainty that enforcement will occur, accompanied by adequately severe sanctions.

Among the three dimensions of deterrence, the certainty of apprehension consistently emerges as the strongest predictor of compliance. Fleiter and Watson (2006), in a study of Queensland drivers, found that the perceived probability of being caught significantly reduced self-reported speeding, whereas the perceived size of the fine did not. This finding aligns with the broader criminological literature, which generally finds that perceived certainty of punishment exerts a larger effect on behaviour than perceived severity (Nagin, 2013). Barnum et al. (2021), using an experimental survey design, further demonstrated that perceptions of apprehension risk for speeding were grounded in objective conditions and meaningfully predicted behavioural intentions to speed. With crowdsourced enforcement alerts being presented to drivers, the perceived risk of being apprehended, irrespective of the objective risk, for their offending behaviour may be diminished (Paternoster & Bachman, 2012), undermining the deterrence of police enforcement.

Technology-Facilitated Punishment Avoidance and Deterrence

Punishment avoidance theory extends classical deterrence by emphasising that individuals are motivated not only by the risk of formal sanctions, but also by opportunities to evade detection and punishment. Stafford and Warr's (1993) reconceptualisation of deterrence highlighted the role of both personal and vicarious experiences of avoiding sanction in shaping perceptions of risk and future offending, a theme further developed in work on impulsivity and offending trajectories (Piquero & Pogarsky, 2002). Qualitative research with young drivers has shown that punishment avoidance is a salient feature of real-world decision-making about speeding, with participants actively describing strategies to "beat the system" while maintaining an appearance of compliance (Bates & Anderson, 2019). More recent studies have documented how digital technologies enable new forms of punishment avoidance, with drivers using social media and enforcement-location tools to locate police and adjust their behaviour only when detection is likely (Barnum et al., 2021; Mills et al., 2022; Truelove et al., 2025). In this context, crowdsourced navigation apps that disclose enforcement locations can be understood as a contemporary punishment avoidance mechanism, potentially reshaping how drivers perceive and respond to enforcement risk on the road.

Building on this work, technology-facilitated and crowdsourced enforcement information can be understood as a contemporary mechanism for punishment avoidance within road policing context. Crowdsourced navigation apps and social media groups that share police enforcement information allow members of the public to share real-time information about enforcement locations (Mills et al., 2022). This sharing of real-time enforcement information enables drivers to selectively and temporarily adjust their behaviour only when detection is imminent and to resume offending once they have passed the area where enforcement was reported. Qualitative and survey-based studies already document that some drivers use Waze-like platforms and police location pages on social media specifically to locate enforcement and avoid sanctions for their offending behaviour, rather than to comply with road rules per se (Barnum et al., 2021; Mills et al., 2022; Truelove et al., 2025; Truelove, Stefanidis, et al., 2023). In deterrence terms, each successful instance of "beating the system" via crowdsourced alerts constitutes a punishment avoidance event that

may erode perceived certainty of apprehension over time, potentially reshaping the risk–reward decision making evaluation of drivers about committing traffic offences in a digitally connected traffic environment.

Enforcement Visibility and the Halo Effect

A substantial body of evidence demonstrates that the visible presence of enforcement, whether actual or perceived, reduces vehicle speeds. Simpson et al. (2020) conducted a multisite field study in British Columbia, Canada, in which an inanimate but realistic police cut-out was deployed along arterial roadways while vehicle speeds were measured using radar. The study found that the presence of the cut-out significantly reduced speeding, providing evidence that even the perception of police presence can produce deterrent effects. Earlier research had similarly demonstrated that stationary police vehicles, whether occupied or unoccupied, reduce speeds along urban and rural highways (Armour, 1986; Ravani & Wang, 2018), and that police speed-check warning signs alone can reduce motorist speed (Holland & Conner, 1996).

The halo effect of enforcement refers to the spatial and temporal generalisation of speed reductions beyond the immediate point of enforcement. Research on speed cameras has demonstrated that speed reductions can extend upstream and downstream of camera locations, though the magnitude of the effect attenuates with distance (Hauer et al., 1982). The halo effect is a critical mechanism through which limited enforcement resources produce broader road safety benefits, as it implies that enforcement at one location can influence speeds across a wider area (Vaa, 1997). However, the halo effect depends on drivers being uncertain about the precise location and timing of enforcement, a condition that crowdsourced enforcement alerts may directly challenge.

Crowdsourced Navigation Apps and Enforcement Alerts

Crowdsourced navigation applications represent a significant technological shift in the information environment surrounding road policing (Truelove, Stefanidis, et al., 2023). Waze, the most prominent of these platforms, was developed as a community-based navigation tool in which users contribute real-time information about road conditions, traffic congestion, and enforcement locations (Buganza et al., 2015). The platform's enforcement reporting feature allows any user to flag the presence of police or speed cameras, with the report immediately visible to other users navigating nearby routes. Google Maps (which incorporates user reports of enforcement from Waze) and Apple Maps have since introduced similar features, ensuring that enforcement alerts are available to the vast majority of smartphone-equipped drivers. The potential implications of crowdsourced enforcement alerts have been noted in the deterrence literature, though not empirically examined. For example, Barnum et al. (2021) included the use of navigation apps to detect police as a variable in their study of speeding deterrence, finding it to be a feature of driver behaviour worthy of consideration in perceptual deterrence frameworks. More recently, Truelove et al. (2025) found that some drivers regulate their speeding behaviour using Waze-like technology, while another paper from that same study found that drivers reported also using apps to avoid being caught for road rule violations (Truelove, Nicolls, et al., 2023). Furthermore, another study by Truelove and Oviedo-Trespalacios (2026) found that drivers who use navigation apps with enforcement notifications (Waze, Google Maps) reported more frequent speeding and lower perceptions of enforcement legitimacy. However, no published study has directly measured whether the appearance of an enforcement alert on a crowdsourced platform produces measurable changes in vehicle speed.

This identified gap in the current literature is notable for several reasons. First, the propagation of these apps among the driving population has grown substantially, with Waze continuing to grow in popularity with reportedly over 150 million monthly active users globally at the end of 2022 (Waze, 2022). Second, the real-time nature of enforcement alerts means that information about police presence can spread far more rapidly than through traditional word-of-mouth or other social media channels. Furthermore, this enforcement information is then available to drivers at a time when they are able to use this information to circumvent detection and punishment for traffic offences. Third, the crowdsourced nature of the alerts means that enforcement locations are reported by members of the public, effectively creating a distributed surveillance network that monitors road police activity, possibly undermining the potential road safety impacts of police presence. For police focused on road safety, understanding the behavioural consequences of this technology is essential for designing enforcement strategies that remain effective in a crowdsourced, punishment avoidant environment.

The Present Study

This study provides the first empirical examination of the impact of crowdsourced enforcement alerts on driver behaviour. By measuring vehicle speeds before and after the appearance of a Waze enforcement alert across multiple road environments in Queensland, Australia, this research offers direct evidence on whether or not these alerts produce measurable speed reductions. The study contributes to the deterrence literature by examining a novel mechanism through which perceived enforcement presence may influence driver behaviour, as well as to the road policing literature by providing evidence relevant to enforcement strategy and deployment decisions.

Method

Design

This study employed a quasi-experimental pre–post design. At each data collection site, vehicle speeds were measured continuously using a Kustom Signals ProLaser 4 speed detection device. The appearance of a crowdsourced enforcement alert on Waze served as the intervention point, dividing observations into a pre-alert (baseline) period and a post-alert (treatment) period. The duration of the post-alert period was matched to the baseline period at each site, producing a balanced comparison.

Sites

Data were collected at 33 sites across Southeast Queensland, Australia. Sites were selected to represent a range of road environments and speed zones, including arterial roads, residential streets, commercial areas, active school zones, highways, and mixed-use corridors. Selection criteria included the posted speed limit (ranging from 40 to 100 km/h), the availability of safe and legal parking for the operation of the ProLaser 4, and sufficient traffic volume and line-of-sight to approaching vehicles.

Data

The primary data utilised by this study was the individual vehicle speed measurements of vehicles on the road. The dataset comprises 9052 speed observations across 33 sites. All observations were of vehicles passing through the data collection site on public roads; no individual or identifying vehicle or driver data was collected, and the study was conducted in accordance with the ethical principles governing observational research in public spaces. Ethics approval for this research was obtained by the appropriate University Human Research Committee (Approval Number A262940).

Materials and Equipment

Vehicle speeds were measured using a Kustom Signals ProLaser 4, a handheld laser speed detection device widely used by law enforcement agencies in Australia and internationally. The ProLaser 4 provides individual vehicle speed readings accurate to ± 1 km/h, with a maximum detection range of 1,000 metres. The device records the speed, detection range, and timestamp for each measurement, which were subsequently transferred to a secure database for analysis.

Crowdsourced enforcement alerts were monitored using Waze (version current at time of data collection) on a dedicated mobile device. The research team also monitored Google Maps and Apple Maps for enforcement alerts, though Waze was the primary platform for determining alert timing. While monitoring multiple navigation apps, Waze was consistently the app of which the enforcement alert first appeared. The appearance and disappearance of enforcement alerts were recorded via timestamped field notes.

Procedure

At each site, the data collection procedure followed a structured protocol. Upon arrival, the research team set up at the selected location and commenced speed measurement using the ProLaser 4. The exact start time of data collection was recorded. During

this initial period, Waze, Google Maps, and Apple Maps were actively monitored to determine when the enforcement location first appeared as a speed enforcement marker on any platform. The time at which the enforcement alert first appeared on Waze was recorded, defining the boundary between the pre-alert (baseline) and post-alert (treatment) periods. After the alert appeared, data collection continued for a duration equal to the baseline period, producing a matched pre–post dataset at each site. For example, if the enforcement alert appeared 14 minutes after the commencement of data collection, the baseline window was 14 minutes, and the post-alert period was also 14 minutes. Following data collection at each site, the research team monitored the duration for which the enforcement alert persisted on Waze after their departure, recording the time at which the alert was cleared.

Variables

The primary dependent variable was speed variation, calculated as the difference between each vehicle's recorded speed and the posted speed limit at the site (Recorded Speed minus Speed Limit). Positive values indicate speeds above the limit; negative values indicate speeds below the limit. The primary independent variable was the Before/After condition, indicating whether the observation occurred before or after the appearance of the Waze enforcement alert. Additional variables recorded at each site included: Site ID, collection date, road type (arterial, residential, commercial, school zone, highway, mixed), posted speed limit (40, 50, 60, 70, 80, or 100 km/h), detection range (metres), time to Waze alert appearance (minutes), total data collection time, time for alert clearance after departure, and number of user "likes" on the Waze enforcement report.

Data Analysis

All analyses were conducted using IBM Statistical Package for the Social Sciences (SPSS; version 29). Descriptive statistics (means, standard deviations, medians, interquartile ranges, frequencies, and percentages) were first computed to characterise the sample and the distribution of speed observations across speed zones and road environments. A chi-square test of association compared the proportion of vehicles exceeding the posted speed limit before and after the appearance of the Waze enforcement alert, with an odds ratio and 95% confidence interval reported as a measure of effects. Independent samples t-tests, including Cohen's d as an estimate of effect size, examined pre- to post-alert differences in speed variation overall and individually within each speed zone and road usage category. Finally, non-parametric Kruskal–Wallis tests assessed whether alert appearance time, clearance time, and the number of user likes differed across speed zones and road environments, while Spearman rank-order correlations examined associations between these alert characteristics and the magnitude of speed reduction at each site. Statistical significance levels were set at .05 throughout.

Results

Sample Descriptives

A total of 9,052 vehicle speed observations were recorded across 33 sites in Southeast Queensland. Sites spanned six speed zones (40, 50, 60, 70, 80, and 100 km/h) and three road classifications: Secondary/Arterial, Connector, and Local. Road usage contexts included Arterial, Residential, School Zone, Commercial, and Roadworks. The distribution of observations across sites was broadly consistent with the matched pre–post design, with each site contributing both a baseline and a post-alert window of equal duration. Waze alerts appeared an average of 13.8 minutes (SD = 6.9) after data collection commenced, and took an average of 14.9 minutes (SD = 8.2) to disappear after completing data collection and leaving the site.

Table 1
Sample Descriptives

Category	Variable	<i>n</i>	%
<i>Vehicle Observations</i>	Before Waze Alert	4,115	45.5%
	After Waze Alert	4,937	54.5%
<i>Speeding Drivers</i>	Before Waze Alert	2,255	54.8%
	After Waze Alert	1,276	25.9%
<i>Road Classifications</i>	Secondary/Arterial	6,404	70.7%
	Connector	2,146	23.7%
	Local	502	5.5%
<i>Road Usage</i>	Arterial	4,506	49.8%
	Residential	2,467	27.3%
	Active School Zone	1,003	11.1%
	Commercial	763	8.4%
	Roadworks	313	3.5%

Pre- and Post-Alert Speed Analysis

Prior to the appearance of the Waze enforcement alert, vehicles were travelling an average of 1.23 km/h (SD = 8.342) over the posted speed limit and thus were travelling marginally above the speed limit during the baseline period. Following the appearance of the enforcement alert, vehicles were travelling an average of 3.92 km/h (SD = 7.77) under the posted speed limit. Furthermore, the overall proportion of vehicles exceeding the posted speed limit declined markedly following the appearance of the enforcement alert. During the baseline period, 54.8% of vehicles ($n = 2,255$) were recorded as travelling above the speed limit. After appearing on Waze, this proportion fell to 25.8% ($n = 1,276$). A chi-square test of association confirmed that this difference was statistically significant, $\chi^2(1) = 789.599$, $p < .001$. Further analysis determined that the odds of a vehicle exceeding the speed limit were 3.48 times more likely during the pre-alert period than the post-alert period (OR = 3.478, 95% CI [3.181, 3.804]). Therefore, vehicles shifted from travelling above the speed limit before the alert to travelling below it after the alert appeared. Further statistics around variations in vehicle speeds, before and after the Waze alert, based on the different speed limits and road usages are reported below (see Table 2).

A linear mixed-effects model was estimated with variation in speed as the dependent variable, before or after appearing on Waze as a fixed effect, and a random intercept for site (33 sites; 9,052 observations) to account for the clustering of observations within sites. The intervention period was associated with a substantial and statistically significant reduction in variation in speed, with mean speeds above the limit decreasing from 1.23km/h before appearing on Waze to – 3.92km/h afterwards and a fixed-effect estimate of 5.19 (SE = 0.15), $F(1, 9023.75) = 1134.39$, $p < .001$. The model explained a modest proportion of variance via fixed effects alone (marginal $R^2 = .092$) but a larger proportion when including site-level random effects (conditional $R^2 = .279$), indicating meaningful between-site heterogeneity.

Effect of Waze Enforcement Alerts Across Road Environments

To examine the impact of Waze enforcement alerts on the speed of vehicles in varying road environments, analysis was conducted separately across speed zones and road classifications. An independent samples t-test confirmed that the overall difference in speed variation between pre- and post-alert periods was statistically significant with a medium-to-large effect size (see Table 2). This trend was evident at all speed limits with each examined individually using independent samples t-tests with all results being statistically significant and having a medium-to-large effect size. Medians shifted downward in every speed zone following the appearance of the enforcement alert, confirming that the effect reflected a broad downward shift in the distribution rather than being driven by a small number of high-end offenders. The most pronounced effects were observed in the 100 km/h speed zone, where the mean speed variation shifted from 0.72 km/h over the speed limit before the alert to 9.26 km/h below the speed limit

after the appearance of the Waze alert, with the median moving from 3 km/h over to 8 km/h under the limit. Overall, there was a speed reduction of 9.98 km/h and a reduction in the proportion of vehicles speeding from 64.0% to 12.1%. The smallest effect by speed zone was observed in the 40 km/h zone, though even here the proportion of speeding vehicles fell from 64.3% to 38.5% following alert activation.

Table 2
– Descriptives and T-Tests of Variations in Speed Before and After Waze Enforcement Alerts by Speed Limit

	Before Waze Alert					After Waze Alert					t	p	d
	N	M	SD	Mdn	IQR	n	M	SD	Mdn	IQR			
Overall Sample	4115	1.23	8.34	1.00	9	4937	-3.92	7.77	-3.00	9	30.376	< .001***	.641
40km/h Speed Limit	414	2.67	6.12	2.00	7	589	-0.66	6.46	-4.00	7	8.209	< .001***	.526
50km/h Speed Limit	557	1.83	6.20	2.00	8	580	-1.95	6.16	-2.00	6	10.321	< .001***	.612
60km/h Speed Limit	1155	2.01	9.55	1.00	8	1511	-3.31	7.28	-3.00	9	15.748	< .001***	.638
70km/h Speed Limit	413	0.13	5.61	0.00	6	568	-3.73	6.12	-4.00	7	10.075	< .001***	.651
80km/h Speed Limit	1076	0.19	8.68	0.00	10	1225	-5.25	8.57	-4.00	11	15.096	< .001***	.631
100km/h Speed Limit	500	0.72	9.68	3.00	11	464	-9.26	8.80	-8.00	12	16.714	< .001***	1.077
Note: Speed Variation = Recorded Speed – Posted Speed Limit. Positive values indicate speeds above the limit; negative values indicate speeds below the limit.													

Independent samples t-tests examined the difference in variations in vehicle speeds across all road usage environments compared to the posted speed limit between pre- and post-alert periods. Results of the t-tests found that the differences in speed pre- and post-alert were statistically significant with a medium-to-large effect size (see Table 3). Median speeds shifted downward across all road environments following the appearance of the enforcement alert, indicating that the results reflect a broad downward shift in driver speed rather than being driven by a subset of high-end offenders. School zones produced the smallest overall effect and 38.5% of vehicle speeds collected after the appearance of the enforcement alert on Waze were exceeding the posted 40 km/h limit, the highest residual speeding rate of any road usage category. Roadworks sites produced the largest effect size, though this should be interpreted with caution given the smaller number of observations within this environment; the markedly elevated baseline speeding rate at roadworks sites (83.4%) likely reflects the challenge of compliance in those environments regardless of enforcement alerts.

Table 3
Average Variations in Speed Before and After Waze Enforcement Alerts by Road Usage

	<i>Before Waze Alert</i>					<i>After Waze Alert</i>					<i>t</i>	<i>p</i>	<i>d</i>
	<i>n</i>	<i>M</i>	<i>SD</i>	<i>Mdn</i>	<i>IQR</i>	<i>n</i>	<i>M</i>	<i>SD</i>	<i>Mdn</i>	<i>IQR</i>			
Arterial Road	2079	0.54	8.08	1.00	10	2427	-4.31	8.14	-3.00	10	20.001	< .001***	.598
Residential Area	1172	0.74	6.36	0.00	15	1295	-3.56	6.78	-6.00	12	16.209	< .001***	.654
Active School Zone	414	2.67	6.12	2.00	7	589	-0.66	6.46	-4.00	7	8.209	< .001***	.526
Commercial Area	299	-0.82	10.60	2.00	7	464	-6.81	8.56	-1.00	7	8.198	< .001***	.636
Roadworks	151	14.56	12.71	13.00	22	162	-4.7	7.28	-6.00	11	16.595	< .001***	1.877
Note: Speed Variation = Recorded Speed – Posted Speed Limit. Positive values indicate speeds above the limit; negative values indicate speeds below the limit.													

Appearance and Removal of Enforcement Alerts

This study also sought to examine whether alert timing and user engagement varied across road environments, and the extent to which these alert characteristics were or were not associated with reductions in speed or the duration of the alert before it was cleared from Waze. Kruskal–Wallis tests indicated that the number of user likes on Waze enforcement reports varied significantly by road usage type ($H = 9.675$, $p = .046$). Arterial roads attracted the highest mean number of likes (see Table 4), reflecting the greater volume of Waze users navigating higher-traffic arterial environments who are available to confirm reports. Roadworks sites also attracted relatively high engagement ($M = 5.00$, $SD = 1.41$), while commercial ($M = 2.00$, $SD = 1.41$) and active school zone sites ($M = 2.75$, $SD = 0.96$) attracted fewer confirmations, consistent with lower traffic volumes in those environments. Neither alert appearance time ($H = 7.038$, $p = .134$) nor clearance time ($H = 4.087$, $p = .394$) differed significantly by road usage type. Similarly, Kruskal–Wallis tests found no significant differences in appearance time ($H = 10.207$, $p = .070$), clearance time ($H = 0.453$, $p = .994$), or likes ($H = 8.739$, $p = .120$) across speed zones, although a non-significant pattern indicated that alerts appeared somewhat more slowly at higher-speed sites compared with lower-speed environments.

Table 4
Alert Appearance, Clearance, and User Likes by Speed Zone and Road Usage

Variable	Appearance time in minutes	Clearance time in minutes	Likes
	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>
Overall Sample	13.8 (6.8)	15.2 (8.4)	4.6 (3.4)
40km/h Speed Limit	10.3 (6.7)	15.5 (10.5)	2.8 (1.0)
50km/h Speed Limit	14.8 (6.2)	15.3 (10.9)	1.8 (1.0)
60km/h Speed Limit	12.2 (8.0)	15.2 (7.2)	4.9 (2.5)
70km/h Speed Limit	11.3 (6.4)	12.7 (6.4)	4.0 (1.7)
80km/h Speed Limit	16.0 (2.2)	16.2 (11.8)	7.7 (5.8)
100km/h Speed Limit	22.3 (4.2)	12.0 (4.0)	4.0 (2.7)
Arterial Road	16.5 (7.4)	14.9 (7.6)	6.3 (4.1)
Residential Area	14.8 (3.9)	17.6 (9.2)	3.4 (2.1)
Active School Zone	10.3 (6.7)	15.5 (10.5)	2.8 (1.0)
Commercial Area	7.8 (5.6)	8.3 (8.1)	2.0 (1.4)
Roadworks	8.5 (6.4)	16.0 (0.0)	5.0 (1.4)

Critically, Spearman's correlations revealed that none of the alert characteristics (appearance time, clearance time, or number of likes) were significantly associated with the magnitude of speed reduction at the site level. The speed reduction produced by the enforcement alert was neither larger at sites where the alert appeared quickly, nor at sites where the report attracted greater user engagement.

Discussion

This study provides the first quasi-experimental, real-world examination of the impact of crowdsourced enforcement alerts on driver speed, addressing a significant gap in both the deterrence and road policing literature. Across 33 sites and 9052 vehicle observations in Queensland, Australia, the appearance of enforcement alerts was associated with a significant and consistent reduction in mean speed and speeding prevalence, with effects observed across all of the posted speed limits and road usage environments examined within this study. These findings carry important implications for how technology that provides enforcement alerts to drivers is understood within deterrence frameworks and for how road policing activities are planned and evaluated in an increasingly connected and crowdsourced traffic environment.

Crowdsourced Enforcement Alerts and Vehicle Speed

The first aim of the study was to determine whether or not crowdsourced speed enforcement alerts reduce mean vehicle speed and the proportion of vehicles exceeding the posted speed limit at the point of enforcement. The results are clear that following the appearance of a Waze enforcement alert, vehicles shifted from travelling marginally above the speed limit on average, to travelling several kilometres per hour below it, and the total proportion of speeding vehicles declined by almost 30% (54.8% before the alert to 25.8% after the alert). These changes were not only statistically significant but of a magnitude likely to indicate meaningful change on the road and given the established non-linear relationship between small reductions in mean speed and large reductions in serious and fatal crashes (Elvik, 2009; Elvik et al., 2019; Nilsson, 2004), a reduction in crash risk.

Another aim of this study was to assess whether the impact of crowdsourced alerts on driver speed varied across road environments and speed zones. Analyses showed that speed reductions between pre- and post-alert periods were statistically significant with medium-to-large effect sizes across all posted limits and road usage categories, with the most pronounced effects observed at 100 km/h sites and in roadworks zones, and the smallest effects in 40 km/h school zones. It is notable that even in the

least responsive environments, i.e. 40km/h school zones, the proportion of speeding vehicles decreased significantly following alert activation, demonstrating that the behavioural impact of Waze alerts is both broad-based and robust across diverse traffic contexts.

Temporal Dynamics of Enforcement Alert Appearance and Persistence on Waze

The second aim of this study was to examine how long it took for enforcement alerts to appear and how long they persisted for after the research team departed. On average, Waze alerts appeared 13.8 minutes after the commencement of data collection and remained visible for a further 14.9 minutes after the team left the site, with no significant variation in appearance or clearance times based on the road usage types or speed limit on the road. These findings indicate that, for typical police checkpoint-style enforcement operations, there is only a small window of time where the approaching motorists are not being warned of the police enforcement ahead, possibly facilitating speeding offenders to reduce speed or, in the case of impaired driving, detour to avoid the police enforcement. These findings would suggest that in the digital age, extended checkpoint-style enforcement operations may not be as effective as they have been in the past where efficacy was often attributed to placement and screening capacity.

Theoretical Implications

A critical consideration for deterrence theory is not merely whether crowdsourced enforcement alerts produce localised speed reductions, which this study demonstrates, but what the systematic facilitation of punishment avoidance on our roads means for driver behaviour beyond the immediate enforcement site. Stafford and Warr (1993) reconceptualisation of deterrence theory established that punishment avoidance, the experience of offending without detection or sanction, is not a neutral outcome but an active mechanism that erodes the perceived certainty of apprehension and encourages future offending. Applied to the results of the present study, each occasion for which a driver receives a Waze alert, decelerates briefly, and resumes normal speed having evaded detection constitutes a direct experience of successful crowdsourced punishment avoidance. The cumulative effect of such experiences, repeated across multiple enforcement encounters over time, is a progressive weakening of deterrence, specifically certainty of apprehension, on which speed enforcement depends. Piquero and Pogarsky (2002) demonstrated empirically that personal experience of punishment avoidance produces significant downward updating of risk perceptions, with individuals who had previously evaded detection reporting lower estimates of future apprehension likelihood, and higher offending intentions as a result. Qualitative evidence specific to road policing further supports this trajectory. Bates and Anderson (2019) found that young drivers who experience punishment avoidance, either directly or vicariously, are emboldened in their offending behaviour as a result of diminished certainty of apprehension by police on the road. Truelove et al. (2025) found that drivers who used enforcement-alerting technology reported feeling emboldened, with one participant explicitly describing feeling "probably slightly more invincible" capturing precisely the attitudinal consequence of repeated, technology-facilitated punishment avoidance predicted by deterrence theory. Mills et al. (2022) observed a consistent pattern among users of Facebook police location groups, suggesting the emboldening effect of crowdsourced enforcement intelligence generalises across platforms rather than being unique to Waze. Taken together, the current literature and the results from this study highlight a troubling dynamic: crowdsourced enforcement alerts may produce a population of drivers who are increasingly competent at managing their exposure to detection while remaining fundamentally committed to offending on our roads. Compliance driven solely by instrumental threat avoidance, absent any normative internalisation of speed limits, is inherently unstable and context-dependent (Nagin, 2013). The risk, therefore, is that while enforcement alerts appear to reduce speeds at the point of detection which may offer a brief and geographically limited safety benefit, they may simultaneously reinforce the conditions for non-compliance across the wider road network, emboldening rather than deterring the very behaviour they appear to suppress.

Practical and Operational Implications

In order to examine the practical and operational implications of this study, the findings were presented to a group of frontline road policing officers. These officers were asked to reflect on how the findings align with their own observations and experience and further, how the findings could impact the conduct of their enforcement activities. First, police identified opportunities to use enforcement alerts on apps such as Waze as a mechanism for determining when to reposition enforcement sites. The notion behind this idea was to continue interacting with drivers that have not been prewarned of the enforcement, therefore providing an opportunity for offenders to divert around the police. A related extension is the use of repositioning to produce a force multiplier effect, whereby a single police crew conducts static enforcement until reported on Waze and then relocates further along the road,

producing the appearance of multiple, geographically dispersed enforcement units when in fact only one is active. Second, police discussed the deliberate use of the enforcement alerts as a deterrence instrument. Officers noted that the appearance of an enforcement notification, irrespective of the actual scale of police deployment, may function as a deterrent signal for drivers in the surrounding area who do not themselves pass the enforcement site, producing an effect similar to a technologically delivered halo effect. If this was coupled with a single police crew relocating upon the enforcement alert appearing, there is potential for creating a phenomenon similar to an afterimage or palinopsia with technological halo effects lingering beyond police deployments. Supporting these operational implications police discussed how ensuring that enforcement interactions are conducted in a manner that maximises their visibility to passing motorists, thereby increasing the likelihood that the encounter will be reported on Waze and other apps. Together, these practical implications reflect a shift in how crowdsourced enforcement alert technology can be considered and leveraged within road policing, positioning Waze not solely as an instrument facilitating punishment avoidance but as a platform that can be integrated into strategic operational planning to amplify the perceived reach of a finite enforcement resource.

Limitations and Future Directions

There are several limitations of this study that need to be addressed. First, the quasi-experimental design of this study, as with many real-world experimental studies, is unable to control for a number of confounding factors which could impact the results of this study. These include fluctuations in traffic volume, changes in the weather, or the presence of other vehicles slowing traffic during the post-alert period. Second, this study was conducted solely in Queensland, which limits the generalisability to other jurisdictions with different road policing enforcement cultures, road environments, and levels of uptake in navigational apps such as Waze. Third, while this study captured a snapshot of driver behaviour before and after the appearance of an enforcement alert on Waze, the speed of vehicles was only measured at the site of the enforcement alert and does not examine the behaviour of drivers upstream or downstream of the enforcement alert. Despite these limitations, this study makes a notable contribution as one of the first to examine the effect of a crowdsourced Waze enforcement alert on real-world vehicle speeds, at the site of the enforcement alert, using a before-and-after design, with a large dataset (N = 9052). These findings extend the current knowledge base by providing a more direct measure of driver behaviour than self-report, average, or overall road segment speeds and offers a strong empirical foundation for future investigation and frontline policing application.

Future research should seek to examine how crowdsourced enforcement alert technologies, such as Waze, influence driver behaviour across broader sections of the road network, beyond the specific alert site examined in this study. Furthermore, future research should examine how these notifications affect drivers beyond the immediate enforcement location and could clarify the duration and distance over which behaviour change persist in response to an alert. Such work would deepen understanding of the “halo effect” or wider area of influence that active police enforcement, and the associated alerts, have on the surrounding road environment.

Conclusion

This study examined the crowdsourced enforcement alerts provided by navigational applications such as Waze, and the impact these alerts have on driver behaviour. Across 33 sites, 9052 vehicles had their speed measured both before and after the appearance of an enforcement alert on Waze. Overall, the average speed difference between vehicles travelling prior to the enforcement alert, and after the enforcement alert was approximately 5.15km/h. These speed reductions were observed in all of the difference speed limits and environments examined. Beyond the immediate benefits and reductions in crash risk associated with lower speed, these findings have implications for how enforcement is conceptualised in a digitally connected environment where punishment avoidance can be crowdsourced. The rapid appearance of enforcement alerts on these apps suggests that the window of drivers approaching unaware of the enforcement activity is brief. As a result, after only a short time, offending drivers are able to adjust their behaviour and effectively circumvent detection and punishment. While this study demonstrates that following the enforcement alert appearing, there is a mean reduction in vehicle speeds, the broader concern is how this technology may be emboldening driver offending through experiences of technology-facilitated and crowdsourced punishment avoidance over time. Each crowdsourced alert to avoid detection is not a neutral event but an experience that may erode perceived certainty of apprehension and embolden future offending behaviour on the road. Frontline officers identified that crowdsourced alerts need not be regarded solely as a threat to deterrence but may be deliberately leveraged to support enforcement objectives. As a practical implication of this study, strategies aimed at maximising offender detection are likely to favour shorter, more dispersed

deployments, with officers using the appearance of an enforcement alert as a trigger to reposition. Such repositioning may also function as a force multiplier, with a single crew producing the appearance of multiple dispersed units and generating a technologically delivered halo effect that extends the perceived presence of enforcement beyond the deployment site. In this way, the very technology that facilitates crowdsourced punishment avoidance may also be co-opted to amplify the reach of a finite enforcement resource. Realising and operationalising this potential, while managing the longer-term risk that repeated punishment avoidance erodes deterrence, represents an important direction for both road policing activities and future research.

Declarations

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References

1. Armour M (1986) The effect of police presence on urban driving speeds. *ITE J* 56(2):40–45
2. Australian Automobile Association (2020) *Drive in the Moment: Comparative Analysis of Phone Use While Driving*. <https://www.aaa.asn.au/wp-content/uploads/2024/11/Drive-in-the-Moment-Comparative-Analysis-Aug-2020-1.pdf>
3. Barnum TC, Nagin DS, Pogarsky G (2021) Sanction risk perceptions, coherence, and deterrence. *Criminology* 59(2):195–223
4. Bates L, Anderson L (2019) Young drivers, deterrence theory, and punishment avoidance: A qualitative exploration. *Policing: J Policy Pract*. <https://doi.org/10.1093/police/paz075>
5. Beccaria C (2009) (1764/. On crimes and punishments and other writings. University of Toronto
6. Becker GS (1968) Crime and punishment: An economic approach. *J Polit Econ* 76(2):169–217
7. Buganza T, Dell'Era C, Pellizzoni E, Trabucchi D, Verganti R (2015) Unveiling the potentialities provided by new technologies: A process to pursue technology epiphanies in the smartphone app industry. *Creativity Innov Manage* 24(3):391–414
8. Cohn EG, Kakar S, Perkins C, Steinbach R, Edwards P (2020) Red light camera interventions for reducing traffic violations and traffic crashes: A systematic review. *Campbell Syst Reviews* 16(2):e1091
9. De Pauw E, Daniels S, Brijs T, Hermans E, Wets G (2014) Behavioural effects of fixed speed cameras on motorways: Overall improved speed compliance or kangaroo jumps? *Accid Anal Prev* 73:132–140
10. Dons E (2024) *The impact of in-vehicle speed camera warning systems on driving speed and road safety* International Co-operation on Theories and Concepts in Traffic Safety
11. Elvik R (2009) *The Power Model of the relationship between speed and road safety: update and new analyses*
12. Elvik R, Vadeby A, Hels T, Van Schagen I (2019) Updated estimates of the relationship between speed and road safety at the aggregate and individual levels. *Accid Anal Prev* 123:114–122
13. Fleiter JJ, Watson BC (2006) The speed paradox: the misalignment between driver attitudes and speeding behaviour. *J Australasian Coll Road Saf* 17(2):23–30
14. Fu C, Liu H (2023) Investigating distance halo effect of fixed automated speed camera based on taxi GPS trajectory data. *J Traffic Transp Eng (English Edition)* 10(1):70–85. <https://doi.org/https://doi.org/10.1016/j.jtte.2021.05.005>
15. Hauer E, Ahlin F, Bowser J (1982) Speed enforcement and speed choice. *Accid Anal Prev* 14(4):267–278
16. Holland CA, Conner MT (1996) Exceeding the speed limit: an evaluation of the effectiveness of a police intervention. *Accid Anal Prev* 28(5):587–597
17. Liu Y, Feng T (2023) The effect of crowdsourced police enforcement data on traffic speed: a case study of The Netherlands. *Appl Sci* 13(21):11822
18. Mills L, Truelove V, Freeman J, Davey J (2022) Police location pages and groups on Facebook: Does knowing where the police are influence perceptions of certainty and drug driving behaviour? *Saf Sci* 147:105601. <https://doi.org/https://doi.org/10.1016/j.ssci.2021.105601>

19. Nagin DS (2013) Deterrence in the Twenty-First Century [Article]. *Crime & Justice*, 42(1), 199–263.
<http://libraryproxy.griffith.edu.au/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=cja&AN=90256797&site=ehost-live&scope=site>
20. Nilsson G (2004) Traffic safety dimensions and the power model to describe the effect of speed on safety
21. Oviedo-Trespalacios O, Watson B (2021) Navigation apps are becoming a threat to road safety (beyond distraction), vol 27. BMJ Publishing Group Ltd, pp 103–103
22. Paternoster R, Bachman R (2012) Perceptual Deterrence Theory. In: Cullen FT, Wilcox P (eds) *The Oxford Handbook of Criminological Theory*. Oxford University Press, p 0. <https://doi.org/10.1093/oxfordhb/9780199747238.013.0033>
23. Piquero A, Pogarsky G (2002) Beyond Stafford and Warr's reconceptualization of deterrence personal and vicarious experiences, impulsivity, and offending behavior. *J Res Crime Delinquency* 39(2):153–186.
<https://doi.org/10.1177/002242780203900202>
24. Ravani B, Wang C (2018) Speeding in highway work zone: an evaluation of methods of speed control. *Accid Anal Prev* 113:202–212
25. Ritchey M, Nicholson-Crotty S (2011) Deterrence Theory and the Implementation of Speed Limits in the American States. *Policy Stud J* 39(2):329–346. <https://doi.org/10.1111/j.1541-0072.2011.00410.x>
26. Simpson R, McCutcheon M, Lal D (2020) Reducing speeding via inanimate police presence: An evaluation of a police-directed field study regarding motorist behavior. *Criminol Public Policy* 19(3):997–1018
27. Soole D, Watson B, Fleiter J (2013) Effects of average speed enforcement on speed compliance and crashes: A review of the literature. *Accid Anal Prev* 54:46–56
28. Stafford M, Warr M (1993) A reconceptualization of general and specific deterrence. *J Res Crime Delinquency* 30(2):123–135
29. Truelove V, Nicolls M, Oviedo-Trespalacios O (2025) I probably feel slightly more invincible: The impact of technology that discloses enforcement locations on drivers' behaviours. *Saf Sci* 181:106707.
<https://doi.org/https://doi.org/10.1016/j.ssci.2024.106707>
30. Truelove V, Nicolls M, Stefanidis KB, Oviedo-Trespalacios O (2023) Road rule enforcement and where to find it: An investigation of applications used to avoid detection when violating traffic rules. *J Saf Res* 87:431–445
31. Truelove V, Oviedo-Trespalacios O (2026) How visibility and alerts shape speed enforcement legitimacy. *Transp Res Part F: Traffic Psychol Behav* 119:103592. <https://doi.org/https://doi.org/10.1016/j.trf.2026.103592>
32. Truelove V, Stefanidis K, Mills L, Oviedo-Trespalacios O (2023) Police and public perspectives on the use and impacts of technology that expose enforcement locations for phone use while driving. *Saf Sci* 164:106155.
<https://doi.org/https://doi.org/10.1016/j.ssci.2023.106155>
33. Vaa T (1997) Increased police enforcement: effects on speed. *Accid Anal Prev* 29(3):373–385
34. Waze (2022) *Waze Discuss Forum - Waze Update*. <https://www.waze.com/discuss/t/waze-update/299054>