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FINAL REPORT

NACOE R121: Evaluation of Traffic Control Devices and Technologies at Roadwork Sites (Year 2)

NTRO Project No.: 000619

Project Managers: TMR: Dana Geaboc

NTRO: Melanie Venter

Quality Manager: David McTiernan

Author/s: Trevor Wang, Zi Chen and Patrick Wilton

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Summary

A selection of 2 traffic control devices was trialled in the first year of the project. These 2 traffic control devices were flashing beacons and speed radar signs (using a variable message sign (VMS)). Similar to Year 1, 2 traffic control devices were evaluated for Year 2 of the project. These were:

- video surveillance signage by using a VMS to portray a message indicating the presence of video surveillance
- portable temporary boom barrier (PTBB).

The first selected traffic control device for Year 2 was video surveillance signage which led drivers to believe video surveillance was in place recording driver behaviour (speeds). This was performed using a VMS showing the message 'Road Safety Camera' and 'Check Speed'. The second traffic control device included a combination of the previous video surveillance signage (using a VMS) and a PTBB.

For this project, the key evaluation objective for the selected traffic control devices' trials was primarily measuring the effectiveness in reducing travel speeds at roadwork sites.

A graphical representation of the speed distributions is shown in Figure S.1 and Figure S.2, showing these distributions for both traffic control devices located at Site 1 and 3, respectively.

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Figure S.1: Speed distribution across traffic control devices at Site 1

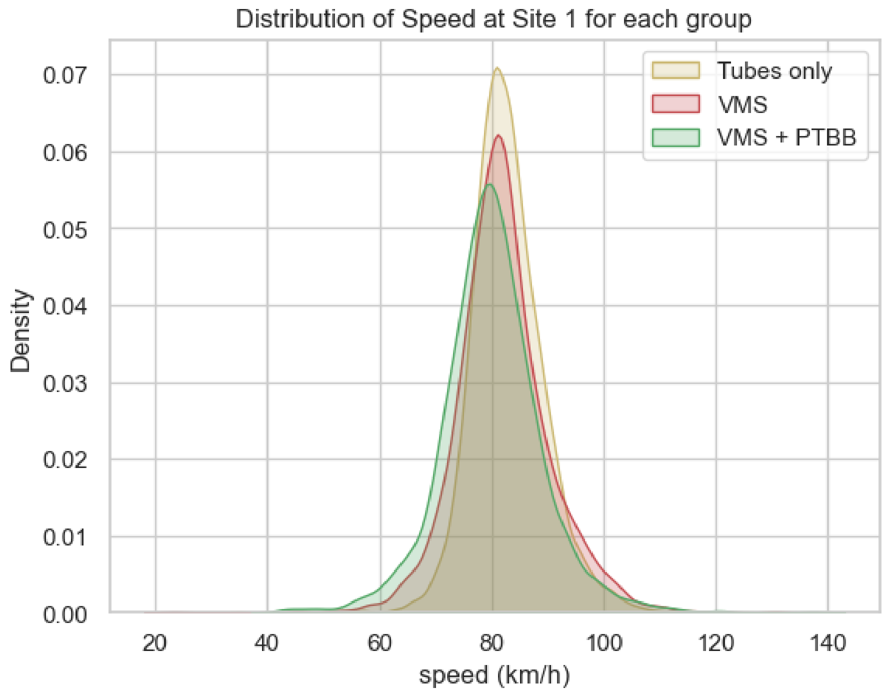

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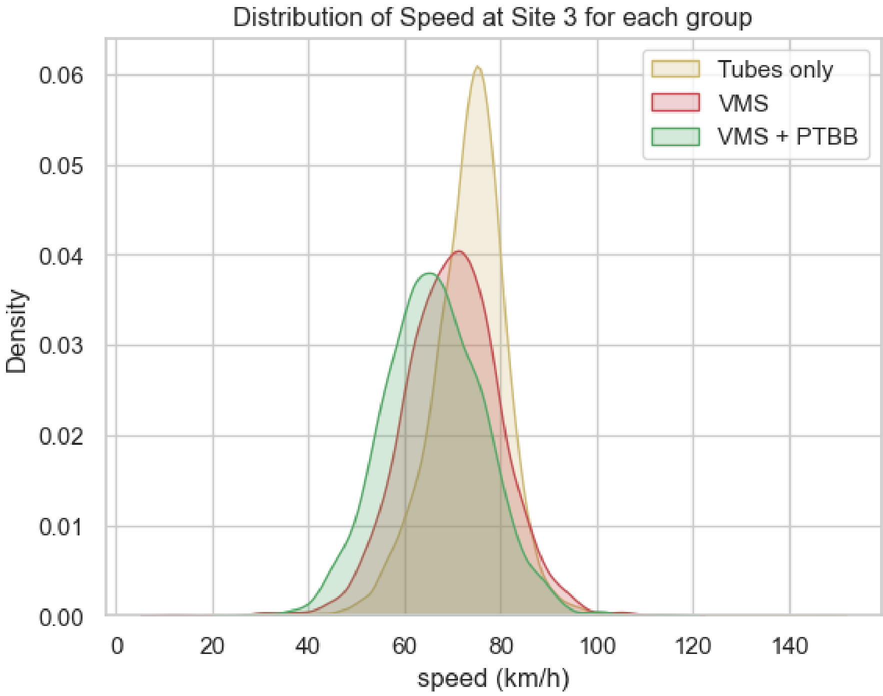
Figure S.2: Speed distribution across traffic control devices at Site 3



All graphs show a bell curve shape, which implies the data is highly likely to be normally distributed (as expected).

Figure S.1 indicates that the traffic control devices had little effect so far away from the roadwork site due to how closely the distribution curves match, as expected. This is in stark contrast with Figure S.2 where the peaks of each distribution are noticeably shifted towards lower average speeds as the traffic control devices are introduced. Both figures also indicate that the combination of the VMS and the PTBB was the most effective traffic control device in these isolated tests at reducing driver speeds.

From the statistical analysis of the Site 1 and Site 3 data, the 2 traffic control devices reduced the average speed when compared to having no traffic control devices. The statistical testing identified that both measures had significant effect sizes, with the Cohen's *d* value of VMS + PTBB vs tubes (control) being almost twice the value of VMS used on its own, 0.88 vs 0.42.

Further, the use of the combined VMS + PTBB traffic control device reduced the proportion of drivers exceeding the speed limit by more than 10 km/h by 37% in comparison to no traffic control devices (tubes only).

For all tests conducted during Year 1 (2021–22) and Year 2 (2022–23) of the project, the statistical analysis results show that all traffic control devices reduced traffic speed to a certain extent. Table S.1 presents the lower values of the 95% confidence intervals, the Cohen's *d* values and the percentage of vehicles grossly exceeding the speed limit (> 10 km/h) for all the traffic control devices tested.

Table S.1: Comparison of the traffic control device effects on traffic speed

Year	Traffic control devices	95% confidence interval range – lower value	Cohen's *d*	% of vehicles exceeding posted limit (60 km/h) by > 10 km/h
Year 1	Flashing beacons (Site B) vs only tubes	2.7	0.44	4.3% (down from 6.5% only tubes)
	Speed radar (Site B) vs only tubes	2.9	0.49	2.8% (down from 6.5% only tubes)
Year 2	VMS (Site 3) vs only tubes	3.0	0.42	50% (down from 70.7% only tubes)

Year	Traffic control devices	95% confidence interval range – lower value	Cohen's *d*	% of vehicles exceeding posted limit (60 km/h) by > 10 km/h
	VMS + PTBB (Site 3) vs only tubes	7.0	0.88	33.8% (down from 70.7% only tubes)

After completing the trials, it can be concluded that all 4 traffic control devices did reduce the traffic speed; therefore, non-compliance of drivers to speed limit can be reduced by employing traffic control devices. The combined VMS + PTBB traffic control device delivered the most promising statistical result to decrease speeds, followed by the other 3 traffic control devices whose statistical results were similar. The speed radar signs seem to be the simplest second-best traffic control device.

The effectiveness of the traffic control devices varied, i.e. the magnitude of the speed reduction (statistically evaluating the means) and the percentage of drivers exceeding the speed limit or grossly exceeding the speed limit by more than 10 km/h. The most pronounced reduction in vehicles speeding occurred whilst trialling the combined VMS+ PTBB traffic control device.

For the Year 1 tests, it is to be noted that the permanent speed limit, as well as the speed limit during the roadworks, remained at 60 km/h, and therefore, a smaller reduction occurred in the percentage of vehicles exceeding the posted speed limit by more than 10 km/h in comparison to the Year 2 tests which involved an 80 km/h permanent speed limit and a 60 km/h speed limit during roadworks.

It should be noted that video surveillance warning signage using a VMS had a diminished effect on drivers' compliance after being used for a lengthy time period. Also, the flashing beacons were difficult to fasten to the road signs, and members of the traffic control team expressed concern about possible confusion resulting from combining the flashing beacons with the other warning lights forming part of the temporary traffic management (TTM) setup.

After undertaking these 2 years of testing, it is recommended to conclude with the list of traffic control devices suggested by AfPA, as the testing for all the traffic control devices believed to suit these trials is now complete. It is further recommended to consider the findings discussed in this report and to apply engineering judgement at each roadwork site when deciding which traffic control devices to implement when targeting improved speed compliance.

A future option to extend the reach of this research might be to trial the combination of speed radar signs and the PTBB.

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1. Introduction

1.1 Background

Through the National Asset Centre of Excellence (NACOE) partnership, the National Transport Research Organisation (NTRO) and the Queensland Department of Transport and Main Roads (TMR) seek to improve safety at roadwork sites.

Hazards from live traffic at roadwork sites were identified by members of the National Safety Committee of the Australian Flexible Pavement Association (AfPA) as the highest priority issue to be addressed based on their considerations of high-risk and high-impact incidents experienced across the industry.

AfPA has formed an internal working group to liaise with other stakeholders in the industry, such as the Traffic Management Association of Australia (TMAA) and jurisdictional road agencies, to evaluate a few proposed traffic control devices. Each state and territory's road agency has been asked to partner with AfPA and TMAA to evaluate these measures in order to determine their effectiveness in various road environments and traffic situations.

1.2 Project Aim and Objectives

This project, *NACOE R121: Evaluation of Traffic Control Devices and Technologies at Roadwork Sites* (referred to as the project in the rest of the report), has completed its second year (July 2022 to June 2023) following the release of the Year 1 project report at the end of FY 2021–22.

The overall objectives of this project were to:

1. determine if the investigated traffic control devices can reduce the occurrence of drivers exceeding the speed limit while travelling through roadwork sites
2. determine the effectiveness of the proposed traffic control devices to reduce road safety risk
   – in addition, developing KPIs for each traffic control device under investigation, for example, a reduction of maximum and average speeds approaching and driving through roadwork sites.

1.3 Project Scope

Initially, AfPA provided a list of proposed traffic control devices, which were discussed in the Year 1 report. For the second year of the project, 2 measures were selected in collaboration with the relevant stakeholders.

For each traffic control device, the following tasks were undertaken:

- developing a research method to investigate the impact of using the traffic control device
- planning the trial and assessing the site
- confirming KPIs to measure the change in road safety performance
- procuring a subcontractor to provide the required equipment/services, then explaining the set-up, monitoring, requirements and data collection relevant to the traffic control device
- undertaking the physical testing onsite
- analysing the data statistically
- reporting the findings.

1.4 Methodology

Table 1.1 provides the methodology adopted for Year 2 (2022–23) of this project.

Table 1.1: Project methodology

<table>
<tr><th>Task #</th><th>Task</th><th>Task description</th></tr>
<tr><td>1</td><td>Select traffic control devices</td><td>• Determine traffic control devices to be tested in collaboration with the relevant stakeholders.</td></tr>
<tr><td>2</td><td>Develop a framework for testing</td><td>Site selection
• For each traffic control device, determine the required road environment i.e. duration of construction activity, suitable road geometric layout, speed environment, type of construction activity being undertaken, day or night shifts and preferred traffic volumes (high, medium or low).
• Site selection will need to ensure that the testing is undertaken in typical traffic conditions, for example, outside school holidays and extended public holiday periods (travel behaviour is likely to be affected due to these external factors).
Testing
• Determine the KPIs to measure the change in road safety performance for the selected traffic control device and develop a research method for each traffic control device.
• The selected traffic control device must be accommodated within the traffic management plan of the construction project. The onsite personnel will need to be briefed and trained accordingly.</td></tr>
<tr><td>3</td><td>Test traffic control devices</td><td>• The proposed traffic control devices are to be demonstrated as part of a 2-stage trial:
– Baseline assessment stage: the first stage assessing the traffic management operation of the construction site in the absence of the proposed traffic control devices.
– Second stage: add the proposed traffic control device to the baseline scenario. Collect the data after implementing the change/alternate technology to the baseline situation.
• The service provider of the traffic control device will be responsible for setting up the device, monitoring the equipment during the trial, collecting the data and providing it to NTRO afterwards.
• The provider of the traffic control device will be required to provide a cost breakdown of all the components of the trial. This will assist the industry to assess the return on investment for the implementation of such technology in a suitable environment.</td></tr>
<tr><td>4</td><td>Evaluation</td><td>• Objectives achieved or not.
• Documentation of the results.</td></tr>
</table>

2. Selected Control Measures to Trial

2.1 Selection of Measures

Two traffic control devices were trialled in the first year of the project: flashing beacons and speed radar signs (using a variable message sign (VMS)). Similar to Year 1, 2 traffic control devices were evaluated in Year 2. These were:

- video surveillance warning signage by using a VMS to portray a message indicating the presence of video surveillance
- a portable temporary boom barrier (PTBB).

These measures were determined in collaboration with the project's stakeholders (TMR and AfPA) based on:

- probability to influence road users
- ease of use and practicalities
- feedback from the roadwork industry.

Stakeholders also indicated that road users are more likely to comply with road safety signage when possible financial implications can occur (i.e. the possibility of receiving a speeding fine, which might result from video surveillance) or due to the social pressure of not complying (i.e. using a speed radar sign indicating either an approving or disapproving image as trialled during Year 1 of the project) or when there is a physical consequence (i.e. when the PTBB physically prevents road users from entering the roadwork site).

2.2 Guiding Principles: Safe System

This project has been conceptualised in alignment with core guiding principles, including the Safe System approach and the fundamentals of risk management. The outcomes of this project have been developed to support the roadwork industry with practical, implementable and informed decisions intended to reduce road trauma without adversely affecting productivity or performance.

The National Road Safety Strategy 2021–2030 aims for a significantly reduced burden on the economy and society from road crashes – in terms of deaths; life-changing injuries; costs on the health sector; and trauma for families, first responders and communities, including mental health impacts, over the next decade. The Strategy for 2021–30 sets targets to reduce road trauma over the next 10 years, aiming for a 50 per cent reduction in fatalities and a 30 per cent reduction in serious injuries by 2030 (Commonwealth of Australia 2021).

The Safe System approach (Figure 2.1) is a human-centred approach that involves different elements of the road system working together to help reduce and eliminate death and serious injury.

Figure 2.1: The Safe System approach

Source: TMR Road Safety Policy (2022).

This project developed a research method to trial the selected traffic control devices at the designated site and record the data, with the aim of achieving the KPIs that were developed to increase compliance with speed limits.

2.3 Selected Measure 1: Video Surveillance Warning Signage Using a VMS

The first selected traffic control device was video surveillance warning signage. This was performed using a VMS (details can be found in Section 4.1.3) showing the message 'Road Safety Camera' and 'Check Speed'.

The aim of using this device was to alert road users about the presence of video surveillance for speed monitoring, which advised the drivers to take extra care and comply with the speed limit. Digital messages on sizable boards were used as they have higher visibility and are thought to reduce the likelihood of drivers missing (not seeing/observing) the VMS. It was decided to use a VMS for this purpose instead of a typical road sign, as it was anticipated that this project would take place during both the day and night.

2.4 Selected Measure 2: Portable Temporary Boom Barrier

PTBBs use physical barrier arms that raise and lower to provide or restrict access to a roadwork site.

The aim of using this device was to physically prevent road users from entering the roadwork sites. This could improve road safety for all road users when combined with a portable traffic signal, as stakeholders have mentioned that road users have previously ignored the portable traffic signal and continued into the roadwork site along the temporary open lane with a potential fatal head-on crash with road users driving in the opposite direction.

The PTBB itself was not expected to have a major influence on improving speed behaviour for drivers approaching the roadwork site due to its placement at the end of the approach (start of the taper) to the roadwork site. Therefore, the video surveillance VMS was retained to be trialled in combination with the PTBB, displaying the same message as previously – 'Road Safety Camera' and 'Check Speed'.

3. Framework for Traffic Control Devices Set-up and Evaluation

The purpose of this section is to describe which factors were considered in the planning phase of the tests.

Every effort was made to consider and control testing, evaluation and circumstantial factors according to the framework described in this section. However, the anticipated and actual (real-life) testing and evaluation methodology sometimes differed. The change in the actual approach or method was due to implications resulting from construction scheduling (contractor working on multiple sites), inclement weather and site-specific aspects (working on different road sections affecting the set-up of traffic control).

The purpose of trialling innovative treatments at roadwork sites was to determine if they demonstrate statistically significant road safety benefits. Given the known solid relationship between speed (which affects both likelihood and severity of crashes) and crash risk, particularly fatal and life-altering injury crashes, a key focus of the evaluation was to measure the effectiveness of the selected treatments in reducing vehicle approach speeds.

For this project, the key evaluation objective for the selected traffic control devices' trials was primarily measuring the effectiveness in reducing travel speeds at roadwork sites.

3.1 Key Performance Indicator (KPI)

The proposed data requirements to satisfy each KPI for the road safety evaluation are documented in Table 3.1.

Table 3.1: Key performance indicators and data requirements for demonstrating the treatment trial objective

Treatment trial objective	KPIs	Data requirements
Effectiveness in reducing travel speeds at roadwork sites	Speed measurements on approach and start of the work site.	Vehicle speeds (spot or continuous profile) as compared to control group.
	Proportion of vehicles not complying with the temporary speed limit (can include compliance with signals).	Proportion of vehicles exceeding temporary speed limit as compared to control group.
	Proportion of vehicles grossly exceeding the speed limit.	Proportion of vehicles exceeding temporary speed limit by > 10 km/h as compared to control group.

A discussion of the data collection and the analysis performed is included in Section 5, followed by the findings.

3.2 Collection of Speed Data

For this project, pneumatic tubes were used to measure spot speeds and were placed at certain locations based on a typical roadwork configuration. The data collection at the suggested locations included:

- speed measurement taken at a set distance upstream from the start of the roadwork site
  The exact distance depended on the speed environment but was at a sufficient distance downstream so that drivers were yet to start deceleration on approach to the roadwork site.
- speed measured at the first warning sign on the approach to the roadwork site
- speed measured at the roadwork temporary speed limit sign
- speed measured adjacent to the start of the roadwork site

The multiple measurements of speed were considered necessary to gather the full picture of drivers' behaviour as they approached and entered the roadwork sites.

Measurement equipment was used to record speed data for every vehicle entering the area of interest. The measurement equipment included portable vehicle counters and classifiers (pneumatic tubes).

3.3 Comparison after Implementing Device

A 'with' and 'without' comparison for each proposed treatment involved collecting data during the baseline assessment and, next, with a traffic control device installed, evaluating the difference between the 2 scenarios.

For the video surveillance warning signage tests undertaken as part of this project, the control site was constituted by placing pneumatic tubes at 3 locations on the approach to the roadwork site, which measured speeds while having the conventional traffic management layout in place. Next, the treatment site was developed at the same site by adding the traffic control device (video surveillance warning signage) to be tested.

The second treatment testing took place by retaining the first measure (video surveillance warning signage) at the same location and placing the second measure (PTBB) next to the portable traffic signal, thereby employing a combination of temporary traffic control devices. The reason for this combination was due to the PTBB being placed next to the portable traffic signal. Road users could not see this PTBB when approaching from downstream; therefore, there was no visible measure in place to influence speeds on the approach. It was believed that the combined set-up might be more influential to road users on the approach as well as when entering the roadwork site. This prediction was tested by trialling these 2 measures in combination.

3.4 Site Selection

AfPA provided a site for Year 2 of this project. NTRO evaluated the suitability of the site based on the factors listed in Table 3.2.

Table 3.2: Optimal/desired site characteristics

Factor	Desired conditions
Traffic volumes and flow at treatment locations	• Traffic volumes that allow for free-flow speed approaching the roadwork site. • Maximum of 2 lanes per direction (pneumatic tubes used to capture speeds). • Aim for sufficient sample sizes for statistical significance.
Traffic composition	• Includes heavy vehicles, light vehicles and motorcyclists. • Free from frequent pedestrian crossing activity.
Road geometry including altered geometry under temporary traffic management (TTM) conditions	• The road section should be without elements that would encourage drivers to decelerate due to factors other than the devices, e.g. intersections. • Straight section of road (horizontal and vertical curves). • Free from sight distance hinderance.
Geographical location	• In proximity to Brisbane for travel purposes.
Surrounding land use	• Avoid areas with commercial or property accesses. • Avoid areas with high pedestrian activity.
Speed limits and operating speeds	• Permanent speed limit of, ideally, 80 km/h with incremental decreases to temporary speed limits of e.g. 60 km/h or 40 km/h.

Factor	Desired conditions
Crash history	• No obvious likely crash risk at the site (based on site inspection) – avoid roads with existing crash history complexities as it might skew the results.
Nature of roadworks and TTM aspects	• Roadworks to be static. • The site should not have elements that could interfere with the treatment set-up. • Daily traffic management plan should remain unchanged for the entire testing period.

3.5 Duration of Evaluation Limitations

The timing, frequency and duration of data collection were planned to account for the following:

- travel patterns and volumes during typical roadworks shifts (day, night, weekday or weekend day, preferably not public holidays or other significant outliers such as event days)
- treatment installation duration
- the minimum sample size required for statistical significance
- data collection location, especially for speed and traffic volume data (not located close to problematic road geometry influencing speeds, e.g. tight turns)
- consistency with TMR data collection recommendations and practice.

A sufficient sample size is required to determine the effectiveness of a treatment. The longer the duration of speed measurements for the before and after scenarios, the greater the probability of securing statistically significant results. However, it was acknowledged that for this project, the duration of the control and testing periods with traffic control devices would likely depend on the duration of the roadworks.

4. Site Testing

4.1 Site Context

The roadwork site where the Year 2 testing took place is located along Ipswich–Rosewood Road in Amberley; see Table 4.1 for details about this road. The site falls within the Ipswich City Council area, adjacent to the RAAF Amberley Base, north of the Cunningham Highway (see Figure 4.1).

The roadwork project entailed pavement resurfacing works conducted as part of the Road Asset Management Contract (RAMC) project undertaken by the contractor. AfPA nominated this RAMC project as an available site for the tests to be conducted.

As the roadworks commenced at an intersection on the eastern approach following a horizontal curve (with reduced sight distance to the roadworks), the proposed traffic guidance scheme (TGS) could be retained for the whole duration of testing along this approach.

The full length of the western approach formed part of the roadworks (both directions), and therefore, it was not possible to place pneumatic tubes across the road to measure speeds as the road surface was impacted by the roadworks.

Figure 4.1: Location of the roadworks (ORANGE) and eastern approach (YELLOW)

Source: Nearmap 2024, 'Ipswich–Rosewood Road Amberley', aerial map data, Nearmap, Sydney, NSW.

Table 4.1: Details about Ipswich–Rosewood Road

Parameter	Details
Road name	Ipswich–Rosewood Road
Road number	304
Road hierarchy	State-controlled road
Road type	Two way
Suburb	Amberley
Speed environment	80 km/h
Land use zoning	Operational Airspace Buffer – Wildlife Attraction Restriction Area
Annual average daily traffic (AADT)	7,770 (both directions)

Source: City of Ipswich (n.d.) accessed 2022.

This project only conducted trials at 2-lane roads, and future trials will have to be conducted on other road types to provide additional data about the performance of traffic control devices under different circumstances.

4.1.1 Temporary Traffic Management

The contractor responsible for the site provided NTRO with the TGS drawing set, 'TGS04-01' (see Appendix A). The drawing shows a schematic layout of the signage installed during the roadworks.

4.1.2 Tubes Only (Control)

The pneumatic tubes vendor was subcontracted to conduct the traffic survey. The survey was performed with pneumatic tubes using a data logger to collect the traffic data.

The data logger utilised the vendor's purpose-driven software that provided data such as traffic speed, vehicle class, traffic count, traffic volume and speed profile. In terms of location, based on the TGS drawings for the RAMC project, tubes were strategically placed at 3 locations, as shown in Appendix A:

- Tube #1 was used to measure the free-flow approach speed.
- Tube #2 was used to gauge driver compliance with multiple 60 km/h warning signs (with and without the proposed traffic control device).
- Tube #3 was used to gauge driver compliance (with and without the proposed traffic control device) after passing multiple warning signs.

4.1.3 Video Surveillance Warning Signage Using a VMS

The VMS, which was used to show that video surveillance warning signage was in place, was the first traffic control device tested for Year 2 of this project. The VMS was provided by the traffic control team (shown in Figure 4.2) and was self-powered (solar). The message shown on the VMS was:

- Road Safety Camera
- Check Speed.

Figure 4.2: VMS (photo taken at the project site)

In terms of location, based on the traffic guidance scheme drawings for the RAMC project, the VMS was located at a mid-block location following multiple 60 km/h warnings, as illustrated in Appendix A. It was located there to alert drivers to these traffic control signs and to improve awareness and visibility. Tube #2 and Tube #3 were installed on either side of this VMS to check vehicle speed compliance before and after adding this VMS device.

4.1.4 PTBB

The PTBB was the second traffic control device tested in Year 2 of this project. The PTBB (synchronised with the portable traffic signal) was provided by the traffic control team (shown in Figure 4.3).

Figure 4.3: Combined portable traffic signal and PTBB (photo taken at the project site)

In terms of location, based on the TGS drawings for the RAMC project, the PTBB was located next to the portable traffic signal prior to the tapered lane, as illustrated in Appendix A. It was located here to physically prevent drivers from entering the roadwork site and to improve awareness.

The PTBB itself was not expected to have a major influence on improving speed behaviour for drivers approaching the roadwork site due to its placement at the end of the approach zone. Therefore, the VMS was retained to be trialled in combination with the PTBB, displaying the same message – 'Road Safety Camera' and 'Check Speed'.

4.2 Schedule of Testing

The schedule for trialling the devices is shown in Table 4.2.

The contractor confirmed that the traffic control set-up (i.e. warning signage and traffic signals) indicated in Appendix A was in operation at the times and dates shown in Table 4.2. Due to tube repair works, construction scheduling and inclement weather, data could not be collected for consecutive days, as seen in Table 4.2. Additionally, one of the tubes did not function properly on 29 November; hence, the 'tubes only' data was only collected during 2 shifts on 18 and 19 December 2022.

Table 4.2: Schedule of testing

Traffic measurement/control device	Installation	Dates of testing (2022)
Tubes	28 November (9 am)	• 29 November (6:30 am) – 29 November (5 pm) – tubes malfunction • 18 December (6:30 am) – 18 December (1 pm) • 19 December (6:30 am) – 19 December (2 pm)
VMS	4 December (6 pm)	• 6 December (6 pm) – 7 December (4:30 am) • 7 December (6 pm) – 8 December (3 am) • 15 December (6 pm) – 16 December (4:15 am)
VMS + PTBB	8 December (6 pm)	• 8 December (5:30 pm) – 9 December (4:30 am) • 9 December (5:30 pm) – 10 December (5:30 am) • 14 December (6 pm) – 15 December (4 am)

5. Data Analysis

5.1 Data Processing

The tube data vendor provided the raw pneumatic tube data in the format of a CSV file. This data was divided into 6 separate spreadsheets, one for each direction at each of the 3 sites. The context of this study only required northbound traffic volume data for the analyses, and hence, southbound data was removed. The tube locations correspond to the site locations in the following way:

- Tube set 1 (Site 1)
- Tube set 2 (Site 2)
- Tube set 3 (Site 3).

For each vehicle that passed over each of the pneumatic tube sets, the following data fields were collected:

- date
- time
- speed
- wheelbase
- headway
- gap
- axles
- vehicle class.

Most of this report's data analysis is concerned only with the **speed** of the passing vehicles.

The time periods without roadworks taking place were removed from the dataset before the data was analysed. The data was then grouped into sets according to the traffic control devices in operation per period. The data collected during periods where no traffic control devices were in place (i.e. tubes only) is included as the control scenario.

Table 5.1 shows the sample size for each collected dataset. It is noted that the speed data collected at Site 1 is effectively the free-flow speed, as no traffic control devices were visible to the approaching traffic at this location.

Table 5.1: Sample sizes of collected datasets

Dataset	Sample size collected (number of vehicles)
Site 1 – Tubes only (free flow)	6,492
Site 2 – Tubes only	3,141
Site 2 – VMS	1,602
Site 2 – VMS + PTBB	2,469
Site 3 – Tubes only	8,214
Site 3 – VMS	1,599
Site 3 – VMS + PTBB	1,924

5.2 Analysis

All analyses conducted for this report concern the comparison between speeds approaching the roadwork site with and without traffic control devices. As described in Section 4, these traffic control devices included a VMS showing a video surveillance message and the subsequent addition of a PTBB. Given the collection schedule of the data as described in Section 4.2 and the statistical tests intended for this report's analyses, it was assumed that the datasets are independent of each other. In this context, independent of each other means each dataset within each site will contain different vehicles that cannot be paired. Continuing with this analysis, traffic control device 1 – video surveillance warning signage using a VMS, will be referred to as **VMS** for ease of reference.

Under this assumption, statistical methods can be utilised to identify whether the average speed did change by comparing the control to each traffic control device for each site. An unpaired t-test was used to conduct hypothesis tests and determine whether the populations were significantly different. An example of the hypothesis test between the tube only (i.e. control) versus the VMS at Site 3 is shown in Equation 1:

$$H_0: \mu_{control} - \mu_{VMS} = 0 \quad (1)$$

$$H_1: \mu_{control} - \mu_{VMS} \neq 0$$

where

H_0	=	hypothesis that the average speeds at Site 3 (control) and Site 3 (VMS) are equal
H_1	=	hypothesis that the average speeds at Site 3 (control) and Site 3 (VMS) are not equal
$\mu_{control}, \mu_{VM}$	=	average speed at Site 3 (control) and average speed at Site 3 (VMS)

This statement asks whether the difference in the means of the 2 populations is different (H_1) or not different (H_0). If the means are different from the t-test analysis, the null hypothesis of H_0 can be rejected, and therefore, the difference in means is statistically significant. The opposite applies if H_0 failed to be rejected. This project was interested in whether the means are statistically different (H_1 is true) and by how much they differ.

Prior to any statistical analysis, the sample sizes for each hypothesis test must be calculated. This is a theoretical sample size found for each dataset within each site, so it can be said that the data has statistical validity. In order to achieve this, a power analysis was conducted with basic assumptions around average speed and standard deviation for each test.

The power analysis was conducted in the programming language Python using the package 'statsmodels' to create a theoretical sample size for an individual Cohen's *d*, which is calculated as shown in Equation 2 (where μ is the average speed):

$$d = \frac{\mu_{tubes} - \mu_{cm}}{\sigma_p^2} \quad (2)$$

where

d	=	Cohen's *d*, how many standard deviations lie between the 2 means
μ_{tubes}	=	theoretical average speed with no traffic control devices
μ_{cm}	=	theoretical average speed with a traffic control device
σ_p^2	=	theoretical pooled standard deviation between the averages

In terms of assumptions:

1. A speed of 60 km/h was incorporated as the average speed for the tube only dataset for Site 2 and for Site 3 (posted roadwork speed limit). An observed standard deviation of 7 km/h was assumed for all tests relating to those sites.
2. A minimum observed difference in average speed is 3 km/h for both traffic control devices. With a speed difference below this value, the experiment can then be regarded as not having succeeded. A statistical significance of 0.05 and a power of 0.8 were used, correlating with standard practice as the most common choice in experimental design.

By using the ‘TTestIndPower()’ function in the ‘statsmodels’ package, we were able to incorporate the Cohen’s *d* values derived from the above formula, as well as $\alpha = 0.05$, power = 0.8 and ratio = 1, to calculate the required sample size to perform an unpaired t-test.

Table 5.2 illustrates the required sample sizes for the 4 scenarios for statistical validity where t-tests were performed. From this table, it is evident that the most demanding scenario is ‘Tube only versus VMS’ at Site 2, which requires a sample size of 192. Since all sample sizes exceeded 192, with the smallest sample size being 1,599 (from Table 5.1), it is appropriate to say that all sample sizes met the minimum sample size requirement.

Table 5.2: Power analysis minimum sample sizes

Sample size requirement	Tube only vs VMS	Tube only vs VMS + PTBB
Site 2	192	91
Site 3	15	22

6. Results

6.1 Summary of Results for Year 2

The initial analysis revealed significant skewing of data in speed distributions at Site 2. This led to a decision to exclude Site 2 data from the main t-test and distribution analyses. A detailed analysis of this skewing and its causes is provided in Section 6.2.

Statistical t-tests were conducted using the package ‘pingouin’ in Python. The results of these tests are provided in Table 6.1 below. It contains each hypothesis test conducted and its respective 95% confidence interval of the difference between the means, the p-value for the test, as well as the Cohen's *d*. If the p-value of the test was below 0.05, then the difference between the 2 groups was considered to be statistically significant. The 95% confidence interval represents the range at which the < 0.05 significance holds true.

Table 6.1: Hypothesis test outcomes

Site 3	Tube only vs VMS	Tube only vs VMS + PTBB
95% confidence interval	2.95, 4	6.95, 7.93
P-value	$p < 0.05$	$p < 0.05$
Cohen's *d*	0.42	0.88

Table 6.1 shows that both traffic control devices reduced the average speed for Site 3. Judging by the confidence intervals, the traffic control devices have effectively reduced the speed by at least 2.95 km/h for VMS only and by at least 6.95 km/h for the combined VMS + PTBB traffic control device. Table 6.1 also identifies the Cohen's *d* values, also known as the effect size. This statistic identifies how many standard deviations lie between the 2 means. For each comparison, the larger the effect size, the bigger the difference between the 2 average speeds.

For Site 3, the Cohen's *d* value for the combined effect of VMS + PTBB was considerably larger than that of the VMS, indicating that VMS + PTBB has created a much larger reduction in the average speed when compared to only using VMS.

A graphical representation of the distributions of speed is seen in both Figure 6.1 and Figure 6.2, showing these distributions across the traffic control devices for Site 1 and 3, respectively.

Figure 6.1: Speed distribution across traffic control devices at Site 1

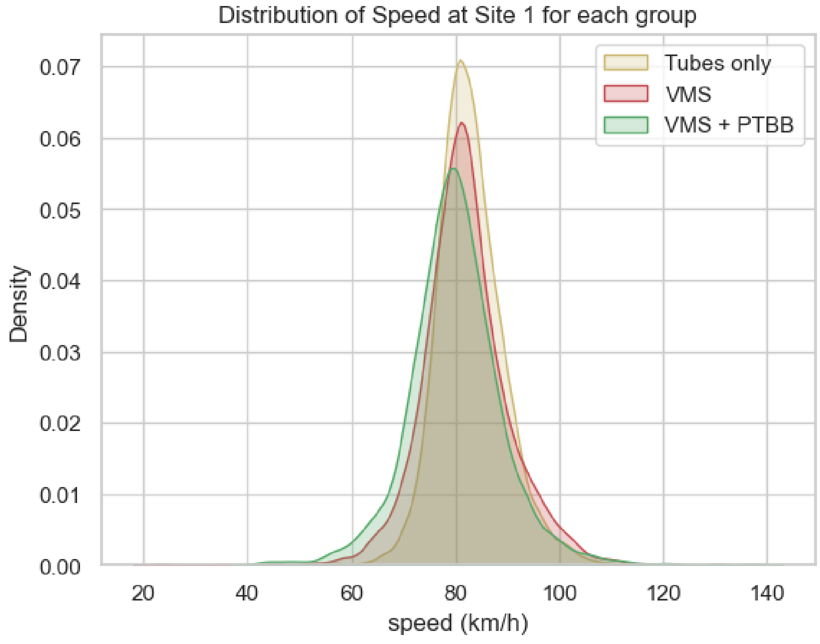
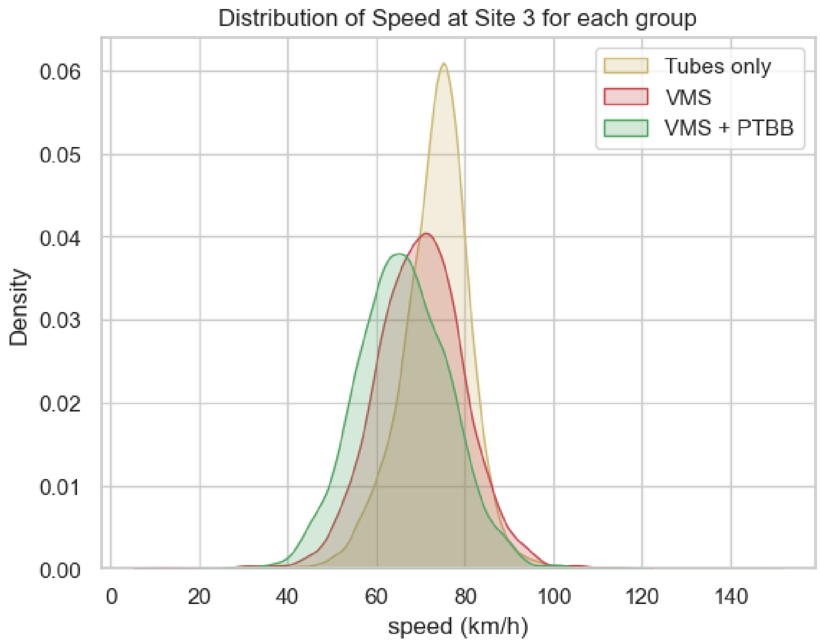


Figure 6.2: Speed distribution across traffic control devices at Site 3



All graphs show a bell curve shape, which implies the data is highly likely to be normally distributed (as expected). Figure 6.1 indicates that the traffic control devices had little effect so far away from the roadwork site due to how closely matching the distribution curves are, as expected. This is in stark contrast to Figure 6.2 where the peaks of each distribution are noticeably shifted towards lower average speeds as traffic control devices are introduced. Both figures also indicate that the combination of the VMS and the PTBB was the most effective traffic control device in these isolated tests at reducing driver speeds.

Another useful metric is whether a vehicle driver complies with the posted speed limit and the proportion of vehicles exceeding the limit grossly (here measured as 10 km/h over the speed limit). The posted site speed limit for Site 3 was 60 km/h. Table 6.2 shows the percentage of vehicles that were driving above the posted speed limit at each site and for each group within each site. Table 6.2 shows that although there is still a substantial amount of speeding, the use of the VMS + PTBB traffic control device had effectively reduced the percentage of **speeding** drivers from 94.3% with no traffic control devices to 71.9% with the combined traffic control device.

The figures for those **exceeding the speed limit by more than 10 km/h** are more significant, with a reduction of almost 20% from tubes only (70.7%) to VMS (50%) and another 17% reduction from VMS to VMS + PTBB (33.8%).

Table 6.2: Percentage of vehicles above posted speed limits for each site

Site 1	% of vehicles above posted limit (80 km/h)	% of vehicles exceeding posted limit by > 10 km/h
Baseline (free flow)	66.4%	12.3%
Site 3	**% of vehicles above posted limit (60 km/h)**	**% of vehicles exceeding posted limit by > 10 km/h**
Tubes only	94.3%	70.7%
VMS	85.2%	50.0%
VMS + PTBB	71.9%	33.8%

In summary, from the statistical analysis of the Site 1 and Site 3 data, the 2 traffic control devices reduced the average speed when compared to having no traffic control devices. The statistical testing identified that both measures had significant effect sizes, with the Cohen's *d* value of VMS + PTBB vs tubes (control) being almost twice the value of VMS used on its own (0.88 vs 0.42).

Both traffic control devices were seen as statistically significant in reducing the average speed, with the combined effect of VMS and PTBB being more effective than the VMS on its own. Table 6.2 also shows that the use of the combined VMS + PTBB traffic control device reduced the proportion of vehicles exceeding the limit by more than 10 km/h by 37%.

6.2 Additional Analysis for Site 2 (Year 2)

Initial results from Site 2 speed distributions showed significant unexpected skewing when compared to Sites 1 and 3. Figure 6.3 shows the overall speed distributions for each traffic control device at this site.

Figure 6.3: Speed distribution across traffic control devices at Site 2

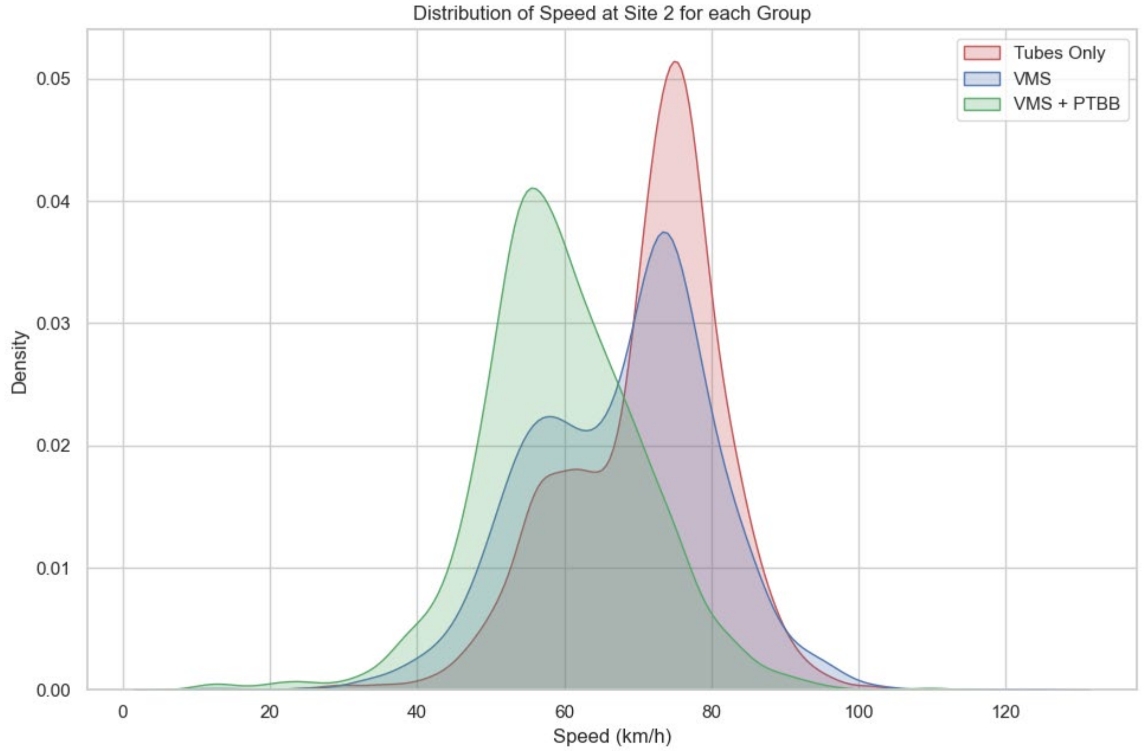


Figure 6.3 shows 2 clear and different peaks for tubes only and VMS data, with a small amount of the same behaviour also occurring for VMS + PTBB data. As these curves are not normally distributed in this form like they are for Site 1 (Figure 6.1) and Site 3 (Figure 6.2), it was clear that another factor had caused the underlying data to be dependent on an **external** variable: in this case, causing 2 distinct behaviours within the same traffic control device datasets.

Although there could be many factors contributing to skewed data for these tests, such as unexpected congestion during a specific time period, inconsistent extreme weather patterns, local events causing more traffic and inconsistent site conditions for test set-up, these factors are far more likely to cause a number of clear outliers within the data, not 2 distinctly independent behaviours within the same dataset. This eventually led to investigating individual daily speed distributions and how these related to the testing schedule. Table 6.3 and Figure 6.4 to Figure 6.6 show the speed distributions for each day for each traffic control device at Site 2.

Table 6.3: Site 2 daily analysis

Statistic	Sample count	Mean (km/h)	Standard deviation (km/h)
Tubes only			
Day 1: 18 December 2022	1,258	62.75	9.998
Day 2: 19 December 2022	1,883	76.70	6.252
VMS			
Day 1: 6-7 December	125	60.79	13.419
Day 2: 7-8 December	706	60.23	10.458
Day 3: 15-16 December	771	76.09	7.703
VMS + PTBB			
Day 1: 8-9 December	848	59.25	9.619
Day 2: 9-10 December	974	61.10	12.256
Day 3: 14-15 December	647	57.47	11.292

Figure 6.4: Site 2 tubes only daily distributions

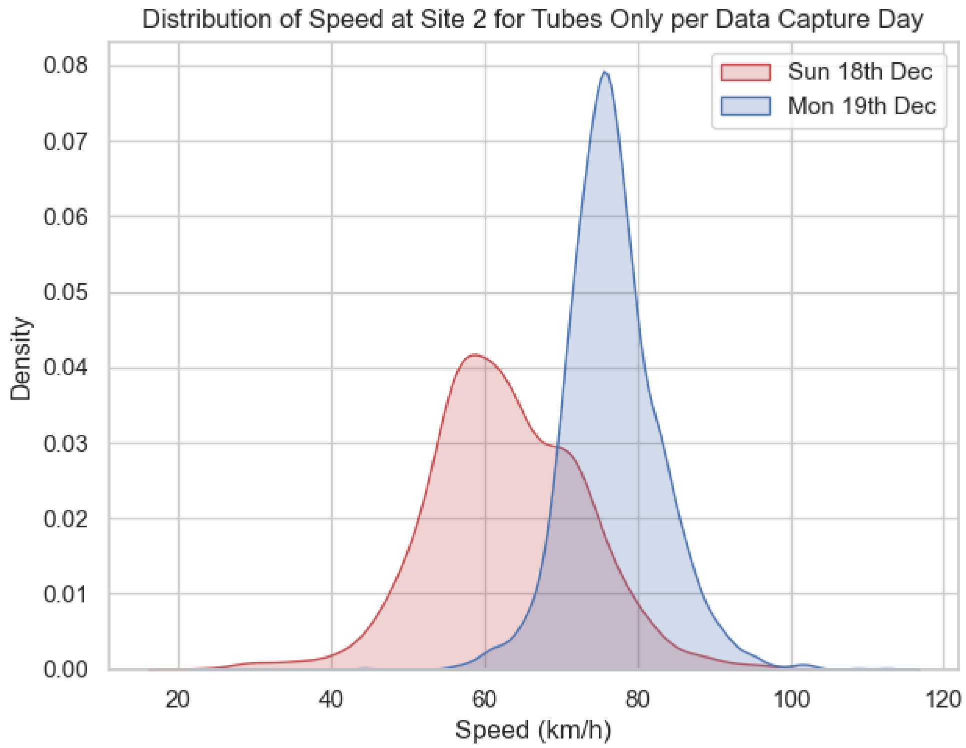


Figure 6.5: Site 2 VMS daily distributions

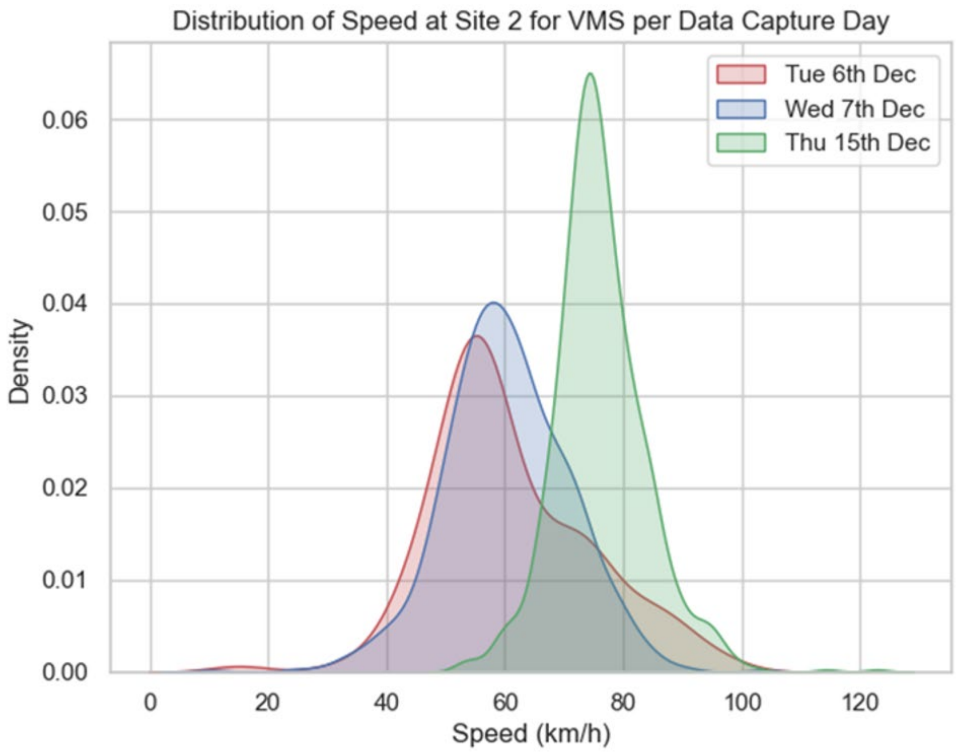
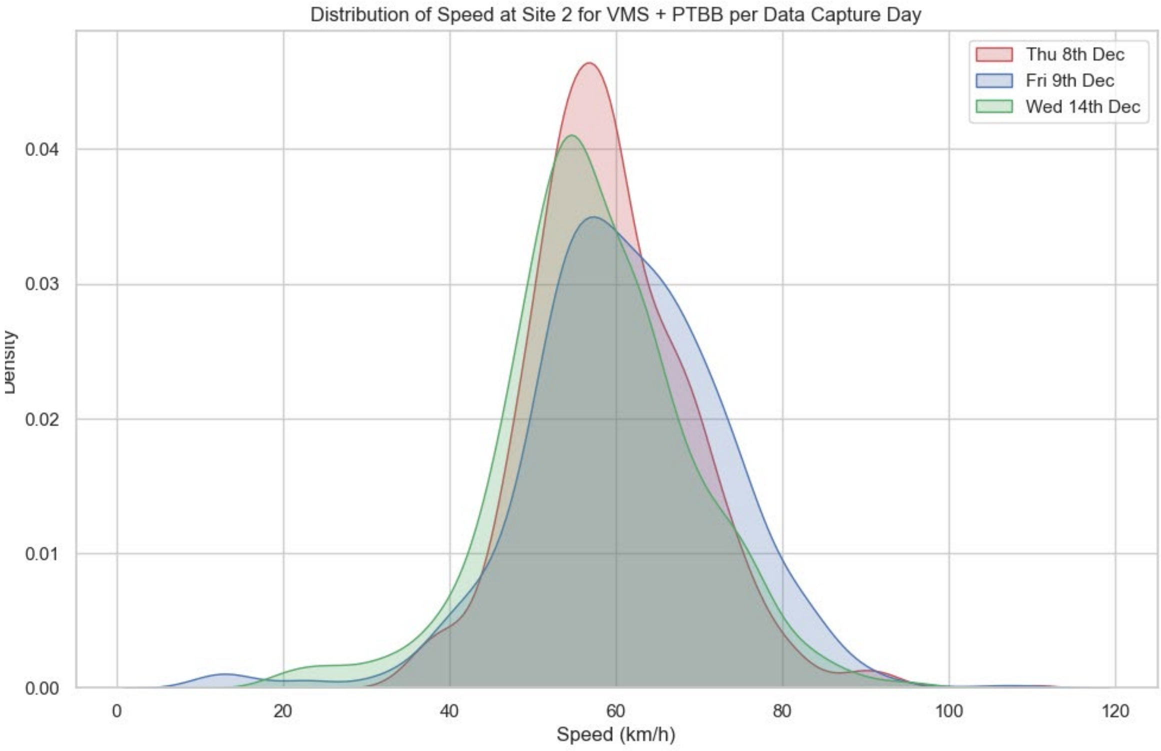


Figure 6.6: Site 2 VMS + PTBB daily distributions



These figures (Figure 6.4, Figure 6.5 and Figure 6.6), along with the data in Table 6.3 reveal some key points:

1. Particular days/nights in the tubes only and VMS datasets for Site 2 (15 and 19 December) are far more densely populated towards higher speed when compared to other days in their respective datasets.
2. The days in the tubes only dataset for Site 2 differ as one is a weekend day and one is a weekday.
3. The days in the VMS dataset for Site 2 differ as 2 were scheduled before PTBB implementation and one was scheduled after PTBB implementation.
4. The use of the PTBB seemed to keep speeds far more consistently distributed when compared to the other 2 datasets, especially considering there is almost a week in between the first day of data collection and the last in this dataset.

These points led to some logical conclusions about the data inconsistency at Site 2. The **first** is that weekend speed distributions are different from weekday speed distributions. More tests on this road would be needed to prove this further in a statistical sense. However, as an informed explanation for the difference in curves in Figure 6.4, it makes sense that for a rural road such as this one, those who drive it regularly during weekdays are likely to drive faster than those who drive it occasionally on the weekend. This is especially true when considering the timing described in Section 4.2, which shows that the data for tubes only was collected in effectively a regular period on Sunday morning (18 December 2022) vs a peak traffic period on a Monday morning (19 December 2022).

The **second** important conclusion relates to the test schedule, where there was a significant gap between the first 2 days of data and the last day of data in Figure 6.5 (Site 2 VMS daily distributions). This fact is also combined with 2 other important factors:

- Scheduling in Section 4.2 reveals that all testing for the VMS occurred during afternoon peak hours.
- The PTBB had been installed and removed during the 8-day break of VMS testing.

This suggests that drivers, during VMS data collection, were regular drivers of the road, and after more than a week of witnessing the traffic control devices in place, and with the PTBB removed and no repercussions occurring for exceeding the speed limit earlier on, these drivers were far more complacent and drove at speeds closer to the permanent speed limit of the road without roadworks – 80 km/h – which greatly exceeded the temporary road signs requesting drivers to adhere to the 60 km/h temporary roadwork speed limit.

These conclusions are also supported by the data collected at Site 3, where the mean speed on the last day of VMS testing was over 5 km/h higher than on the first day: 68.56 km/h (day 1) vs 73.92 km/h (day 2).

It is also likely that the introduction of the PTBB did not share the same data inconsistencies as the control and VMS testing because drivers had to physically slow down to pass the PTBB, which was different for the other 2 datasets for Site 2.

The Site 2 data, although inconsistent, has therefore provided an important finding on how long a VMS showing a video surveillance warning message is realistically effective for most passing drivers. However, it does not change the key conclusions outlined in Section 6.1 where the combined VMS and PTBB traffic control device had a statistically significant effect on reducing drivers' speeds.

6.3 Comparison of Trials for Year 1 and Year 2

This section compares the results of the traffic control devices tested for both Year 2 and the previous Year 1, which included:

- flashing beacons (Year 1)
- speed radar signs (Year 1)
- VMS used as video surveillance warning signage (Year 2)
- VMS used as video surveillance warning signage + PTBB (Year 2).

In general, the statistical analysis results show that all traffic control devices reduced traffic speed to a certain extent. Table 6.4 presents the lower values of the 95% confidence intervals, the Cohen's *d* values and the percentage of vehicles grossly exceeding the speed limit (> 10 km/h) for all the traffic control devices tested.

According to the results shown in Table 6.4, Figure 6.7 and Figure 6.8, the combined VMS + PTBB traffic control device delivered the most promising statistical result to decrease speeds. The other 3 traffic control devices provided similar statistical results.

For the Year 1 tests, it is to be noted that the permanent speed limit as well as the speed limit during roadworks remained at 60 km/h, and therefore, a smaller reduction occurred in the percentage of vehicles exceeding the posted speed limit by more than 10 km/h in comparison to the Year 2 tests, which involved an 80 km/h permanent speed limit and a 60 km/h speed limit during roadworks.

It should be noted that video surveillance warning signage using a VMS had a diminished effect on drivers' compliance after being used for a lengthy time period. Also, the flashing beacons were difficult to fasten to the road signs, and members of the traffic control team expressed concern about possible confusion resulting from combining the flashing beacons with the other warning lights forming part of the TTM set-up.

Table 6.4: Comparison of the traffic control device effects on traffic speed

	Traffic control devices	95% confidence interval range – lower value	Cohen's *d*	% of vehicles exceeding posted limit (60 km/h) by > 10 km/h
Year 1	Flashing beacons (Site B) vs only tubes	2.7	0.44	4.3% (down from 6.5% only tubes)
	Speed radar (Site B) vs only tubes	2.9	0.49	2.8% (down from 6.5% only tubes)
Year 2	VMS (Site 3) vs only tubes	3.0	0.42	50% (down from 70.7% only tubes)
	VMS+PTBB (Site 3) vs only tubes	7.0	0.88	33.8% (down from 70.7% only tubes)

Figure 6.7: Distribution of speed seen within experiment – Year 1

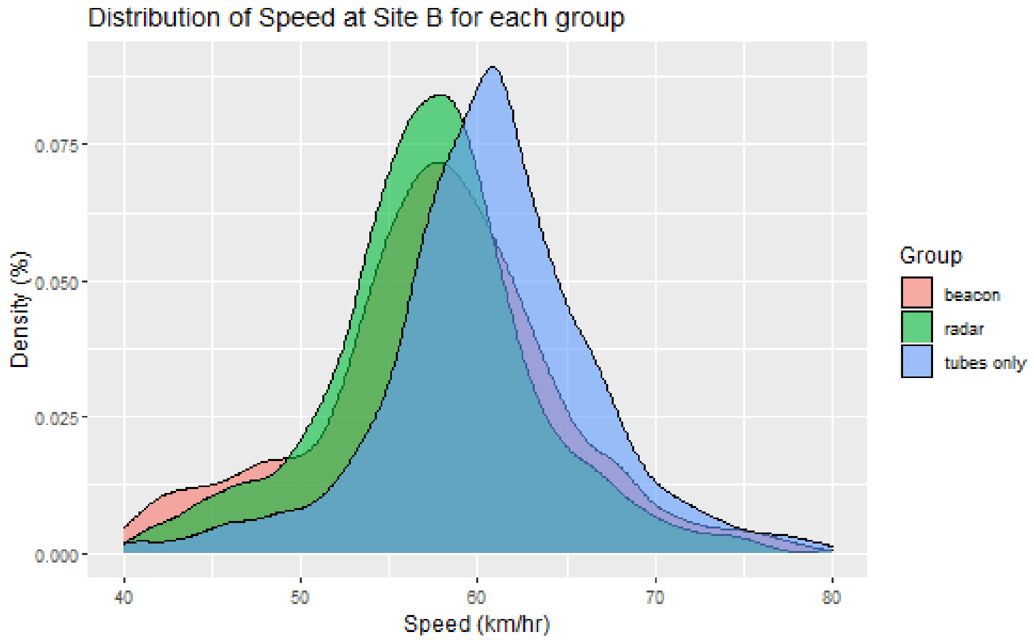
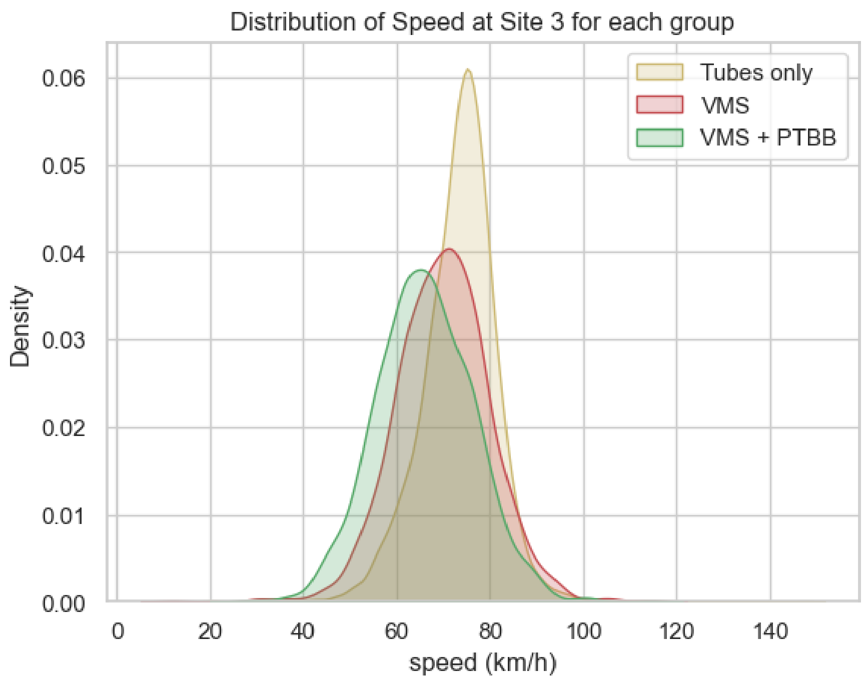


Figure 6.8: Speed distribution across traffic control devices at Site 3 – Year 2



6.4 Conclusions and Recommendations

The overall objectives of this project set out to determine:

1. if the investigated traffic control devices can reduce the non-compliance speed of drivers through roadwork sites
2. the effectiveness of the proposed traffic control devices to reduce road safety risk
   - in addition, developing KPIs for each traffic control device under investigation, for example, a reduction of maximum and average speeds approaching and driving through roadwork sites.

After conducting the trials, it was determined that all 4 traffic control devices did reduce the traffic speed; therefore, non-compliance of drivers to speed limits can be reduced by employing traffic control devices. As mentioned previously, the combined VMS + PTBB traffic control device delivered the most promising statistical result to decrease speeds. The other 3 traffic control devices yielded similar statistical results; however, the speed radar signs seem to be the simplest second-best traffic control device.

The effectiveness of the traffic control devices varied, i.e. the magnitude of the speed reduction (statistically evaluating the means) and the percentage of drivers exceeding the speed limit or grossly exceeding the speed limit by more than 10 km/h. The most pronounced reduction in vehicles speeding occurred whilst trialling the combined VMS+ PTBB traffic control device.

After undertaking these 2 years of testing, it is recommended to conclude with the list of traffic control devices suggested by AfPA, as the testing for all the traffic control devices believed to suit these trials is now complete. It is further recommended to consider the findings discussed in this report and to apply engineering judgement at each roadwork site when deciding which traffic control devices to implement when targeting improved speed compliance.

A future option for extending the reach of this research might be to trial the combination of speed radar signs and the PTBB.

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Appendix A Traffic Guidance Scheme