# USE OF CONNECTED VEHICLE DATA FOR SPEED MANAGEMENT IN ROAD SAFETY

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## ABSTRACT

Traffic speed is one of the most important factors influencing road-based mobility and safety outcomes. Collection of accurate speeds at chosen points in the road network has been costly and limited in scope. Increasing proliferation of connected vehicles generates new types of data sampled from mobile and navigation devices, and from onboard systems. Internationally, this anonymous sampling technique is referred to as floating-car data (FCD). FCD offers a unique opportunity to measure speeds at any point across the entire road network. The validity of this data and its usefulness in road safety applications has been unknown.

This paper presents findings of validation of FCD speeds against conventionally collected point-speed data for different parts of the road network in Victoria. Analysis showed a clear relationship between the two data types. FCD was shown to be a viable source of speed monitoring information which can influence road safety policy, speed management (e.g. setting of speed limits), and in road safety evaluations. Availability of FCD speeds was much greater than for point-speed data, covering most of the public road network. Several use cases for this data are presented to demonstrate its practical applications. The paper discusses various limitations of the data, and the expected evolution of this important data source.

## INTRODUCTION

Traffic speeds are one of the most significant factors in road safety performance, one which has been relatively well understood through research over the past twenty years. Changes in speeds are a proxy indicator of success of some road safety policies and projects, e.g. speed enforcement, or traffic calming. If percentages of vehicles speeding by more than 10 km/h, 20 km/h, and 30 km/h are reduced, then such policies/projects are contributing to overall safety improvement. Changes in personal crash risk can be estimated using relationships developed by Kloeden et al. (2001, 2002).

Typically, road safety practitioners are interested in mean speed changes, and these can be used to estimate likely safety impacts using Elvik's Power Model (e.g. Nilsson 2004, Elvik 2009, 2013). Operating speeds (85th percentile) are also sought as they are an important operational and road design factor.

Transport Accident Commission (TAC) sponsored an ARRB study to better understand conventional and emerging 'big data' sources of speed information, their strengths and weaknesses in the context of system-wide speed monitoring and evaluation for road safety purposes. The study objectives were to explore the relationship between conventional point-speeds and floating car data (FCD) speeds sampled from connected vehicles. This involved exploring respective road network coverage of both speed data sources, their latency and

[1] Currently at the Industry Capability Network

availability, and potential use-cases for road safety. The study concluded with preliminary recommendations regarding use of FCD speeds in road safety monitoring and evaluations.

# POINT VS. FLOATING CAR DATA SPEEDS

Conventionally, speeds of all vehicles are collected at a point location on the road for a defined period (e.g. two weeks). The methods of measurement vary and include pneumatic tube counters, electromagnetic or piezo-magnetic loops, or TIRTL laser technology. Radar is another form of data collection typically using small samples of vehicles over a short time.

The common aspect of conventional techniques is the assumption that the point measurement is applicable to the whole road section of interest (TRB, 2011). This approach means that traffic speed data is available in a limited number of locations on the road network, rather than as a continuous map of speeds. Also, if speed information is needed at a specific location, it usually is measured at a considerable expense and delay.

The second feature of point-speed data is that it is collected under established guidelines avoiding geometric and operational constraints (i.e. on flat straights and away from intersections). The industry standard seeks this information to be presented as free flow speeds, i.e. with headways between vehicles greater than 4 seconds (Austroads 2017). This approach seeks to strip off the effects of congestion, road geometry, and of other road users' presence on drivers' choice of speed.

In recent years, vehicle navigation devices began offering a sizeable sample of accurate global positioning data across the entire road network. This 'big data' source is called floating car data (FCD), or probe vehicle data. FCD has been used internationally in road transport management, especially in monitoring of network performance and congestion, and in evaluation of traffic flow improvement projects (Rose 2006, Leduc 2008, Bessler and Paulin 2013, Espada and Bennett 2015).

FCD comes from a variety of connected vehicle sources such as in-built navigation services, taxi instrumentation, commercial vehicle logistics and tracking devices, and from mobile phone applications. Data is always provided with users' consent and is stripped of any identifying information. Data comes from multiple sources and is aggregated into a uniform format by commercial providers such as HERE, TomTom or Intelematcs.

In most cases, speeds are calculated from distance covered along a route between time-stamped satellite GPS 'pings' (10-60 sec apart). In other cases, vehicles provide speed at the instant of the satellite 'ping'. Thus, FCD speeds are averaged over road segments defined by navigation service providers' maps (30m – 2000 m, typically ~200 m).

Unlike point-speeds, there is no direct way to screen headways, as the data is sampled (2-10% of all traffic) based on connected vehicles' proprietary navigation technology.

Theoretically, mean point speed (time-mean speeds, or arithmetic mean speed) tends to be greater than the mean link speeds from FCD (space mean speed, or harmonic mean speed) (Austroads 2017). This gap is greater when standard variation of point speeds is higher. There is also an observed tendency for the gap to increase with the length of the link. Overseas studies have shown promising correlations of FCD speeds with point-speeds (Bekhor et al. 2013, Aarts et al., 2015, Reinau et al. 2016, Ambros et al. 2017).

# STUDY METHODS

The study reviewed the speed data sources currently used in Victoria from the perspective of the following strategic goals set by TAC:

1. Monitor trends in speeds across the network to assist in managing the State Road Safety Strategy.
2. Provide input into speed management programs such as speed limit setting.

3. Evaluate the effectiveness of broad programs and local deployments of speed management programs and speed enforcement.

Point-speed samples were obtained courtesy of VicRoads' Traffic Information System for several different source types. The sources were assessed across several criteria driven by the above strategic objectives, such as spatial and temporal availability, availability of speed KPIs (e.g. mean speeds, 85th percentiles, etc.), and frequency of data collection. The authors then sampled FCD speeds from two commercial providers and subjected the data to the same assessment for comparison.

In the second stage of analysis, authors sought FCD data from HERE, TomTom and Intelematics, the three providers who expressed interest in project collaboration. VicRoads conventional point-speed data was sampled from the first stage. HERE and TomTom provided corresponding FCD speed samples for the same locations and for similar time periods.

Data was sampled from urban freeways and arterials, and from a rural road. The mean and 85th percentile speeds, and statistical distributions were compared between the two speed data sets, drawing preliminary validation conclusions and qualifications about the FCD speeds.

Preliminary use-cases were then explored to better understand the FCD speeds in their different applications to safety.

# FINDINGS

## Conventional point-speeds data sources

Samples of VicRoads speed data sources were analysed, and the key custodians were interviewed to obtain information pertaining to aspects which could not be directly measured. The following assessment of the data sources for speed was made. The assessment criteria were agreed to by TAC and VicRoads based on informing the needs of a future speed distribution management system. Table 1 presents the results.

**Table 1. Assessment of conventional point-speeds sources**

| Point-speed data source type | Availability everywhere across public network | Frequent updates | Long historical data available | All leading KPIs possible | Short time periods | Comments |
|---|---|---|---|---|---|---|
| **Tube data (Metrocount)** | × | × | ✓ | ✓ | ✓[1] | Specific locations on **rural arterials**. Annual updates, or less often. |
| **Telemetry sites (pavement loops)** | × | ✓ | ✓ | ✓[2] | × | Specific locations on **rural arterials**. |
| **TIRTL** | × | ✓ | × | ✓ | ✓[1] | Several sites on **urban freeways**. |
| **Freeway data stations (pavement loops and studs)** | × | ✓ | ✓ | ✓[2] | × | Specific locations on **urban freeways**. Data of better standard than telemetry sites. |
| **Arterial data stations (pavement loops)** | × | × | ✓ | ✓[2] | × | Specific sites on principal **urban arterials**. Updated annually. |
| **Radar gun** | × | × | ✓ | ✓ | × | 76 locations on **urban arterials**, sampled annually for a two-hour period. |

1. Yes, if set up at new locations for the required periods. Expensive to deliver and manage.

2. Available but unclear how biased the means and 85th percentiles are, as distributions are based on aggregated samples and/or and speed bins. These sources cannot measure vehicle headways and can only estimate free-flow speeds (e.g. speeds late at night).

The assessment confirmed that none of the point-speed data source covered the entire road network. Rather, all sources provide data at selected points across the state-controlled road network (local government roads were not included in the VicRoads system).

Also, it was found that each source had specific technical limitations related to data collection technology, data storage and aggregation, and calculation of speed KPIs. These limitations make these sources non-comparable. For instance, freeway data stations measure speeds in 20 sec averages, continuously. Since individual vehicle speeds are not reported, this source cannot provide headway. Hence, only general speed profile was available regardless of headways and congestion. Free-flow speeds could only be inferred (e.g. in the middle of the night). In contrast, radar gun studies were conducted twice a year, for two hours, and were based on a sample of 100 surveyor-selected free-flowing vehicles with headways exceeding 4 sec. Thus, speed KPIs obtained from such different sources and different parts of the road network cannot be directly compared.

The findings suggest that there was no single 'ground truth' speed data source representing all parts of the road network. Rather, some of the point-speed data sources should be noted for their accuracy and versatility. TIRTL and tube count data are proven low-error techniques, measuring individual vehicles, and thus providing rich data sets for analysis and interpretation.

# Connected vehicle sources – FCD speeds

The same assessment criteria were applied to three proprietary sources of FCD speeds. Some samples were obtained, and the data provider representatives were interviewed to obtain further information. The data characteristics were similar across all three providers, with small variations in technical presentation of the data and in the sampled vehicle fleet composition. Table 2 shows the results of the assessment.

**Table 2. FCD speeds, assessment vs. TAC data criteria**

| Data source | Availability everywhere across public network | Frequent updates | Long historical data available | All leading KPIs possible | Short time periods | Comments |
|---|---|---|---|---|---|---|
| **FCD speeds** | ✓ | ✓ | ✓ | ✓[1] | ✓ | May not cover some very low volume roads (e.g. access lanes). Quality and availability of short-period KPIs (e.g. 15 min) will be better on high-volume roads. Long extraction time periods may be needed on low-volume roads. |

1. No headways can be provided, and speed data is available as KPIs only, e.g. mean, std. dev, and a 5-percentile increments. Two of the three providers can also provide a sample size.

It was evident that FCD can provide a consistent source of speed data across the entire state. Given that FCD speeds are measured over longer distances, they are expected to be different to point-speeds (time-mean, see Austroads 2017 for definitions). The main expected effect would be that the FCD speeds would have lower values as they are averaged over a known road length, rather than representing a speed under idealised location and driving conditions.

Most critically, no headway information is available, hence free-flow speeds cannot be directly measured. FCD speeds are not available in raw format, but the data is quality assured by the provider. Providers are bound by privacy laws, and then exceed these requirements by destroying parts of the information which could be used to identify individual vehicles/users, before the data is released for use. This may pose issues to some analysts, as data quality cannot be directly assessed as it can be with tube counter or TIRTL data[2]. Instead, data providers offer information about data filtering and cleaning methods (e.g. how stationary vehicles, personal navigation devices, or multiple devices per vehicle are stripped out of the data).

Since FCD speeds are sampled from GPS-enabled vehicles and devices, there is an issue with biased representation of the vehicle fleet. Heavy and commercial fleet vehicles are over-represented in the historical data sample, as these were the early adopters of the technology. Also, specific vehicle makes are over-represented depending on the specific data partnerships entered by the data providers. To check for representativeness, data providers enable simple data filtering options (e.g. compare FCD speed results with and without heavy vehicles). Also, each year, new data sources are added expanding the breadth of different classes of vehicles and drivers.

FCD speeds are available from 2008 for much of the road network, with the last three years of data being of the best quality due to rapid increase in use of navigation services and vehicle connectivity. This means that the first strategic objective, i.e. high-level speed trend monitoring across the entire network, can be satisfied if the data is deemed to be acceptable by researchers and practitioners.

FCD speeds are available for all types of road links, including sections with steep grades, curves and intersections, during congested and uncongested periods, and in road sections with traffic calming. Figure 1 shows a historical snapshot of FCD mean speeds for Wednesday daytime off-peak period across part of the Melbourne road network. Speeds on local streets have been turned off for display clarity. Such features of the data mean that the second strategic objective (speed management program inputs) may be met, subject to satisfactory assessment of the FCD speeds. These questions of validation are tackled in the next section.

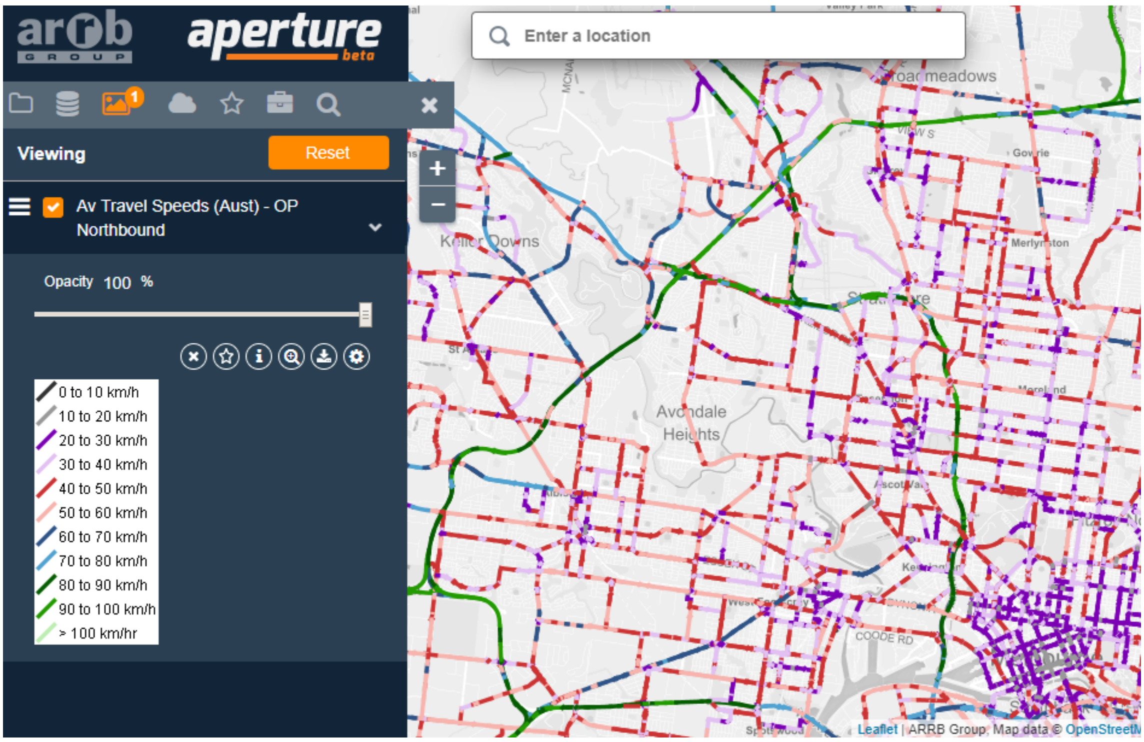



***Figure 1. Snapshot of FCD mean speeds across the arterial network***

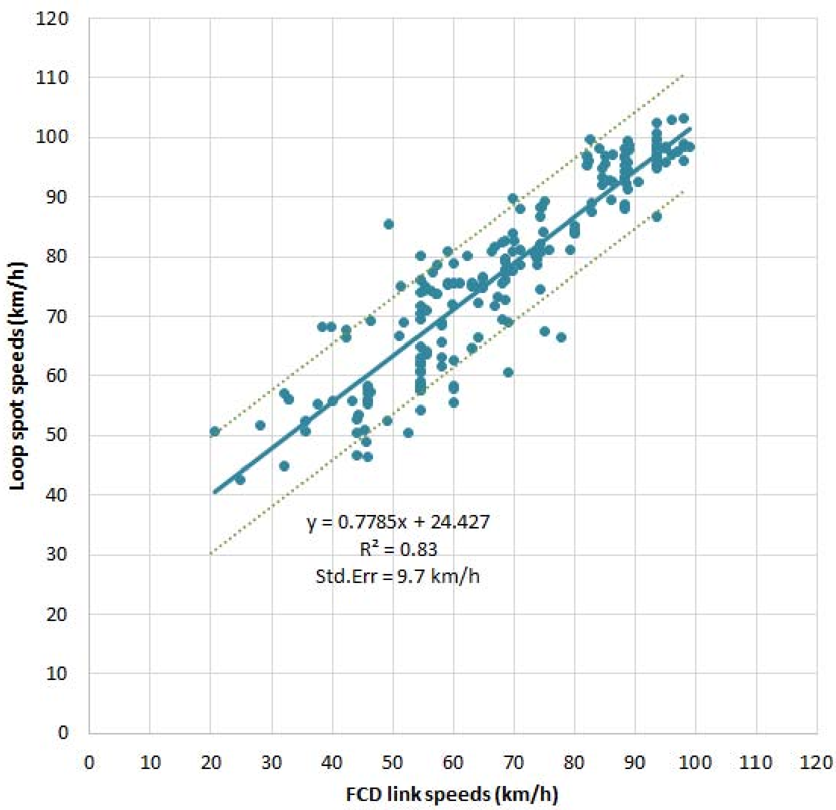
[2] Such options may also not apply to other conventional point-speed data sources such as loops, studs and radar due to automated data aggregation to reduce storage.

# Findings from data analysis and preliminary validation

The study's second and third strategic objectives sought to establish whether data could be used to inform speed management programs, and to evaluate their effectiveness. To answer this, preliminary validation of FCD speeds was undertaken against known conventional sources of point-speeds.

The first test sought to establish if there was a general relationship between point-speeds and FCD speeds. For this purpose, a publicly available set of VicRoads speeds was used and matched with FCD speeds. The VicRoads point-speeds were based predominately on inductive loops, measured at metropolitan freeway and arterial data stations (see Table 1 for the assessed characteristics of point-speed data),. The finest level of point-speed data available were hourly mean speeds sampled during 2012 (dates unknown, no headway information). These data stations were geographically matched with corresponding FCD links. FCD speeds were extracted from HERE Traffic Analytics system for the available three-year period (2012-14), also presented as hourly means. Locations with insufficient FCD data sample size were removed from further analysis[3] to reduce error. Analysis was carried out on data from 235 locations, with speed limits between 50 km/h and 100 km/h.

Direct comparison of the hourly mean speeds provided little insight due to significant data scatter (24 hourly values x 235 locations, with differences in data periods). Figure 2 shows more aggregated level of analysis, comparing the average hourly mean speeds for each location using both data sources. Figure 2 shows that while there were location-based effects (different road types and operational categories), there was a strong overall relationship between averaged mean loop point-speeds and FCD speeds ($R^2$=0.83). FCD speeds, being space-mean speeds were lower than time-mean point-speeds, as expected. The standard error was 9.7 km/h, similar to that found previously by Espada and Bennett (2015). Also, Hrubeš & Blümelová (2015) found FCD speeds to be similar but lower than loop speeds. The relationship was also statistically significant. Also, the observation that link speed was greater than point speed was consistent with theoretical expectation of the relative differences between time mean and space mean speeds.




[3] FCD data was improving continuously. Data quality issues present in 2012-14 may not be an issue in 2018.

***Figure 2. Averaged hourly mean speeds for every location***

Further analysis was carried out, averaging hourly mean speeds across all similar locations, i.e. by speed limit. Results for different speed limits showed similar trends, and the results for 80 km/h roads are shown in Figure 3. It is clear, that both speed data sources showed similar trends across the day in response to congestion, but FCD speeds were systematically lower. FCD mean hourly speeds were typically 11 km/h lower than loop mean hourly speeds (range 7 – 15 km/h for this speed limit). Figure 3 also shows the standard deviation for each data source; both overlapped, suggesting that the 11 km/h difference was not statistically significant (using $p \leq 0.05$) in this case.

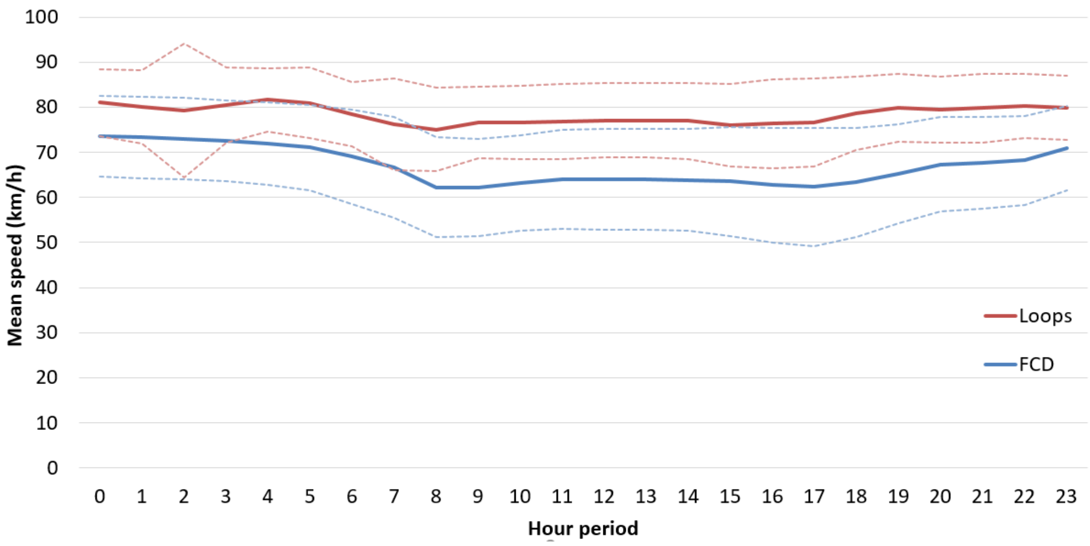



***Figure 3. Comparison of hourly mean speeds averaged across all 80 km/h locations***

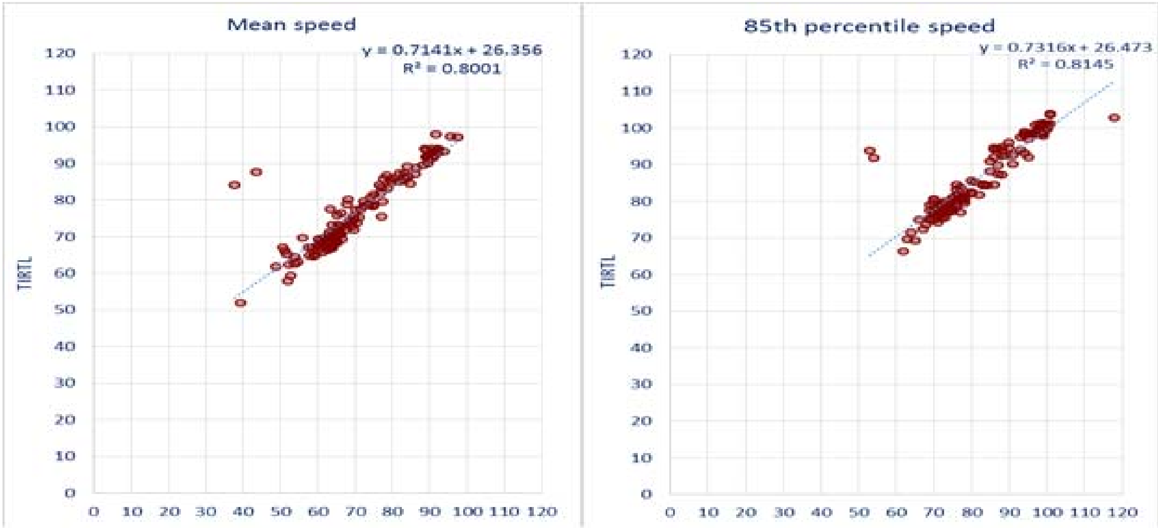
Point-speeds from loop data stations were just one of the data sets currently used in strategic speed monitoring and management in Victoria. TIRTL technology developed in Australia has been used more frequently in recent years to provide very precise point measurements for traffic counting and classification, and for speed measurements (CEOS, 2017).

The analysis was limited to two locations, inbound and outbound at the same Monash Freeway chainage, to better understand if FCD data can relate sudden changes in speeds as well as a trusted conventional source.

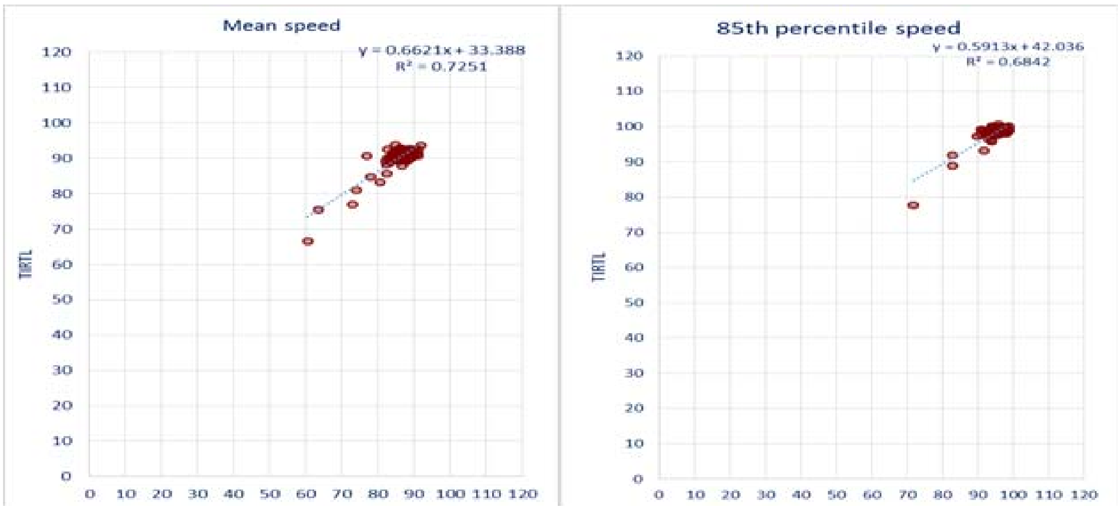
All-traffic data was used in the analysis. Disaggregation of free-flow speeds was possible but difficult without access to proprietary TIRTL software. FCD data was extracted for links matching the two TIRTL locations. In this case both TIRTL and FCD speeds were extracted for the same April to June 2016 period. Given very high traffic flows on Monash Freeway, there were no data quality issues with either TIRTL or FCD speeds.

Figure 4 shows the results of the comparison for the AM peak analysis for inbound traffic (a) and outbound traffic (b). Given better access to the point-speed data, analysis was possible for mean and 85th percentile speeds. Other speed percentiles were also compared. Figure 4 shows the effects of peak flow: the inbound speeds (a) presented a range of speeds expected before, during and after the congested period. The outbound speeds (b) presented largely uncongested flow clustered close to the 100 km/h speed limit.

In this analysis, Chi-square tests were carried out showing that the two speed distributions were statistically different, both for mean and 85th percentile speeds (also confirmed by KS and ANOVA tests). The regression analysis showed consistent relationships between point-speed and FCD speeds (see Figure 4). It was noted that the regressed relationship for mean speeds in Figure 4 a) was close to that found from the loop data in Figure 2. This only applied to inbound flow where a broad range of speeds was available. FCD speeds were consistently lower than point-speeds.




a) Inbound




b) Outbound

***Figure 4. Comparison of hourly mean speeds by day of the week for the two locations***

## USE-CASES OF FCD SPEEDS

Availability of FCD speeds across the road network suggests many new uses for policy makers and practitioners. Figure 1 showed basic mean speed mapping functionality. The following figures demonstrate some of other use-cases developed during the study.

Figure 5 shows the effect of reducing the speed limit in Bell St in the Melbourne suburb of Coburg, from 70 km/h to 60 km/h in early June 2015, to improve safety performance. FCD speeds were sampled for a midblock link between March and December 2015. Figure 5 shows mean and 85th percentile FCD speeds applicable between 10am and 2 pm, i.e. off-peak when speeds could be assumed to be free-flowing.

Figure 5 shows the immediate effect of speed limit reduction on the 8 June, with a slight down-trend until September. Discounting this transitional period, the mean and 85th percentile speed before/after changes were in the range expected from a short follow-up study, even if the absolute values may require calibration (e.g. the relationship from Figure 2). Mean speed change can be used in Elvik (2009) to estimate the expected crash reduction due to speed limit reduction. Lack of speed change would prompt additional action (e.g. enforcement, and/or traffic calming measures)

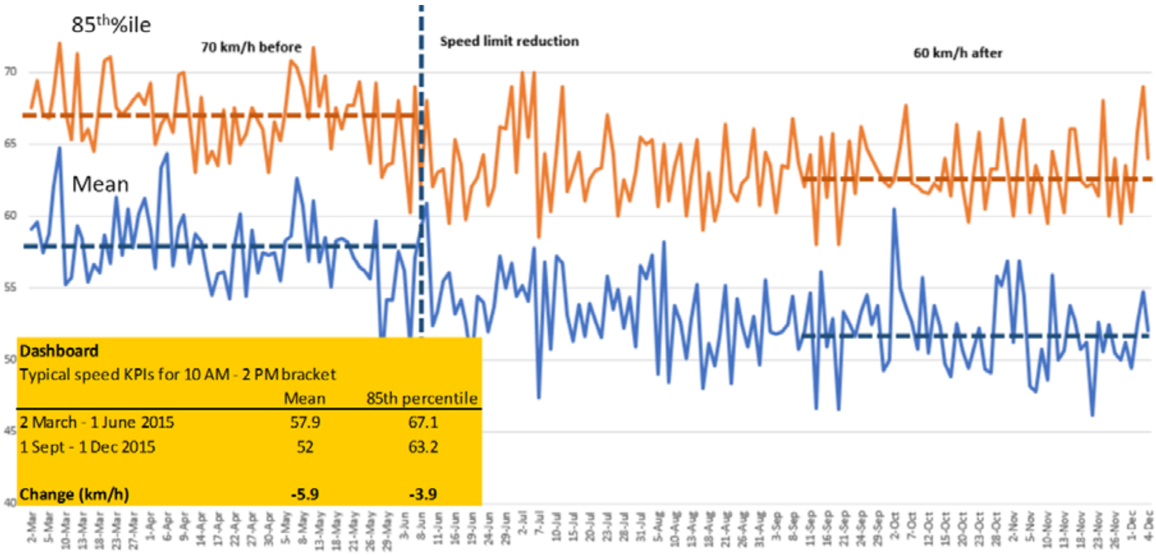



*Figure 5. Bell St speed limit reduction, June 2015*

The critical new development was that collection of before and after tube count data would have required road agency resources, if done at all. Placement of counters at this busy location would result in traffic management costs and delays. FCD speeds offer an opportunity for easy retrospective access to speed data, and thus enable monitoring and evaluation of speed management (strategic objective three).

Another use case involves observation of different types of speed time-trends for a rural location, something which could be used to inform speed limit enforcement programs along with other data (traffic volumes, crash history). An FCD link was selected for Midland Highway in Bonie Doon area, Victoria. Figure 6 shows hourly mean and 85th percentile speed plots for a period between 1 July 2016 and 23 March 2017. A clear trend was exhibited: speeds increased above the 100 km/h speed limit during the night, between 10 pm and 6 am. This is the time when majority of motorists may feel that the risk of police enforcement is at its lowest. Even without accurate calibration, the relative FCD speed data suggest that increased night-time enforcement would reduce risk of speeding-related crashes.


*Figure 6. Mean and 85th percentile hourly speeds for the Bonie Doon link*

There were many other proposed use-cases to be explored with FCD data. Some examples included:

- Area-based detection of traffic speed changes in response to traffic calming.
- Short-term evaluation of treatments, where speed change is a proxy measure of safety.

- Input into enforcement planning through identification of temporal speeding hot-spots, and road segments with high crash / severe injury risk due to speeding.
- Inputs into network-wide safety performance modelling and planning of investment programs (e.g. ANRAM).

These and other use-cases can be accommodated in a spatial analysis system for FCD speeds. Further ARRB investigations were exploring development of an online business analytics software for lean delivery of such a system. This approach would provide agility for data updates and system functionality evolving with the needs of its users.

# OTHER FINDINGS AND DISCUSSION

The following observations about FCD were made from the preliminary validation:

- FCD speeds can be retrospectively extracted for any defined road link on the road network.
- Roads with high traffic volumes generate sufficient FCD data samples more quickly – shorter data extraction periods can be accommodated (e.g. one month).
- Lower-volume roads generally require longer data extraction periods.
- Obtaining speeds for short time periods (e.g. hourly) requires longer data extraction periods (weeks, months). Longer time periods (e.g. peak period, off-peak, 24h) would require shorter extraction periods.
- Knowledge of ‘probe’ vehicle sample size is the best way to assure quality of the extracted data. Minimal sample size required for analysis varies with standard deviation. For relatively free-flowing traffic (std. dev < 5 km/h), a sample of 100 probes will produce speed KPIs accurate to 1 km/h. For more varied flows, or longer time periods, larger samples will be needed to provide same accuracy (around 700 vehicles for std. dev. of 13 km/h). Sample size and standard deviation are included in the data outputs provided by some of the FCD providers.
- FCD is becoming more plentiful as navigation services and connected vehicles proliferate via IoT phenomenon (Internet of Things). Analysis of 2017 FCD speed data showed significant improvement in quantity and quality compared to 2014.
- Pedestrian and cyclist movement or speed FCD data was some time away from realization. Data providers traditionally focused on road vehicle navigation and data services for other modes of transport remain a future priority.

This paper proposed some preliminary calibration relationships between FCD and point-speeds, based on available data (e.g. Figure 2). Such calibration may be useful as traffic practitioners may seek to sense-check FCD speeds against the expected point-speed values collected using conventional methods. Current speed-safety models (e.g. Elvik 2009) rely on mean point-speeds, so conversion of FCD speeds may be necessary.

Calibration models should be developed using many locations across different road stereotypes. One possible solution would be multivariate models for mean or 85th percentile point-speeds considering input variables such as relevant FCD speeds, rural/urban environment, speed limit and road geometry.

Error sources and structure of FCD require further investigation to better understand how precise FCD speeds data can be (e.g. temporal, fleet biases, sample size effects). This can be investigated through specific use cases to inform how well they support the three strategic objectives (i.e. set clear limitations of the current FCD).

This paper considered all-traffic speeds. Many traffic and design practitioners prefer using free-flowing speeds (headways greater than 4 sec), as they are intended to indicate driver response to speed limit and road geometry, rather than to presence of other road users.

Views on this are evolving. Some propose that such free-flow conditions are rare for most of the travel undertaken on Australian roads. Consequently, these are not the traffic conditions under which majority of crashes and injuries occur. In this context, deeper understanding of speeds may be needed under different operational conditions. Mobility practitioners embrace this concept in their studies of operational network efficiency and congestion.

FCD speeds may be used to develop a new generation of speed-safety models to replace the Elvik (2009) Power Model. Some of the possibilities include intersection-specific models where approach speeds could be statistically related to crash outcomes. Also, specific relationships could be developed for pedestrian and cyclist safety outcomes given prevailing speeds. Temporal speed-safety models can be developed leading to better appreciation of the safety effects of congestion and speeding. Most importantly, use of FCD speeds would assist in proactive approach to road safety planning and Safe System implementation.

# CONCLUSIONS

The study provided a significant leap in the understanding of FCD speeds and their application to road safety. FCD speeds provided by HERE were validated against samples of conventional point-speeds (loops, TIRTL) showing FCD speeds to be systematically lower. It was suggested that FCD speeds could be calibrated to estimate mean point-speeds, e.g. for use in Elvik's Power Model.

Use-cases in the paper showed that all three strategic safety objectives for network-wide speed monitoring, and for informing and evaluating speed management programs could be met using FCD. Many speed distribution indicators can be derived from FCD speeds, e.g. mean and 85$^{th}$ percentile speeds, standard deviation.

Further work is needed to understand functional data limitations in specific use cases, and to develop new practices, e.g. FCD speeds calibration, sampling technique guidance, and new speed-safety performance models.

# ACKNOWLEDGEMENTS

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http://acrs.org.au/files/papers/arsc/2017/Jurewicz_00078_EA.pdf

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