Cyclist conflict at intersections

Development and application of a hybrid analysis method

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Executive summary

A key component of the government's investment in cycling is ensuring that cycling safety can be improved and not worsened by increased participation. Accordingly, the 2014 Cycling Safety Panel report[1] highlighted urban intersections as a high-risk area for cyclists and among its recommendations sought to ensure that intersections are designed so that they are safe for cyclists. Key to addressing both the risk to cyclists and improving the intersection experience for all users is the development of an understanding of cycle and vehicle interactions and the factors associated with poor actual and perceived safety, crash risk, and discomfort at intersections.

Previous studies have used manual methods to understand road user interactions, and others are developing automated machine vision methods. In 2016, the AA Research Foundation, in partnership with the Transport Agency, embarked on feasibility research to develop a method that enables the understanding of conflict and behaviours that are likely to be associated with poor actual and perceived safety for cyclists at intersections. This study follows that feasibility research by testing a hybrid method at three urban intersections. The hybrid approach combined the automation of computer vision technology with the richness that can only be delivered by a human analyst.

This study has shown that through a hybrid approach, there can be a more nuanced way of understanding cyclist risk and discomfort at intersections. The findings from the four main components to this research are outlined below, and recommendations are given at the end of this report.

1. **Trialled a novel hybrid method:** The study provided new knowledge about the development and application of a novel hybrid method of conflict evaluation at intersections. It combined computer vision technology with a behavioural evaluation framework. It delivered practical guidance around the ingredients that would be needed to run a successful conflict evaluation program, including footage requirements, cost-effective analysis, and considerations for improving the feasibility of the automated component. Finally, the study demonstrated the complexity of intersections and the need to better understand how road users interact at them.
2. **Captured cyclist-motorist event interaction data:** Cyclist-motorist interaction data were collected and analysed from three major intersections. The research confirmed an ability to quantify relative conflict rates at intersections (to complement crash history analysis).
3. **Identified conflict patterns:** The study identified cyclist-motorist interaction patterns, many of which had not previously been identified, and may be generalisable to a wider set of intersections. In collaboration with local road authorities, these data may be used to inform future evidence-based design and education-based solutions
4. **Provided snapshots of intersection performance:** The baseline data from this study could be used to inform interventions at the specific intersections examined. The approach highlighted the ability of this method to reveal emerging design implications. Follow-up monitoring could then provide case studies of the success of improvements using the hybrid conflict evaluation method.

[1] Cycling Safety Panel (2014). Safer Journeys for People Who Cycle. Cycling Safety Panel Final Report and Recommendations.

Contents

1. Introduction

1.1. Background

A key component of the government's investment in cycling is ensuring that cycling safety can be improved and not worsened by increased participation. Crashes in urban settings account for the highest proportion (90%) of police-reported cyclist deaths and serious injuries. In particular, intersections have been identified as key areas where cyclist safety is compromised. Indeed, in 2016, 40% of the police-reported cycle crashes consisted of movement codes typical of intersection crashes[2]. Accordingly, the Cycling Safety Panel, among its recommendations, seek to ensure that intersections are designed so that they are safe for cyclists. Key to this safer design is understanding the factors that are associated with cyclist casualties and discomfort at intersections.

The AA Research Foundation, in partnership with the Transport Agency, embarked on feasibility research to develop a method that enables the understanding of near misses and other behaviours that are likely to be associated with poor actual and perceived safety for cyclists at intersections. The comfort of all road users is also important and so a method to better understand cyclist/ vehicle interactions needs to consider both motorist and cyclist potential for injury as well as comfort.

This report presents the findings of the development and application of a hybrid method for assessing cyclist near misses and behaviours that are likely to indicate motorist and cyclist risk or discomfort, with a focus on commuter cycling at urban intersections.

1.2. Purpose

This research has four main aims:

1. **Trial a novel hybrid method:** The primary purpose of this work is to provide new knowledge about the development and application of a hybrid method of conflict evaluation at intersections that combines computer vision technology with a behavioural evaluation framework.
2. **Capture cyclist-motorist event interaction data:** The study collected unique cyclist-motorist interaction data at three major intersections. In collaboration with local road authorities, these data could be used to inform evidence-based improvements.
3. **Identify conflict patterns:** The intersection data revealed cyclist-motorist interaction patterns. These may be generalisable to a wider set of intersections and used to inform future design and education-based solutions.
4. **Provide snapshots of intersection performance:** The baseline data from this study could be used to inform interventions at the specific intersections examined. Follow up monitoring could then provide case studies of the success of improvements using the hybrid conflict evaluation method.

[2] Ministry of Transport (2017). Cyclist crash facts. Wellington, New Zealand, Ministry of Transport.

1.3. Why are road user interaction analyses important?

Current practise for understanding road safety issues at urban intersections usually involves some sort of analysis of crash data and/or a site visit by a safety engineer to assess the environment and how road users are behaving. While crashes ultimately define the problem, it is very difficult to understand the contextual factors surrounding crashes. Conversely, observing behaviour on site provides a rich understanding of road user behaviours for the period a safety engineer is willing to observe, but that period is rarely long enough to observe the full range of behaviours that would explain risky situations for cyclists at intersections. Hence, video-based methods to efficiently capture and process road user behaviour over many hours or days, is likely to be useful in filling a gap in understanding cyclist/motorist interactions at intersections. This is important because the relatively few number of crashes that occur do not tell the full story of the risk and discomfort people experience while cycling through many intersections.

1.4. Literature Summary

In an earlier stage of this project[3], academic and other literature describing methods for analysing safety aspects of road user interactions (i.e. traffic conflicts, near misses) were reviewed, with a particular focus on studies involving intersections. Interactions of interest included motorist-bicycle, and motorist-pedestrian conflicts. Within the studies reviewed, three main methodological approaches were identified.

Manual methods: Where human observers code video footage manually, or directly observe and code their observations in the absence of video footage.

Automated computer vision methods: Where video footage is automatically processed by software designed to identify cyclists and conflict events using positional, spatial, and temporal data parameters.

Hybrid methods: Where a combination of automated and manual methods (or semi-automated methods) are used.

A summary of existing methods, including the data collection protocol, analysis, and key lessons is provided in Figure 1. A full list of references from that literature review is provided at the end of this report.

Of the studies outlined in Figure 1 which followed a hybrid approach, most used manual coding combined with automated coding as a validation tool, rather than a method to provide richer data. However, one study[4] highlighted the benefit of using the automated system to identify and prioritise important events, with the purpose of relaying these events to a human coder who could provide richer contextual analysis of the events. This perspective formed the backbone of the hybrid approach described in this report.

[3] Mackie, H., Thomas, J., Hirsch, L. and A. Davison (2016). A method for understanding conflicts between cyclists and other road users at urban intersections. Auckland, New Zealand, Mackie Research and Opus for AA Research Foundation

[4] Ismail, K., Sayed, T., Saunier, N., Lim, C. (2009) Automated Analysis of Pedestrian-Vehicle Conflicts Using Video Data. Journal of the Transportation Research Board, No. 2140, 44-54

Figure 1: Summary of the literature

Manual approaches

Data collection methods

- High-quality camera, high mounting
- Camera on tripod by the road
- Helmet-mounted camera
- Two observers at each site
- Cyclists provide 'think aloud' recording whilst followed by a researcher on a bicycle

Data coding methods

- Zones created on screen to record movement
- Analysis - user type, crossing behaviour
- Coding protocol - record and describe 'events'
- Two analysts conduct an interrater confirmation on a sample of footage
- Repeated viewing of the video footage to better understand the conflict

Data collection barriers

- Permissions to use building/ pole, source of power for camera
- Manual observations - cannot review event
- Helmet-mounted – cyclist point-of-view only
- Lighting, limited video angle, occlusion

Data coding barriers

- On-site observers is costly
- Reviewing the 'think aloud' protocol is labour intensive and costly
- Labour-intensive and costly to identify all cyclists, identify events, and code events
- Coder may miss change in speed events
- No quantitative understanding of behaviour

Automated approaches

Data collection methods

- High-quality camera, high mounting
- Multiple, synchronised cameras
- Observation period can be long because the resource cost of footage analysis is low

Data coding methods

- Automatic detection of; traffic conflicts and ranking of severity (using TTC and PET), different vehicle types, vehicle road rule violations

Data collection barriers

- Permissions to use building/pole, source of power for camera
- Multiple cameras is costly and syncing difficult
- Lighting, limited video angle, occlusion

Data coding barriers

- False detection rates are high
- Some conflicts missed through automation
- PET limited in capturing conflict severity
- TTC less reliable than PET at detecting events
- No qualitative understanding of movement

Hybrid approaches

Data collection methods

- High-quality camera, high mounting
- Observation period can be longer than for manual only

Data coding methods

- Automated can identify and shortlist important events. Once identified, the events can be analysed in-depth by a human coder
- A grid-based overlay as a semi-automated approach - to help with difficult metrics related to manual coding

Data collection barriers

- Permissions to use building/pole, source of power for camera
- Lighting, limited video angle, occlusion

Data coding notes

- System failures ingrained in manual and automated methods cancel each other out in hybrid methods (Where manual misses things, automated will identify/ vice versa)
- Manual coding is resource-intensive - reduced when automated identifies cyclists and events

2. Hybrid approach overview

Based on the findings from the literature, for this study a hybrid methodology was adopted. By using a hybrid approach the study aims to maximise the benefits of the both the manual and automated approaches, while minimising their limiting factors. The hybrid approach is also novel, in that there are very few conflict studies that combine the disciplines of human factors, civil engineering, and information technology. Therefore, this work also fills a large research gap.

Automated systems are cost efficient if capturing a lot of data or carrying out longitudinal studies. They have up to an 85% correct conflict detection rate and allow easier monitoring of speed and distance metrics. Automated systems are able to track road-user / pedestrian movement paths and show 'hot spots' for conflict, which together can help identify the interaction factors, such as high frequency locations for risky manoeuvres, that contribute to repeated patterns of conflict and particularly high-risk scenarios. Automated data processing further allows for the comparison of relative risk at an intersection over time or between different types of intersections, to not only identify design solutions that are effective in minimizing conflict situations, but also to evaluate the impact of any changes to the design / interventions installed in terms of their success in reducing levels and severity of conflict.

Manual methods are necessary for interpreting the movement patterns, the severity, and the context of the behaviour leading up to an event. They allow subtle measurement of behaviours to determine variation in severity assessments. Thus, manual evaluation by a human observer overcomes the typical interpretation errors made by automated systems.

There are ingrained limitations present in both manual and automated approaches, associated with the identification and interpretation of events. For example, automated systems make more accurate judgements about speed change than a manual coder can. However, in automated analyses, false detection and severity rates are often high. The literature, along with our previous experience, suggests that following a hybrid data analysis approach provides the advantage of a complementary approach where the shortcomings of the automatic method are overcome by the manual method and vice versa[5].

Using a hybrid methodology, an automated approach can be used to detect, shortlist, and prioritise critical events and interactions based on a set of pre-defined temporal and spatial parameters, or set of criteria. Following this, the human observer can manually review the target footage, examine the wider context and the associated contributing factors, before, during, and after the event. The complementary manual approach completes the contextual picture by fully coding the complexities and subtleties of road user behaviours, and as such is needed for at least some more subtle and complex aspects of the analysis.

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[5] Ismail, K., T. Sayed, N. Saunier and C. Lim (2009). "Automated analysis of pedestrian-vehicle conflicts using video data." Transportation Research Record: Journal of the Transportation Research Board **2140**: 44-54.
Laureshyn, A., H. Ardo, A. Svensson and T. Jonsson (2009). "Application of automated video analysis for behavioural studies: concept and experience." IET Intelligent Transport Systems **3**(3): 345-357.

3. Detailed Methodology

3.1. Overview of 4-Phase approach

An overview of the 4-phase approach that was followed for this study is outlined in Figure 2. The following sections describe each phase of the method in more detail.

	Phase 1	Phase 2	Phase 3	Phase 4
Hybrid	**Intersection selection and video camera placement**	**Independent manual sampling** Conducted prior to the automated coding An examination of 100 cyclists, or until event/possible event saturation is reached. Footage from peak, off-peak, and weekends. All cyclists coded with a time stamp and zone movement. 'Avoidance', 'close encounters', or unusual 'high risk' manoeuvres coded in more detail.	**Automated cyclist and event identification** Apply computer vision software processing to automatically identify cyclists and cyclist-vehicle interactions.	**Contextual assessment - Manually confirm computer event identification** Manually code all <3 TTC and PET events detected by computer vision to: • Provide more detail of the event (weather, lighting, helmet, lights, signalling, interaction description); • To test the accuracy of the computer vision's ability to detect events.
Why?		Gives a cycle detection accuracy rate between manual and automated. Determines the location and pattern of events that cannot be identified through the automated approach.	Shortcut the manual process. A good indicator of movements that aren't easily observable manually (i.e. TTC in parallel movements).	Provides detail about the automated events that are difficult to describe through computer vision, whilst capturing events that are difficult to identify manually.

Figure 2: Overview of 4-phase approach

3.2. Phase 1: Site selection and data collection

Initially, a convenience approach to selecting intersections of interest was utilised to test and refine a video analysis method. Consultation with local road controlling authority (RCA) staff was used to determine sites of mutual interest. The inclusion criteria for potential intersection sites are listed below and this process is illustrated in Figure 3:

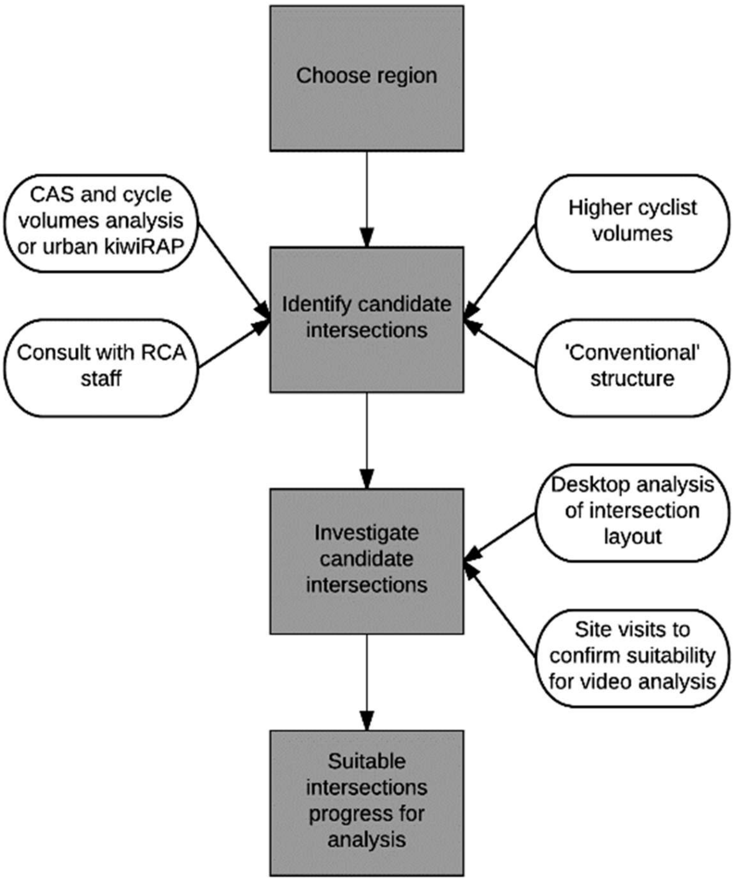

Figure 3: Site selection process diagram

- Are relatively 'conventional' and therefore will allow the method to be scaled up around the country to similar intersections if successful;
- Have higher volumes of cyclists, so that sufficient data can be collected from them;
- Are known hotspots for cyclist conflicts and/or crashes;
- Include cyclist movements that are typically problematic;
- Have obvious locations where video cameras could feasibly be located, or have existing video cameras which provide a useful field of view; and
- Do not include roundabouts.

3.2.1. Camera angle

In terms of perspective, the automatic detection computer software works best from an aerial or birds-eye view. This higher aerial view enables a large part of the intersection to be viewed by a single camera, meaning a high number of interactions can be accurately captured and partial obscuration of objects would be minimised (e.g. where a car may partially block the cyclist so that the software does not detect it). In an urban setting therefore, camera placement is most effective from a building or light pole.

As this was a hybrid approach, considerations for manual coding also had to be taken into account. For manual coding, the higher the camera is located, the less detailed view of the intersection the researcher has for behavioural coding. Therefore, a trade-off had to be made which considered the requirements of the computer vision (height) and the requirements of the manual coder (a detailed view). At each site, a camera was positioned between 6m and 10m in height overlooking the intersection. It ensured that the field-of-view and angle was sufficient for the computer vision, but also provided enough detail for manual observation. Please note that due to the angle of the camera, obscuration of cyclists sometimes occurred such as when a larger vehicle (i.e. bus) moved between them and the camera's view.

3.2.2. Site details

Three intersections (two in Auckland and one in Wellington) were selected for data collection. The Wellington intersection was used initially as a trial site for the pilot study and was subsequently used again in the main study for comparative purposes relating to the impact of video-camera recording quality on the automatic conflict detection rate. The application of the hybrid method to three different intersections helped to establish a data analysis framework that may be effectively applied to multiple intersections in the future. A brief overview of each site is presented below.

Pilot Site / Study Site 1: Wellington CBD

The intersection between Adelaide Road and Riddiford Street in Newtown, Wellington (Figure 4), is a complex cross-intersection that was used as both the pilot site as well as for 'Site 1' for the main study.

For the pilot study, footage from an existing CCTV camera mounted on a pole overlooking the intersection was used, and the conflict detection rate subsequently compared with that achieved from the data capture footage of a higher-quality camera that was installed in the same location for the main trial.

This site was selected because it has a high level of cyclist and motorist traffic. It is a multi-lane urban cross-intersection and the incidence and geolocation of crashes indicate some space, lane position and priority issues between cyclists and motorists.

The main benefits of repeating the evaluation of this pilot site during the main study were:

- To provide a richer data set for this intersection;
- To re-test the validity of the hybrid evaluation approach; and
- To explore any implications for our hybrid methodology of using lower quality (but more readily available and pre-existing) footage commonly captured at key intersections across the network by CCTV cameras, compared with higher quality camera footage in terms of conflict detection rates.

Figure 4: Site 1 intersection between Riddiford St and Adelaide Road

Site 2: Tamaki/ Watene (Auckland)

The intersection at Tamaki Drive and Watene Crescent in Auckland (Figure 5) is a common un-signalised T-intersection, with a T2 Transit lane. This site was selected for its generalisability, high cyclist numbers, and history of cyclist crashes. Bespoke, higher quality camera footage was recorded at this site. The camera was placed on a pole attached to a light pole with an elevation of approximately 6 meters.

Figure 5: Site 2 intersection between Tamaki Drive and Watene Crescent

Site 3: ANZAC/ Short (Auckland)

The intersection between ANZAC Avenue and Short Street in Auckland (Figure 6) is a T-intersection with a bus lane in each direction. It was selected because of its higher level of individual risk for cyclists, with lower cyclist numbers through the intersection but a history of cyclist crashes. The intersection also presented the opportunity to examine an expectancy effect - whereby motorists do not necessarily expect to encounter cyclists and consequently their driving behaviour reflects this. Finally, there was also the potential to directly inform the design of improvements at this intersection based on the evaluation findings, since the local RCA (Auckland Transport) are already considering a traffic light option to mitigate the high crash rate at this intersection. Bespoke, high quality video footage was recorded at this site. A camera was attached to a pole at a height of approximately 6 meters.

Figure 6: T-intersection between ANZAC Avenue and Short Street

3.2.3. Data Collection

For the pilot study at the Wellington site, data were collected using an existing CCTV camera installed overlooking the intersection. For the main Wellington study, data were collected using a higher-quality video camera (30 frames per second) attached just above the existing CCTV camera, at as close to the exact angle and direction of the CCTV camera as possible, in order to record the same view of the intersection for comparative purposes.

Figure 7: Camera set-up

At the Auckland sites, a high-quality camera (30 frames per second) was positioned on a light pole at 6 meters height overlooking the intersection (Figure 7). The camera was attached to a support which was secured to the light pole, thereby achieving height, and removing the need for ladders, subsequently reducing the risk to the installer.

At all of the study sites the cameras were located such that they were not obscured by high passing vehicles and could not easily be interfered with. In addition, measures were taken to secure the camera effectively to the pole to prevent lost footage due to windy conditions. However, at the two Auckland sites, up to half of the data were unusable by the computer vision due to the camera's lack of stability, due to wind movement. All non-CCTV cameras in this study were equipped with a timing device and appropriate storage capacity to enable data capture over the collection period. Video footage was captured over a period of 4-6 dry week days, during morning and afternoon peak periods (7:30-9:30am and 3:30-6:30pm), with some off-peak hours also being collected. The aim was to capture the times that cyclists most frequently use the intersections, but, during off-peak to also understand if irregular cyclist appearances could result in higher personal risk (i.e. motorist may not expect to see a cyclist). At site 2, data were also collected over the weekend due to this site's popularity for training cyclists. Earlier and later times of day were avoided in view of the camera's poor sensitivity in low light conditions. Wet weather and night conditions were not a priority for this initial study.

This study was designed to test a single camera approach. Multiple simultaneous cameras can be used, especially where the behaviour surrounding the intersection is of particular interest. Different camera angles and quality of footage were examined at the more complex Riddiford /Adelaide intersection. The computer vision software runs off standard video footage, and then is calibrated using real-world features to ensure the distance measurements are accurate.

For lessons learned regarding the set-up of the camera, please refer to Appendix E.

3.3. Phase 2: Independent manual sampling

Independent manual sampling of randomly selected footage was conducted prior to the commencement of automated coding. This was done for two reasons: 1) to give a cycle detection accuracy rate and an event detection accuracy rate between the manual and automated approaches; 2) to determine the location and pattern of events that cannot be identified through the automated approach (i.e. red light running, unusual, 'high risk' cyclist manoeuvres).

In the pilot study, 1000 cyclists were sampled, and in the main study only 100 cyclists were sampled. It was determined that for the pilot stage it was important to sample a higher number of cyclists to ensure sound data matching for the rest of the study. The degree of success that would be achieved in the integration between the computer vision and manual identification of cyclists and events was not yet understood and therefore a larger sample was tested.

3.4. Phase 3: Automated Data Processing Framework

A refined methodology based on the pilot was applied to evaluate the main study intersections, where:

- The site video footage was calibrated and processed through computer vision software, audited and an output file produced with relevant row-based data.
- This output file was translated into a compatible format (Microsoft Excel) to allow summary data based on a row event for each cyclist detected. This format also allowed easy matching to the manual coding and behavioural data.
- The output file included data information including:
    - Object detection and vehicle classification (for every cyclist);
    - Time to collision data;
    - Object speed;
    - Distance between cyclist and motorist;
    - Location of event;
    - Movement direction; and
    - Expert insights/review regarding interpretation of the integrated findings.

Data from the pilot and three study sites were analysed, as well as between the pilot site and site 1 in terms of conflict detection rates achieved from video footage.

Common and novel factors and conflict patterns relating to cyclist-motorist interactions were examined with consideration to where commonalities exist that can be generally applied to intersections across the network. For more detail see Appendix D.

3.4.1. Automatic cyclist identification

For automatic cyclist identification, the computer vision software detects a cyclist and makes an entry in a database, noting the event time, cyclist movement direction, cyclist movement speed (averaged across the video).

3.4.2. Automatic categorisation of interactions and conflict events

Following the process of identifying cyclists, instances where some sort of 'conflict' exists then need to be determined. Various levels of conflict are explained further in Phase 4, but a system needs to capture lower-level conflicts (avoidance or negotiated behaviour) as well as more serious conflicts or near misses. Lower level avoidance behaviour is important to capture as it helps to understand not only safety risk but also occasions where cyclists (and motorists) may feel discomfort.

As part of the automated approach measurement parameters of Time to Collision (TTC) and Post Encroachment Time (PET) were calculated to identify events of interest. In order to achieve this the 'computer vision' system automatically identifies and tracks users in the field of view. PET and TTC times where intersection users travelling within 3 seconds of each other were recorded as events of interest. Typically, a PET of less than 1.5 seconds between a cyclist and another road user would be used to identify potential conflicts.

3.5. Phase 4: Manual Coding Framework

As discussed earlier, part of the aim of the hybrid approach was for a computer to identify potential conflict events on behalf of a human analyst, thereby significantly reducing the time required to sift through data.

The output from Phase 3 was used by the manual coder in two ways:

1. To search for all interactions, or 'events' where either the TTC or PET was less than 3 seconds. The literature review identified that using a combined TTC/PET approach in event identification may be beneficial because PET can be limited in capturing conflict severity and TTC can be less reliable than PET at detecting events[6]

2. Using the time and date stamp provided by the automated method, the manual coder was able to efficiently locate the <3 second TTC/PET event in the raw video footage. Once the event was located, the manual coder was able to code the characteristics of the computer-identified interactions and details of conflict scenarios.

Initially, two independent analysts coded cyclist behaviour. Once an acceptable level of agreement has been established between them, one analyst continued to code the main dataset.

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[6] Ismail, K., Sayed, T., Saunier, N., Lim, C. (2009) Automated Analysis of Pedestrian-Vehicle Conflicts Using Video Data. Journal of the Transportation Research Board, No. 2140, 44-54

A modified version of the 'Future Streets' coding framework[7], which in turn was developed from an earlier 'Self explaining roads' analysis[8] was utilised for Phase 4. Significant effort had already gone into developing this tool, including determining an acceptable inter-rater reliability. Modifications were made based on discussion between Mackie Research and Opus, to ensure that the resulting coding framework met the specific purpose of analysing cycle intersection conflict. A summary of the manual coding framework is presented in Figure 8.

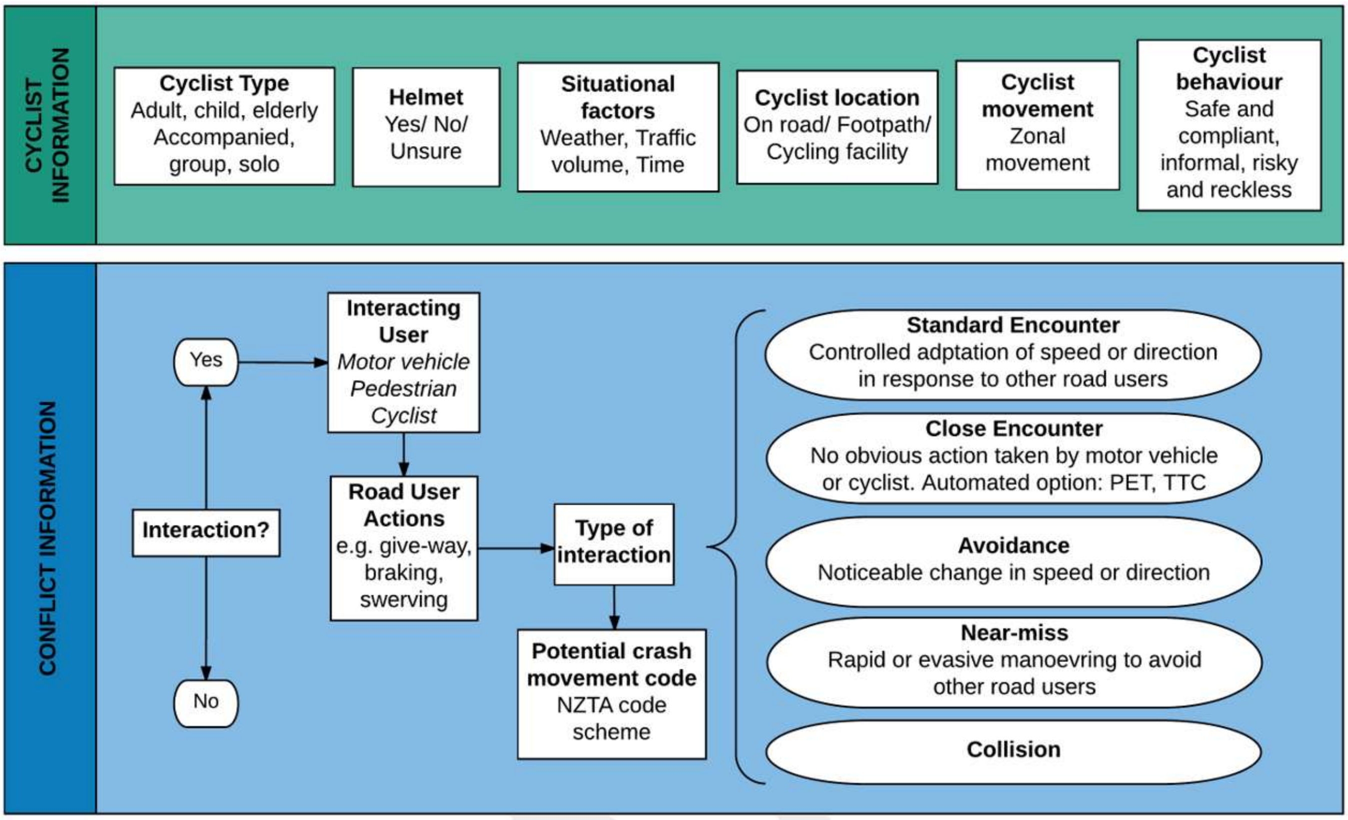

Figure 8: Manual coding framework

A more detailed description of the NZTA movement codes can be found in Appendix B, and a more detailed description of the coding options for each item can be found in Appendix C.

The manual coding as described in Figure 8 above was designed to provide extra depth to each event that is currently beyond the ability of computer vision. These include:

- **Comparing event movement codes**: For each event, the human coder ascribed a NZTA movement code. This allowed us to understand patterns of movement that results in conflict within, and between sites. As yet, computer vision can only ascribe limited conflict codes to events (e.g. head-on, rear end), so currently the manual aspect is able to provide more detail. This may be an area that computer vision can improve on in the future.

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7 Kjærulff, K., Mackie, H., Hawley, G. (2016). "Future Streets - Coding protocol". Unpublished. Mackie Research
8 Mackie, H. W., S. G. Charlton, P. H. Baas and P. C. Villasenor (2013). "Road user behaviour changes following a self-explaining roads intervention." Accident Analysis & Prevention 50: 742-750.
Mackie, H. W., L. Hirsch, N. Wilson and R. A. Scott (2017). Pedestrian behaviour and movement analysis: Ōtāhuhu Town Centre. Auckland, New Zealand, Mackie Research for Auckland Transport.

- **Comparing event movement codes and crash history:** The crash history of each intersection was analysed for the movement code and events leading to the crash. We were able to identify an approximate location within the intersection for each crash and subsequently compare these with the locations of the events in the study. This gave us an understanding of levels of risk within the intersection in comparison with locations of regular discomfort.

- **Design solutions:** Another benefit of pairing computer vision with manual coding was the ability of a manual coder to interpret events regarding the wider built environment context. Thus, the manual coder could interpret areas with conflict patterns and identify design solutions accordingly.

The manual coding undertaken provided sufficient information to understand the nature of the interaction so that patterns of conflict can be identified and solutions can be designed and effectively evaluated. It should be noted that in Phase 4 the analyst was only coding what has been detected by the earlier computer vision phase, meaning some interactions of interest (including those identified manually in Phase 2), will not be analysed in any systematic way in this final Phase.

4. Data Analysis: Pilot Study

The pilot study was completed on a complex cross-intersection in Wellington CBD between Adelaide Road and Riddiford Street in Newtown. The site was selected because it has a high level of cyclist and motorist traffic, it is a multi-lane urban cross-intersection and the incidence and geolocation of crashes indicate some space, lane position and priority issues between cyclists and motorists. Data capture footage from an existing CCTV camera mounted on a pole overlooking the intersection was used for the data analysis.

4.1. Overview of conflict behaviours

Over the course of the data capture period 1000 cyclists were observed, with an automatic detection rate of 78.5% of cyclists. The cyclists were primarily riding in heavy traffic conditions (70% of the time), and mostly demonstrating compliant behaviours.

Through application of the measurement parameters outlined above, over a third of cyclists (36%) were identified as involved in some kind of potential conflict situation, 12.5% of these were classified as Potential Important events, and 3.3% classified as Potential Very Close events.

There were 16 Close Encounters and 9 Avoidance Actions in total, of which 12 of the former and 6 of the latter were likely to have been related to higher exposure in busy traffic. The Close Encounters and 1 of the Avoidant Actions were due in part to cyclists running red lights.

4.2. Conflict hot-spot locations

The computer vision identified a total of 159 TTC or PET events under 3 seconds. When reviewed by the manual coder, the majority of these events were deemed to be standard encounters, in that they were controlled and acceptable movements. There was a total of 87 TTC or PET events identified by the computer vision as being under 1.5 seconds. As per the <3 seconds events, many of these were categorised as 'standard encounter' but the manual coder. A total of 25 events were manually recorded. This included 16 close encounters and 9 avoidances.

Conflict locations were identified by both the manual coder and by the computer vision. The distribution of events is shown in Figure 9. Similar locational patterns are seen across both forms of coding, with the primary hot-spot being in the centre of the intersection. Of note is that at this intersection the event hot spots are not consistent with the crash history (even when looking at crashes over a 10-year period).

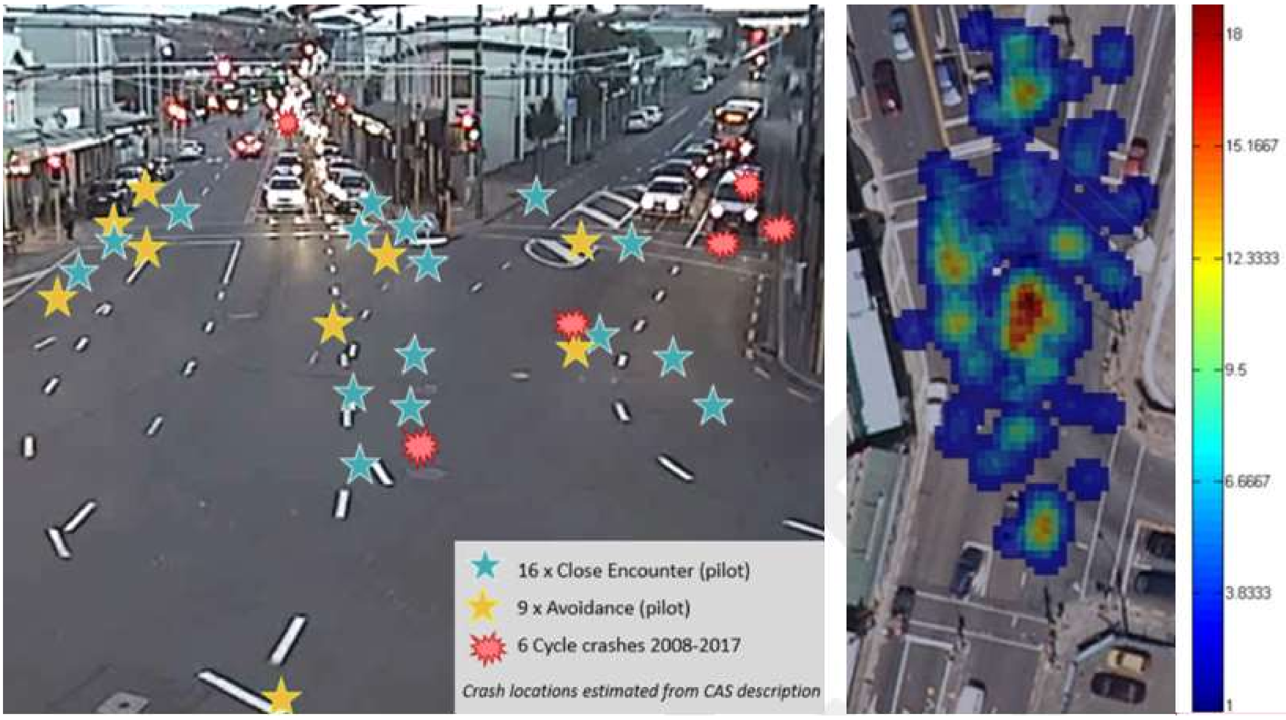


Figure 9: Manually identified interaction events and crash history (left) and computer vision hot-spots (right; showing events/m², for TTC/PET < 3s)

4.3. Interaction movement types

The results from the pilot study indicate that a perfect match between crash locations, crash movement codes, and event locations and movement codes does not necessarily exist. However, it is important to understand the movement codes behind events as they give us a richer picture of the situational context that may lead to rider or driver discomfort and reduced perceived and actual safety.

Of the 25 events manually recorded at this site, 11 movement codes were ascribed. The majority of events (10/25) were coded as FA (rear end). These events primarily occurred at the signals and were mostly associated with the speed differential of cyclists and vehicle as they moved into the intersection at the commencement of a green phase. These events were also associated with the pedestrian build-outs as depicted in Figure 10. The second largest group (5/25) were coded as AA and AG (overtaking and lane change). These events were associated with cyclists weaving past vehicles in heavy traffic, but also with vehicles moving past and cutting in front of cyclists.

Figure 10: Example of an avoidance (FA) event

In addition to the identification of events, the manual aspect of the coding in the pilot study was also designed to identify unusual cyclist movements, behaviours, or interactions with the built infrastructure that could affect their safety and comfort. Of the 1000 cyclists identified, 30 were observed to run a red light. In 25 of these cases, the red light running behaviour appeared to be controlled by the cyclist in that that timing allowed them to get ahead of traffic at the start of a green signal phase. This can have positive safety outcomes as they separate themselves from vehicles in the intersection. However, 5 of the red light running event resulted in a close encounter or avoidance behaviour and 4 of these times appeared to be due to the misjudgement of the cyclist.

In addition to red light running, there were 10 cases where it appeared that the pedestrian build-out on the far right of the intersection may have affected cyclist comfort. In two instances, the placement of the cyclist near the build-out resulted in an event, as illustrated in Figure 10 above.

4.4. Data integration with Computer Vision

There was a 44% match between automated data coding and manual data coding for Close Encounters and Avoidance Behaviours. This increased to 52% when behaviours at the centre of the video were focused on (i.e. higher quality footage). Of the events indicated by the computer vision software as more Potential Very Close Events (< 0.5s) about 23% were also subjectively rated as very close.

Manual coding may have missed some close encounters due to the low frame rate and the ability to judge closeness, for example, using distance-speed cues alone when there is no obvious avoidance behaviour being carried out.

Automated coding may have missed some non-compliant behaviours, such as red light running and footpath riding or unexpected events like the cyclist having equipment issues that result in conflict.

Rules could be put in place to automatically capture and process some of these missed events.

4.5. Behavioural insights

4.5.1. Pilot Study insights: Flow-on driver behaviours

- “Rear End” TTC Events less than 0.5s – Potential predictor of driver frustration.
- As evidenced by poor lane change decisions by immediately following motorist (2 events where following vehicle changed lanes to overtake cyclist without indicating into very narrow gaps – this is 2 of 6 rear end events).

4.5.2. Pilot Study Insights: Rider comfort indicator

- Close events (< 0.5s) were subjectively assessed from a rider comfort perspective.
- This revealed a 58% discomfort level with these events (i.e. many events do appear to be too close for comfort).
- Better data on this could establish a robust ratio or rule of thumb, such that this could be used as an indicator of comfort relating to new cyclists.

4.6. Updated Methodological Approach

Based on the findings of the pilot study and feedback from the team and steering group, an updated methodological approach was adapted for the main study sites, which included;

- Testing higher quality video footage
- Testing on a simpler intersection
- Testing different intersection types
- Testing an intersection longitudinally (to determine repeatability of findings)

5. Data Analysis: Main Study

Data from the three main study sites as well as the pilot site were analysed and their findings are reported here. Table 1 shows the footage that was collected and analysed across the three sites. The limited amount of computer vision footage that was able to be analysed was partly due to wind effects on the camera, and partly due to the relative cost of processing this footage within the context of this new research approach.

Table 1: Summary of data collected and analysed

Measure	Site 1				Site 2	Site 3
	Pilot	View 1	View 2	View 3		
Hours of footage collected	70	42	40	42	60	60
Hours of footage analysed with computer vision	14	2.5	2.5	2.5	8	12
Hours of footage manually analysed*	13.5	0.75	-	-	0.5	9

** For the full study manual analysis was done to gain a sample of 100 cyclists at each intersection*

Site 1

- Pilot CCTV low quality (fixed camera)
- View 1 - High quality (pole mounted, zoomed out)
- View 2 – CCTV low quality (fixed camera)
- View 3 – Low quality (pole mounted, zoomed out)

Site 2 High quality footage (pole mounted)

Site 3 High quality footage (pole mounted)

5.1. Intersection 1: Riddiford/ Adelaide

Intersection 1 is a repetition of the pilot study intersection, a complex cross-intersection in Wellington CBD between Adelaide Road and Riddiford Street in Newtown. The main purpose of the repetition of this intersection was to examine different camera perspectives and levels of footage quality to see how this might alter results. A secondary purpose was to examine the reliability of conflict event findings over time within the same intersection.

5.1.1. Overview of Potential Conflict Events

Table 2 below provides an overview of conflict events for the pilot and Table 3 provides an overview of conflict events for the Main study. The purpose of showing this is just to show how a different camera angle with fewer data points can impact the findings. Arguably the Pilot data shows a better representation of the intersection conflict profile, as it identified more events due to the closer zoom and enabled more robustness around the manually coded events (n = 25 as opposed to n = 6) when rates are examined.

Table 2:Riddiford/ Adelaide event codes for the Pilot (14 hours of footage, lower quality with zoomed in view)

Overall conflict metric	Events	Individual risk indicators (chance/cyclist as %)	Collective risk indicators	
			Events/hour*	1 Event every
Important TTC/PET (< 3s)	98	12.5%	7.4	8 mins
Close TTC/PET (< 1.5s)	69	8.8%	5.2	12 mins
Close encounter rate	16	1.6%	1.2	50 mins
Avoidance behaviour rate	9	0.9%	0.7	89 mins

Table 3:Riddiford/ Adelaide event codes for the Main study looking at View 1 (2.5 hours of footage, higher quality with zoomed out view)

Overall conflict metric	Events	Individual risk indicators (chance/cyclist as %)	Collective risk indicators	
			Events/hour*	1 Event every
Important TTC/PET (< 3s)	31	8.9%	12.4	5 mins
Close TTC/PET (< 1.5s)	25	7.2%	10	6 mins
Close encounter rate	4	1.2%	1.6	50 mins
Avoidance behaviour rate	2	0.6%	0.8	1 hour 40 mins

* *The rate through the intersection was about 140 cyclists/hour*

5.1.2. Event locations and reliability

In terms of the frequency of movements through the intersection (indicated in Figure 11), these do link to the clusters of close encounter and avoidance events for the most part (Figure 12). However, these locations are not necessarily reflected in the crash data. While not much can be suggested from this due to the low frequency of crashes, it could indicate that the less frequent or arguably less expected maneuvers may be a contributing factor to actual crash events.

Figure 11: Riddiford/ Adelaide - Cyclist movement through the intersection (computer vision)

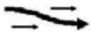
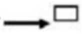
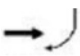
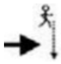
The other aspect to note was that the close encounters and avoidance behaviours in the Main study show similar patterns to the Pilot study in terms of their locations.

Figure 12: Riddiford/ Adelaide event locations and crash history

5.1.3. Event types and reliability

There was consistency in the event types over time (indicating good test-retest reliability in our conflict measures within the same intersection). Even looking at a shorter time frame (2.5 hours) in the full study reveals that the FA and AA event movement codes that were most common as represented in the Pilot Study data. The only difference being that in the larger Pilot data set additional movement codes around AG and GB also come out, and the GB code (left turn side swipe) was also seen in the crash data. Therefore, this also reveals that a longer duration of analysis can reveal consistency with actual crash data (Table 4).

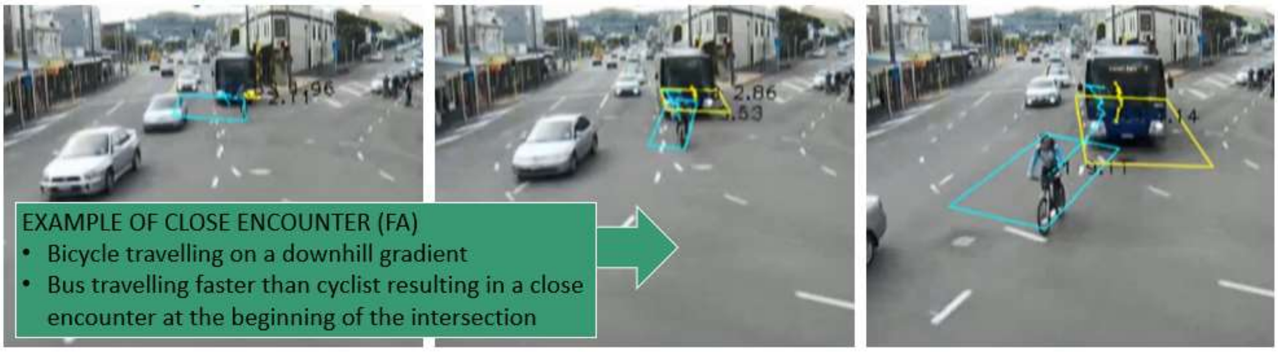
Table 4: Riddiford/ Adelaide historical crash codes and event movement codes for the pilot sample and the full study

Code	Description	Crash history 2012-2016	Event movements (Pilot)	Event movements (Main study)
FA 	Rear end- slower vehicle	0	10	4
AA 	Pulling out or changing lane to the right	0	3	2
AG 	Overtaking and lane change – weaving in heavy traffic	0	2	0
GB 	Turning versus same direction – left turn side, side swipe	1	2	0
EA 	Parked vehicle	0	1	0
AC 	Cutting in or changing lane to the left	0	1	0
GF 	Two turning	1	1	0
JC 	Two turning	0	1	0
JA 	Right turn right side	0	1	0
KA 	Left turn in	0	1	0
NA 	Pedestrian left side	0	1	0

At this site, the historical crash codes comprise of one GF (left turn side swipe), and one GB (two turning). Due to the limited data and complexity of the intersection we also examined the crash data going back to 2008. However, despite four additional crashes, this more in-depth data does not reveal a consistent crash pattern, with each additional crash having unique crash codes.

To provide some context, an example of the most common close encounter event type and location can be seen in Figure 13. Depending on the cyclist, this could cause the cyclist discomfort (as we know larger vehicles in close proximity do increase discomfort). However, if other factors did require the cyclist to stop with urgency the severity of a FA event would be different for a cyclist-bus interaction simply due to the mass difference and vulnerability of cyclists.

Figure 13: Example of a common close encounter event at Riddiford/ Adelaide



5.1.4. Camera view findings

In terms of the camera view, the same 2.5 hours of footage was examined from different perspectives and with different levels of quality of footage (i.e. 12 fps compared with 30 fps). It was expected that improved quality of footage would substantially improve conflict event detection accuracy. Accuracy of cyclist detection and detection of events was highest when examinng footage with a closer zoom (found almost twice the number of events; see Table 5). Looking at the two views in Figure 14 reveals how conflicts that occur further away would benefit from a closer, zoomed view.

Table 5: Detection rates and event detection based on different camera footage

Measure	View 1 (high quality, zoomed out)	View 2 (lower quality, zoomed in)	View 3 (lower quality, zoomed out)
Sample of cyclists (Automated)	347	344	299
Cyclist detection rate (Automated)	80.4%	84.1%	78.5%
Potential conflict event (Automated)			
TTC or PET < 3s	31 (9%)	64 (19%)	38 (13%)
TTC or PET < 1.5s	25 (7%)	47 (14%)	33 (11%)

Figure 14: Camera views showing View 1 (top, with high quality, zoomed out view) and View 2 (bottom, with low quality, zoomed in view) displaying an example conflict detection zone

5.1.5. Design implications

Please note that this study used a small sample of cyclists and events to conceptually understand a methodological approach. In doing so, some emerging design implications for the intersections examined were identified. For the Adelaide/ Riddiford intersection, they are described below:

- **Downhill cyclist speed:** Acknowledge higher cyclist speeds coming downhill and the resulting desire to run a red light. Can the intersection be designed with this in mind?
- **Cycle first phasing:** Consider priority cycle phasing to allow cyclists stopped in the bike box to get ahead of traffic and away from the intersection 'hot spots'.
- **Pinch points:** Consider and optimise the relationship between pedestrian crossing build-outs and cycle lanes to avoid pinch points
- **Left turning vehicle:** Consider locations where vehicles turn left and cyclists go straight. Due to speed difference, they may have an event. This could be rectified with signal phasing.

5.2. Intersection 2: Tamaki/Watene

Intersection 2 is a common un-signalised T-intersection between Tamaki Drive and Watene Crescent in Auckland selected for its generalisability, high cyclist numbers and history of cyclist crashes. Between 2012-2016 there were 6 minor and 1 serious injury cycle crashes at this intersection

5.2.1. Overview of Potential Conflict Events

An overview of potential conflict events for this site is presented in Table 6. The table shows that despite the high rate of cyclists through this intersection and its cycle crash record, the chance of an interaction event occurring is relatively low compared with the other intersections. As outlined in the following sections, this may be partly explained by the relatively simple nature of the intersection and also by the high rate of cyclists meaning that vehicles may be more likely to expect cyclists in this area. This does pose an interesting question about the link between cycle numbers and crashes. On one hand greater cycle numbers would lead to a greater exposure to potential cycle crashes, and on the other relatively few cyclists (where they are not expected by motorists) in dangerous situations might drive a cyclist intersection crash problem.

Table 6:Tamaki/ Watene conflict overview

Overall conflict metric	Events	Individual risk indicators (chance/cyclist as %)	Collective risk indicators	
			Events/hour*	1 Event every
Important TTC/PET (< 3s)	36	3.8%	4.5	13 mins
Close TTC/PET (< 1.5s)	31	3.2%	3.9	15 mins
Close encounters	7	0.7%	0.9	1 hour 26 mins
Avoidance behaviours	3	0.3%	0.4	3 hours 20 mins

** The rate through the intersection was about 120 cyclists/hour*

Table 6 does not show the variation of conditions that exists at this intersection. For example, many training cyclists are likely to travel through the intersections in the early morning hours of the weekend without any conflicting traffic. Quite differently, almost every commuter cyclist through the intersection will be in close proximity to other vehicles and are likely to experience a degree of caution or discomfort.

5.2.2. Event locations

As shown in Figure 15, the movement of cyclists through the intersection favours the special vehicle lane for westbound cyclists and the shared path and road for eastbound cyclists. In addition, there were some cyclists turning left from Watene Crescent onto Tamaki Drive, and a few right-turn movements from Tamaki Drive onto Watene Crescent.

As expected from the cyclist movement patterns the majority of events at this site were located in the main stream of eastbound and westbound traffic. In addition, the majority of events identified in this research followed a similar locational pattern to the site's minor and serious injury crash history (Figure 16).

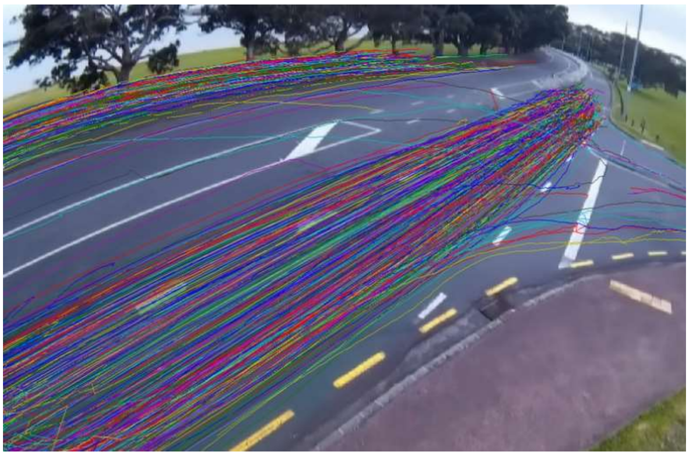


Figure 15: Tamaki/ Watene - Cyclist movement through the intersection (computer vision)

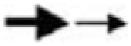
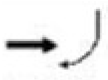
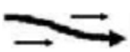
Figure 16: Event locations and crash history at Tamaki/ Watene

5.2.3. Movement types

High cyclist speeds were recorded at this site with an average speed of 31km/h. Although this section of road has a relatively flat gradient, the high speeds are likely due to the popularity of this route for training purposes and for confident commuter cyclists. For vehicles, normally acquainted with relatively low cyclist speeds, this higher, possibly unexpected speed may be surprising, and their behaviour may not allow for this. Indeed, the higher-than-expected cyclist speed at this site was identified as a contributing factor to the occurrence of events, a factor that may not commonly be considered properly.

Of the 10 events that occurred at this site, three movement codes were observed. A description of how the codes were associated with an event are presented in Table 7. Whilst there was little overlap in terms of the pattern of historical crash movements compared with event movements, of note is that most of the events recorded in this study were clustered in similar locations to historical cycle crashes.

Table 7: Tamaki/ Watene event codes and crash history

Code	Description	Crash history 2012-2016	Event movements
LB 	Right turn against - making turn	3	0
AC 	Cutting in or changing lane to the left	2	1
FA 	Rear end- slower vehicle	1	3
JA 	Crossing (vehicle turning) – right turn right side	1	0
AA 	Pulling out or changing lane to the right	0	6

Despite the locational matching, the historical crash codes only have a slight overlap with the event movement codes identified here. Whilst AA was the most common event movement code in this research, it was not associated with any crashes. Conversely, there were 3 LB (right turn against) manoeuvres recorded in the crash codes and none in this research.

The lack of data matching may be due to the amount of data collected and may indicate that to understand this intersection more thoroughly, more hours of footage would need to be coded. For a discussion on the hours of footage needed at each site, please refer to Appendix D.

For those cases where the event movement codes did not match the crash location, it is likely that a measure of discomfort paired with relatively low risk can be ascribed to this location. Figure 17 is a good example of this whereby the cyclist and surrounding cars are in close proximity with the cyclist possibly feeling uncomfortable, yet low speeds are involved, the movement is reasonably controlled, and personal risk is therefore low. Nevertheless, identifying events such as these is important in better understanding the design implications of the intersection as a whole.

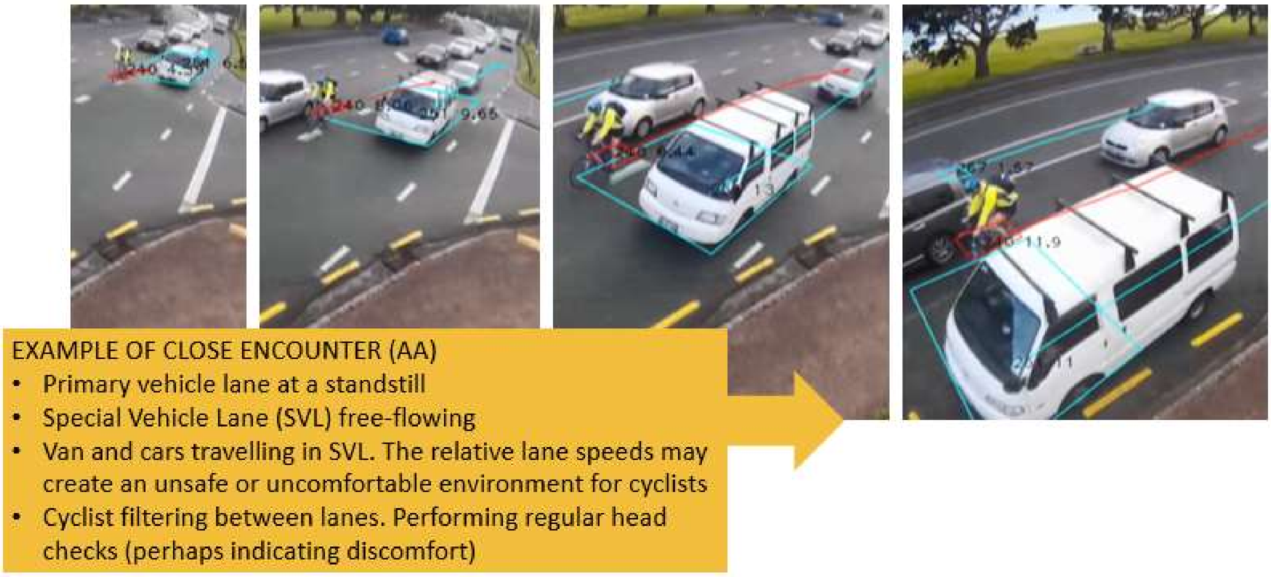


Figure 17: Close encounter (AA) cyclist filtering

5.2.4. Design implications

Please note that this study used a small sample of cyclists and events to conceptually understand a methodological approach. In doing so, some emerging design implications for the intersections examined were identified. For the Tamaki / Watene intersection, they are described below:

- **Peak hours:** The congestion at peak hours often results in the primary westbound lane coming to a standstill. This can mean that general vehicles move into the Special Vehicle Lane in an attempt to avoid the congestion. For cyclists, the presence of general vehicles in the Special Vehicle Lane leads to careful negotiation of space. Cyclists in this study were observed filtering past vehicles primarily near the edge line, but sometimes in the middle of the traffic. Whilst this behaviour was identified by both the manual and automated methods, it was more often observed during the independent manual coding stage. This is likely because, for computer vision often no TTC or PET was identified due to the consistent pathways each user was taking meaning there was no potential encroachment. Rather, it was more an issue of proximity and discomfort.

- **Right turn against:** As described above, during peak hours there can be a build-up of vehicles in the general lane, but also in the Special Vehicle Lane. For eastbound vehicles turning right into Watene, and for vehicles turning right out of Watene, their sightlines may be compromised by the presence of other vehicles. This may have implications for their ability to identify and react to cyclists. A sign alerting motorists to approaching cyclists could be considered.

- **Cyclist speed:** Cyclists at this site were recorded by the computer vision as having the highest speeds compared with the other two sites. Drivers may underestimate the speed of approaching cyclists which could have implications on their gap selection. The introduction of visual cues such painted lines or edge marker posts positioned at short intervals could help drivers gauge the speed of approaching cyclists.

5.3. Intersection 3: ANZAC/Short

Intersection 3 is a T-intersection at ANZAC Avenue and Short Street in Auckland. It was selected because of its history of cyclist crashes coupled with low cyclist numbers. The crash history at this site from 2012-2016 features six (2 serious, 4 minor) right turn against (LB) crashes. In every case, the crash involved a southbound vehicle positioned in the right turn bay on ANZAC Avenue. The vehicle proceeded across the intersection to Short St and encountered a northbound bicycle. The cases were a combination of 'looked but did not see', as well as failure to give way, and misjudgment of the cyclists' speed.

5.3.1. Overview of Potential Conflict Events

An overview of potential conflict events for this site is presented in Table 8. The table shows that there was a low rate of cyclists through this intersection, and reasonably low event rate (as a collective risk indicator). However, at this site the individual risk is much higher than the other sites. At this intersection, due to the low number of cyclists, vehicles may be less likely to be aware of, or expecting cyclists as their presence is less normalised than at the other two sites.

Table 8:ANZAC/ Short conflict overview

Overall conflict metric	Events	Individual risk indicators (chance/cyclist as %)	Collective risk indicators	
			Events/hour*	1 Event every
Important TTC/PET (< 3s)	18	11.0%	1.5	40 mins
Close TTC/PET (< 1.5s)	12	7.3%	1	1 hour
Close encounters	0	-	-	-
Avoidance behaviours	3	1.8%	0.25	3 hours 26 mins

** The rate through the intersection was about 14 cyclists/hour*

5.3.2. Event locations

As shown in Figure 18, the movement of cyclists through the intersection favours the northbound and southbound directions on the major leg (ANZAC Avenue). Less common movements included a left turn from Short Street onto ANZAC Avenue, and a right-hand turn from ANZAC Avenue into Short Street.

Figure 18: ANZAC Ave/ Short St - Cyclist movement through the intersection (computer vision)

At this intersection the gradient generates issues related to cyclist speed (Table 9). The relatively fast downhill speed has implications for cyclist reaction time and the severity of potential collision situations. The slower uphill cyclist speed has implications regarding comfort around buses as the cyclists and busses both travel in the Special Vehicle Lane.

Table 9:ANZAC/ Short cyclist speeds

	Speed km/h (average)	Speed km/h (85^{th} percentile)
Overall	22.4	26
Uphill (southbound)	19.5	22.3
Downhill (northbound)	27.9	32.7

Three avoidance events were identified in this research. The location of these events is depicted in Figure 19 along with the location of cycle crashes from 2012-2016. A shown, whilst the historical crashes are all situated in the same location, the events identified in this research are spread across three locations. This is discussed further in the following section.

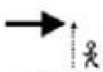
Figure 19: ANZAC Avenue/ Short Street - Event locations and crash history

In addition to the identification of events by the automated approach, some manual identification was also undertaken. This occurred in Phase 2 of the study, where 100 cyclists were independently manually sampled. Of those cyclists, two were observed travelling against the traffic flow. However, both movements did not result in any events.

5.3.3. Movement types

Of the three events that occurred at this site, each occurred in a different location and was ascribed a unique movement code. A comparison of the event movement codes with the movement codes from the intersection's crash history are presented in Table 10.

Table 10:ANZAC/ Short event movement codes and crash history

Code	Crash history 2012-2016	Event movements	Event Description
LB 	6	1	Right turn against - making turn. Cyclist coming down ANZAC Avenue, vehicle turned into Short Street
NB 	0	1	Cyclist coming down ANZAC Ave swerved to avoid pedestrian crossing the road
N/A	0	1	Gradual avoidance of cyclist by bus as bus pulls further into the right-hand lane away from the cyclist

In this study, the existing crash pattern was only mirrored by one avoidance event. This example of a right turn against which was identified by the computer vision and coded manually is illustrated in Figure 20. In this case, the cyclist had to change direction and speed to avoid a right turning vehicle moving from ANZAC Avenue to Short Street. We suggest that factors affecting these crashes and the event could include: the downhill cyclist speed; and relatively few cyclists using this intersection meaning that motorists may be less likely to expect them, consequently turning drivers look for cars rather than bicycles.

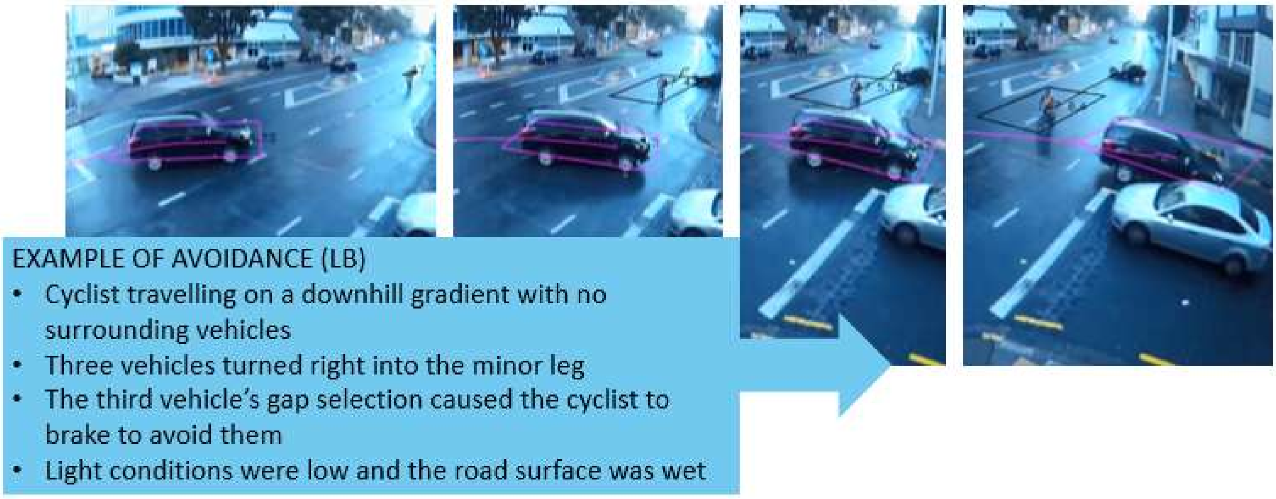


Figure 20: Right turn against event using computer vision

5.3.4. Design implications

Please note that this study used a small sample of cyclists and events to conceptually understand a methodological approach. In doing so, some emerging design implications were identified. For the ANZAC/ Short intersection, they are described below:

- **Bus comfort and uphill cyclist speed:** One Avoidance event and several Standard Encounters were observed between cyclists and busses in the southbound (uphill) Special Vehicle Lane. We suggest that this may be a result of the speed differential between busses and cyclists due to the gradient of the slope. In most instances the buses appeared to carefully negotiate the cyclist. However, a level of discomfort for both users is likely due to their size imbalance and proximity. Therefore, at this location, the speed differential and space requirements were an issue.

- **Right turn against and downhill cyclists speed:** Acknowledge higher cyclist speeds coming downhill at this location. There is a risk of right-turn against events due to the relatively low numbers of cyclists in combination with the unexpectedly high cyclist speeds, meaning that gap observation and selection by motorists may be compromised.

5.4. Overview of Conflict Across Intersections

5.4.1. Relative conflict and individual risk

Analysing crash data, either in their raw form or through some sort of predictive risk rating, is the main way of currently assessing the safety performance of intersections. However, particularly for cyclists, we know this crash data is limited in terms of absolute numbers. It also does not provide an accurate account of individual risk, as cyclist numbers through a location is often not available, or only available on an annual basis at a few key locations.

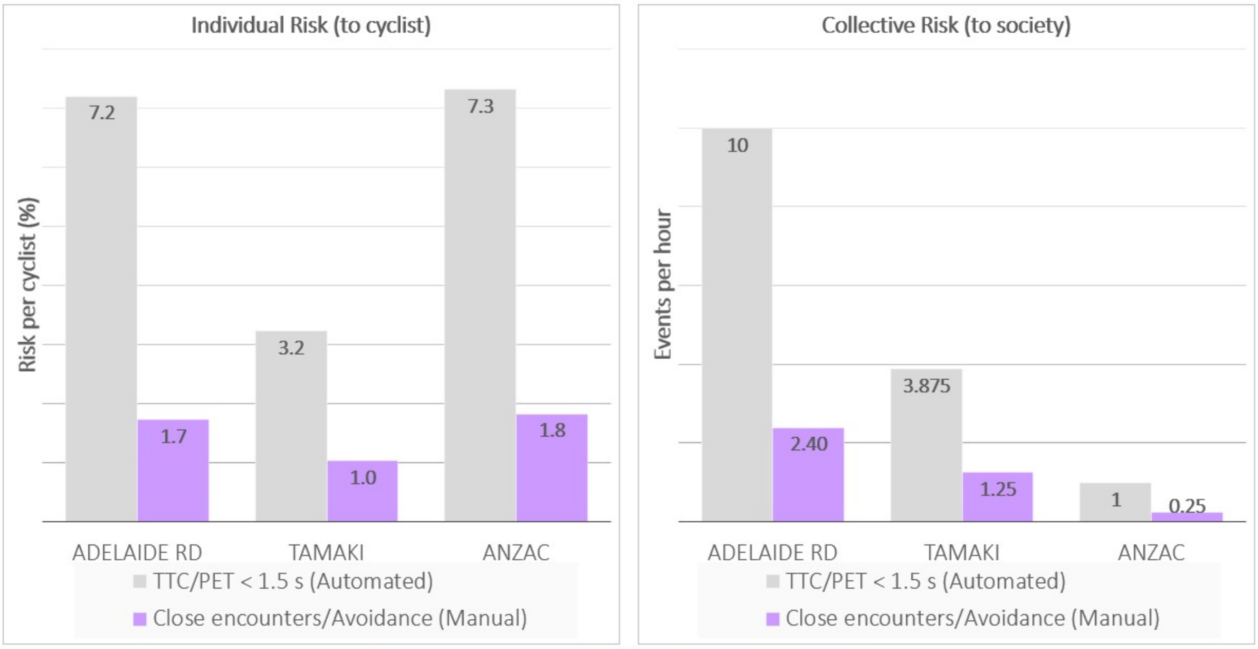
The data generated from the method outlined in this study can provide individual risk information, which is important for understanding the nature of the problems. Furthermore, this method could be used to identify the conditions that are present which might commonly lead to crashes and the relative exposure of cyclists to risky situations (such as a queue of traffic and turning vehicles). With this enhanced understanding, solutions could be tailored to target higher risk conditions.

Where there is a gap between conflict data and crash data it may also be indicative of a lower awareness of the type of events that are causing serious harm. For example, if you compare Tamaki and ANZAC the actual crash risk appears very similar, but the potential conflict rate is lower than at Tamaki so arguably cyclists may view this location as relatively safe and do not employ defensive riding techniques or have heightened awareness to risks (which is known to improve reaction times). An indicator that this may be the case is that cyclists do not appear to slow for the intersection (based on their higher speed selection).

5.4.2. Relative conflict and collective risk

Relative conflict numbers allow comparisons of collective risk between intersections, meaning that we can better understand which intersections have a high number of fatal and serious crashes on them. These data can be used to help determine which intersections would most benefit from infrastructure improvements. Therefore, using this measure of risk can provide another layer of data which may be useful for prioritising intersections. This is also an area where computer vision alone could be used initially to highlight intersections that are worthwhile to investigate further.

Some important comparisons between the intersections from Figure 21 below help to explain the range of conditions to which cyclists may be exposed. At face value, Adelaide Road and ANZAC Avenue have similar Individual risk profiles, but the ANZAC Avenue has movements that are much more susceptible to higher severity crashes, and also has a greater number of cyclist crashes. This is particularly interesting when the Collective risk for these two intersections are compared. With the relatively few cyclists and events at ANZAC Avenue, one could think that this intersection is much safer, but in fact this is not the case. Meanwhile, the cycle/vehicle interactions at Adelaide Road clearly show that this is much more uncomfortable intersection with a very different geometry and movement types. Additionally, when Tamaki Drive and ANZAC Avenue – two sites with a similar geometry - are compared, despite the higher number of cyclists at Tamaki there is clearly more individual risk at ANZAC.



	Adelaide	Tamaki	ANZAC
Crashes (over 5 years)	2	7	6

Figure 21: Individual risk and Collective risk at the three sites

5.4.3. Summary data

The summary of conflict data is outlined in Table 11. Please note that manual coding at Site 1 was only conducted for the Pilot and camera view 1. The summary table provides a good overall view of the sites (or intersections) examined. Overall, the cyclist detection accuracy was high (ranged between 79-93%). Rates of detection and potential conflict events showed variation based on the view, indicating close proximity was useful (as discussed in the Intersection 1 findings). Where manual analysis alone was done in the pilot, other behaviours were identified with greater regularity (such as red light running behaviour).

Table 11: Summary of conflict data by intersection site and view

Measure	Site 1				Site 2	Site 3
	Pilot	View 1	View 2	View 3		
Sample of cyclists (Automated)	785 automated (1000 manual)	347	344	299	959	164
Cyclist detection rate (Automated)	78.5%	80.4%	84.1%	78.5%	85.5%	93.3%.
Average cyclist speed km/h (Automated)	20	17	17	17	31	22
Potential conflict event (Automated)						
TTC or PET < 3.0s	159 (20%)	31 (9%)	64 (19%)	38 (13%)	36 (4%)	18 (11%)
TTC or PET < 1.5s	98 (12%)	25 (7%)	47 (14%)	33 (11%)	31 (3%)	12 (7%)
Encounters (Manual)						
Standard encounters	134	25	N/A	N/A	24	15
Close encounters	16	4	N/A	N/A	7	0
Avoidances	9	2	N/A	N/A	3	3
Other behaviours	36	0	N/A	N/A	0	2

6. Discussion

6.1. Hybrid Methodology Review

This project has demonstrated the potential of the hybrid method for understanding interactions between cyclists and motorists at urban intersections. It provides much richer information than crash data or automated time to collision measurements alone, by allowing risky and uncomfortable situations to be identified and understood, and also by allowing individual and collective exposure to these events to be estimated.

We propose that in addition to detecting events that serve as indicators of possible crashes, certain events could act as indicators of cyclist discomfort and motorist frustration and provide a better understanding of intersection usability. It is critical to monitor events that relate to rider comfort for cycling to grow successfully, as perceived safety is the largest barrier to uptake. Paired with this, and forming the basis of the poor perception of safety is the actual risk to cyclists, particularly at urban intersections. Therefore, close encounters from following or overtaking motorists are useful to capture.

Also, behaviours that indicate motorist frustration are also important to monitor as these can influence network efficiency and flow-on risk taking behaviours (such as erratic lane changes). The fusion of computer vision to highlight critical events and add extra layers of data (e.g. heat maps, TTC/PET, and speed data) combined with manual expert behavioural interpretation and quantification of new layers of data to derive meaning (e.g. event severity, movement type, context) provides a more nuanced approach to monitoring and improving intersection safety and usability.

The outcome of the data and insights that come from this approach is that it allows for: 1) a discussion around a wider set of novel intervention solutions than are presently raised; 2) a better evidence base to underpin the business case for intervention solutions; 3) a consistent approach to compare and rank intersection intervention priorities; and 4) an effective method to quantitatively monitor the success of any improvement.

6.1.1. Conflict and crash relationship validity

It is important to view traffic conflicts as a complementary tool, that provides a more well-rounded safety evaluation (especially where the crash numbers are low). However, as with any proxy measure of actual risk, traffic conflicts may have a mixed relationship in terms of their likelihood of actually leading to deaths and serious injuries. For example, this is demonstrated in previous studies, where factors such as intersection type (signalised vs non-signalised) and crash data quality, can have quite a large impact on the relationship between conflict detection and crashes.[9] One element that is apparent from this study is that crash movement codes are a critical component to monitor. As there is a reasonable understanding of the relationship between crash movement type and severity of crash (non-injury, minor, serious, fatal). The gap in understanding is whether conflict from certain movements are more likely to result in crashes than others.

[9] Sayed, T. & Zein, S. (1998). Traffic conflict standards for intersections. *Transportation Planning and Technology, 22,* 309-323.

6.1.2. Cost-effectiveness and value of the hybrid method

A major limitation of this study is that it only looked at one approach to a hybrid method, so the ability to review different models of how this could work is limited. Automated detection of road user interactions is not currently available in New Zealand (as discussed later). The cost-effectiveness of the current model, stemming mainly from the automated component of the method, may be a barrier to widespread use, and in this study, it meant we did not analyse as much footage using this technology as we had intended. The current hybrid approach is likely to be most beneficial when a larger quantity of footage can be processed using automated computer vision analysis in a way that is more cost-effective than manual processing. In this study, it would have been more cost effective to complete the analysis of conflict behaviours using manual processing alone, acknowledging that this does not take into account the additional data captured by computer vision (such as speed/PET/TTC/heat maps; Figure 22). However, like with any system or product development project, it is inevitable that in developing this system, it won't be cost effective in its early stages and investment is needed up front so that an efficient and cost-effective solution can be used in the future.

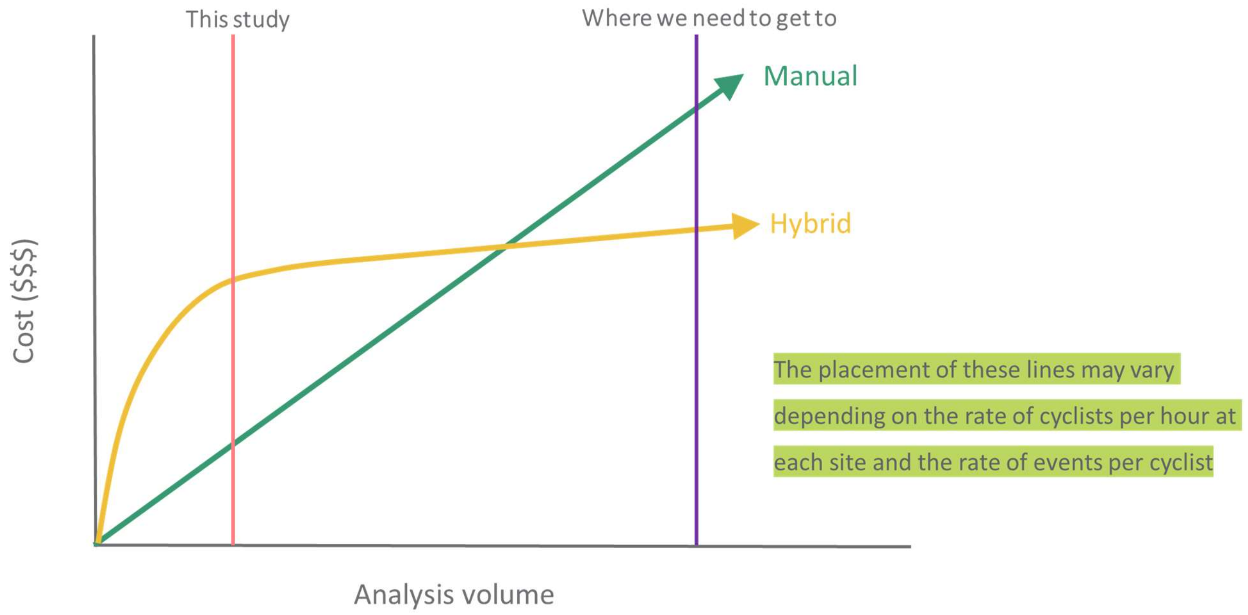


Figure 22: Cost-effectiveness and value of this data

The present study utilised a high-quality computer vision process, as evidenced by the high detection rates (even with poor footage). As technology improves and capability builds, the cost-effectiveness of this hybrid approach will also improve, although this needs to be continually reviewed against data quality. Overall, the manual time savings with a shift from the manual process to the hybrid process within this study indicate this process makes it 4-5 times faster to analyse footage, as can be seen in Table 12.

Table 12: Comparison of manual and hybrid methods to manually analyse footage

Method	Estimated hours required to process 1 hour of automated footage (manual analyst time only)	Comments
Manual method	2-2.5 hours	This will depend on: • The number of variables coded, • The type of variables (e.g. speed or distance judgements were not done here, as they require frame-by-frame analysis which slows coding significantly) • Site conditions (e.g. higher cyclist rates and number of notable conflict events increase time)
Hybrid method	0.5 hours	This could be further improved by: • Running software to provide a library of time-stamped video segments showing each separate potential event (currently the time stamp of interesting events is provided) Note: This does not include the time taken to calibrate and run the automated software.

6.1.3. Value as a multi-modal conflict approach

The value of monitoring speed, conflict "hot spots" and wider behaviours around risk, comfort and frustration for cyclists at urban intersections has not been established, as we currently do not typically resource this in New Zealand. While the scope of this work was cyclist-motorist interactions, taking a multi-modal approach to intersections provides some economies of scale and a more holistic approach to intersection solutions. As many solutions have implications for other modes, both positive (e.g. solutions for cyclists may also support the safety of motorcycle and scooter riders) and other interventions may have competing needs with other modes (e.g. pedestrian build-outs that cause pinch-points for cyclists).

6.1.4. Minimum hours of footage to analyse critical events

Based on our small sample of intersections, the minimum hours of footage required to detect events that represent the crash movements at an intersection, and detect statistically significant changes in events following typical interventions could range from 2 days of video data through to 14 weeks of video data (Appendix D). For most intersections 2 weeks of data collection would allow for the most in-depth analyses of movement type data, and less data collected to examine an overall change in potential conflict (Table 11).

6.1.5. Hierarchy approach to intersection conflict analyses

We propose a hierarchy of intersection conflict analysis methods (Table 13), where the level of understanding required around an intersection (or series of intersections) would be tailored to the effort that is justified in each case. For the highest risk intersections, more effort might be justified in understanding road user movements and interactions.

In terms of the hierarchy of cost-efficiency, hybrid methodologies are unlikely to add a great deal of value to Levels 1-2 below. Where the automated process is not too labour-intensive or incurring a large fee then the hybrid method should start to pay off from Level 3, becoming more cost effective as Level 5 "In-depth understanding" is approached.

Table 13: Hierarchy of intersection conflict understanding

Hierarchy of intersection conflict understanding	Footage required	Benefit	Manual analyst time only
1. Basic review and safety audit	• 2 hours on site • Examination of detailed crash records and available risk maps • Detailed safety audit report	• Recommended regardless of the other complementary analyses performed. • Indication of the movement codes that have historically led to reported crashes. • Wider understanding of other contextual factors that may have contributed to the crash.	
2. Basic level understanding	• 8-12 hours footage	• Revealing wider movements that may lead to conflict and discomfort. • An ability to look at some variation based on time of day.	Manual method analysis time: 16-30 hours Hybrid method analysis time: 4-6 hours
3. Medium level understanding	• 2-7 days footage	• An understanding of a change in behaviour (i.e. success of an intervention) at most intersections	Manual method analysis time: 48-140 hours Hybrid method analysis time: 12-28 hours
4. High level understanding	• 2-4 weeks footage	• An understanding of specific movement code changes at most intersections	Manual method analysis time: 224-560 hours Hybrid method analysis time: 56-112 hours
5. In-depth understanding	• 8-14 weeks footage	• An in-depth understanding of intersection conflict behaviour by movement type, especially at low cyclist volume intersections. • This would mostly be relevant to research applications (such as examining the relationship between conflict events and actual crashes)	Manual method analysis time: 896-1,960 hours Hybrid method analysis time: 224-392 hours

6.2. Lessons to improve data quality

This study has captured some lessons to improve data quality, in terms of elements to consider when capturing footage for automated analysis, and lessons around coding for the data analyst.

6.2.1. Camera equipment lessons and minimum requirements

Whilst the capability in New Zealand is not yet fully established to implement this hybrid approach (see below), nevertheless a positive finding from this study was that existing cameras can be effectively utilised for automated analyses. Many existing CCTV systems currently have a lower frame rate (such as 12 frames per second), but this study indicates that the quality of this footage is usable, which allows for cost-effective data capture. The more important factor to check is that the camera is able to zoom and examine specific parts of an intersection where conflict is occurring. It is also important to make sure there are processes in place to capture this exact same zoom and angle if there is any before-after monitoring (otherwise changes in conflict may relate to the footage rather than an actual change in conflict). For more detailed practical lessons to consider during camera setup see Appendix E.

6.2.2. Manual lessons

The Pilot study allowed for the refined method to be tested. Following the Pilot, certain coding criteria that were both difficult to quickly interpret in the video and deemed unnecessary for this study were removed. These included detailed weather information and the approximate age of the cyclist. Pilot testing to focus on the factors that are most relevant to conflict and can be manually coded easily is important.

In addition to streamlining the required data, a level of agreement, or 'sense-checking' between manual coders was ascertained during Phase 2 of the Main study. This was deemed necessary due to the relatively difficult nature of coding the events into decisive categories, even despite the existence of clear coding guidelines as presented in Appendix C. Consistent coding between independent observers allows us know that the variables being measured are being accurately defined and consistently measured, which is important for replicating this methodology in other studies. Following Phase 2 of the Main study (independent manual sampling of 100 cyclists at three intersections), the agreement between manual coders relating to event types was deemed problematic. Therefore, we went back through a retraining process to see whether we could better define avoidance and close encounter event types. For example, it was clarified that a cyclist changing their course in preparation for a vehicle's movement is only counted as an event if their proximity is within a 3 second TTC or PET. Following this process, the agreement between manual coders was consistently higher.

This was a useful lesson from the manual approach to understand the level of detail and training necessary for manual coders to consistently code events. This is particularly pertinent when coding proximity and encounter events because the lines between event types can easily blur.

6.3. Building New Zealand Capability

Going forwards, for this application to be used more widely (i.e. city councils understanding local intersections), the computer vision/cyclist identification work would benefit from New Zealand capability. Therefore, we asked some of our New Zealand-based contacts in the industry about their capabilities in this area. In particular, we asked the following questions (with the generalized responses provided after each question):

6.3.1. Do you have, or do you know of in New Zealand, computer vision capability that could be used to identify cyclists at intersections?

A number of organisations are familiar with computer vision and are actively involved in developing this technology (mostly with other suppliers). Detecting cyclists seems to be a commonly available technology.

6.3.2. In what way is this capability currently used?

There are a wide range of applications with most used for network management and incident management. Cycle detection is used to activate signs and count cyclists. Although not focusing on cyclists this technology is being used to better understand red light running.

6.3.3. Can this capability also identify interactions (such as near misses or conflicts) between cyclists and other road users?

The potential for this has been identified but no-one is actually doing this yet in New Zealand. One organisation is however working with an overseas organisation to use this technology to identify cycle conflicts overseas, but this does not translate into the capability existing here in New Zealand. Some academic organisations are developing technology that would achieve this objective, based on current work focusing on other modes (pedestrians and vehicles).

6.3.4. Can this capability output data on interactions between cyclists and other road users?

Most applications can currently output data in a usable form, but this does not yet exist for cycle conflicts.

6.3.5. Can this capability distinguish between less significant interactions and more significant avoidance/near miss interactions?

No. This is not possible because cycle/vehicle interactions are not yet being captured and analysed.

6.3.6. Next steps

Given the value of the data shown from this study, it would seem there would be demand for New Zealand based capability in this area. However, we are currently some way from this goal and focussed work would be needed to achieve this.

It is suggested that a hui is convened (outside scope of this work) to determine a strategy for advancing this capability in New Zealand. There may be difficulties for some in talking freely about this, but for those with more altruistic intentions, a clearer pathway could be achieved by taking a cooperative approach, rather than the usual competitive approach where effort and ideas are simply duplicated through lack of cooperation.

Building a shared vision and strategy should help with overcoming barriers. This could include a visioning session looking around strategic areas where this new data could be used to inform critical issues in the next 10 years, as well as some guest presentations around current and potential use by local and international experts.

It is also suggested that the discussion include possible pathways around governance, funding, and integrating into existing monitoring programs. Where there is demand for this capability it needs dedicated time and resource. Previous lessons indicate that this is often an add-on to already high workload roles and if not properly resourced the opportunity and value will be limited value.

6.4. Overview of practical implications for intersections

6.4.1. Cyclist speed

Cyclist speed through the intersection was particularly high at the Tamaki intersection, and at the downwards gradient at the ANZAC intersection, which could be a contributing factor when motorists are judging gap acceptance at intersections. It has been established that motorists underestimate cyclist speed, especially when speeds are higher, such as when cyclists are travelling downhill[10]. In terms of changes to the cyclist fleet, with the high uptake of electric bicycles there is potential for a further increase in the speed profile of cyclists. This signals the need to review effective solutions to improve motorist decision-making around speed and gap judgements around cyclists. It also signals the need to monitor both cyclist and motorist speed at intersections. A more sophisticated understanding of speed management at intersections for all road users may also be needed. For cyclists and motorcyclists, travelling fast when there is an adjacent queue of traffic and the potential for right turning vehicles, brings together a number of ingredients for crashes. This also raises the question of what is an appropriate speed, and what might be needed to create environments that modify cyclist (and scooter/motorcyclist) speed in these situations.

6.4.2. Right turns at T-intersections

This study has shown an example of a very typical conflict at un-signalised T-intersections, where a right turning vehicle crosses in front of an approaching cyclist on the main road. Beyond this actual example there are many examples of situations where the ingredients for these conflicts are present, but the timing of a cyclist or right turning vehicle do not align. For those who are charged with improving intersection safety, it would be advisable to check the periods of time where queuing and right turning vehicles exist. In the same way as the Speed Management Infrastructure Risk Rating (IRR), the presence of these characteristics could signal the potential for risk at any T-intersection.

[10] Johnson, M. (2017). Safe cycling: perception or reality? 2017 Asia-Pacific Cycling Congress, 17th-20th October. Christchurch: New Zealand. http://www.conference.co.nz/files/docs/apcc/thursday/1155%20marilyn%20johnson%20-%202017%20apcc%20johnson%20plenary,%20thursday%2019%20october.pdf

The study also found that there is more than only the most common crash types to worry about. Pedestrian safety, uphill cyclist discomfort (interacting with buses) and interactions between same direction cyclists and vehicles were all also identified as issues at these intersections. It is important to take a holistic view of the road users involved and also the comfort that an intersection affords, in addition to potential for crash risk for cyclists.

6.4.3. Complex intersections and lateral movements

The major concern at intersections has been focussed on low frequency high severity conflict events that are perpendicular in their movement, like right turn against crash movements. As suggested above, this study reveals that parallel movements are also causing issues due to the speed differential between cyclists and vehicles and limited space. This reveals adaptive behaviours by cyclists and motorists that can negatively affect risk, such as cyclists taking unexpected pathways through the intersection, and motorists erratically changing lanes to pass cyclists. While there are improvements at midblock segments of the network for how cyclist space is demarcated (e.g. cycle lane markings, Sharrows), this typically does not extend to intersections even though this is where there is arguably greater uncertainty. The findings of this study call for a greater emphasis on how we may separate modes via signal prioritisation, and better methods to determine how we assign and prioritise multimodal space at intersections when there are conflicting user needs.

An example of how these conflicts might be addressed, could be to take advantage of the time at the end of pedestrian crossing phases before general traffic is given a green light. Many cyclists naturally and cautiously proceed through complex intersections once the pedestrians have crossed but while the traffic lights are still red. While this is currently illegal, more effort should consider these situations which might help to separate modes at intersections.

6.4.4. Other manual-coded events

Some event types that could not be identified by the automated approach using TTC/ PET were observed by the manual sampling approach. These events included: cases of red light running; cyclist issues with the built environment (i.e. pedestrian build-out box); and unusual manoeuvres including lane filtering and travelling against the traffic flow. This further highlights the benefit of a combined approach.

6.4.5. Emerging design implications

A common theme running through all of the intersections is that we rely heavily on the good judgement of road users for safety, in environments that are designed to be unsafe. For example, in Auckland it is expected that the introduction of transit/bus lanes on arterial roads typically has a 12-15% road safety cost associated with them (Personal Communication) and yet there is pressure to implement more of them. For cyclists, motorcyclists and pedestrians, there is a need to make intersections inherently safer, where people will inevitably make mistakes, but they won't result in serious harm. There is a potential hierarchy of treatments that could be applied at the intersections discussed in this report, including removing some movement types where appropriate, removing general traffic lanes and introducing more sophisticated speed management. The more effective solutions are likely to be more difficult to implement, but bold steps may be needed if tangible improvements to the safety of vulnerable road users are expected.

Some specific design considerations include:

- Safe System solutions, such as such as policy and design interventions to remove movements that are known to cause cycle (and motorcycle) crashes
- Support appropriate gap acceptance decisions by motorists, including improved cyclist speed detection by motorists at intersections. Some examples could include:
    - Installing speed feedback information like 'your speed'/'their speed' signs for all road users
    - Acknowledging higher-than-expected cyclist speeds at some locations which may cause conflict for turning vehicles
    - Visual cues from evenly spaced delineation devices could help drivers gauge cyclist speed and distance
- Predictable and obvious pathways for cyclists at intersections, including demarcation interventions and mitigation of pinch points. Some examples could include:
    - More sensitive road markings for cyclists to guide them safely through the intersection, to delineate 'their' space, and avoid pinch points.
    - Vehicles turning right from, and into the minor leg on a T-intersection may have sight-lines concealed due to the build-up of traffic. 'Cyclist approaching' sign
- Separation of cycles and vehicles
    - Consider priority cycle phasing to allow cyclists stopped in bike box to get ahead of traffic and away from the intersection 'hot-spots'.
    - Legally allow cyclists to courteously cross at 'all-red' (Barnesdance) pedestrian crossings, at walking speed, once pedestrians have mostly crossed.

7. Recommendations

Overall, we recommend developing the automated component further and using the hybrid method for conflict detection to complement existing intersection audit and urban cycleway monitoring. A more specific set of recommendations around the adoption of this methodology to improve cyclist conflict monitoring in New Zealand are outlined below.

- **Urban cycleways and other citywide monitoring:** As part of our cycle monitoring program (including initiatives like the urban cycleway program), agree to and implement a consistent core behavioural coding framework around potential conflict events at places that warrant it. This should include event movement codes that align directly with crash codes, and a consistent definition used around event severity (i.e. what constitutes a close encounter or avoidance behaviour). This would enable a wider set of intersections to be examined to build a better understanding of issues and solutions.

- **Value the data:** Establish the value of the conflict data by linking it to existing desired safety and health benefits that have an established economic value. This will support the business case for improved monitoring. For example, examining how reducing close encounters and avoidance events that have higher risk movements could reduce crashes, and examining how reducing comfort-related events may increase cycle growth which has established benefits, especially health benefits.

- **Cyclist speed:** Cyclist speed and gradient be monitored at intersections during the safety audit process, and actively consider how this can be managed through engineering, speed management or education and training. Embed key messages about cyclist speed and safety in the new cycling education system – Bike Ready.

- **Conflict analysis workshop/webinar:** Run workshop and webinar sessions to examine the demand for this method and capability in New Zealand. This could include a visioning session looking around strategic areas where this new data could be used to inform critical issues in the next 10 years, as well as some guest presentations around current and potential use by local and international experts.

- **Build Hybrid Methodology case studies:** Follow-up with the existing intersection analyses with decision-makers within road controlling authorities and monitor the success of any interventions.

- **Computer vision review:** Review a wider sample of existing packages, including accessing different trial software and use this to analyse the existing video footage. Build on the capability scan that has been carried out to better understand how this technology can be developed and applied in New Zealand.

- **Emerging design implications:** Intersections are locations where people will inevitably make mistakes, but these should not result in serious harm. For cyclists, motorcyclists and pedestrians, there is a need to make intersections inherently safer and this study identified a potential hierarchy of treatments that could be applied at the intersections discussed in this report. These could include: removing some movement types where appropriate; better temporal separation between cyclists and motorists, a improving predictability of cyclist pathways; and introducing more sophisticated speed management.

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Appendices

Appendix A: Glossary / Definitions

Traffic conflict: Defined as “an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged” (Amundsen and Hyden 1977, cited by Van de Horst et al 2014)

Near miss: Defined as “the time between the moment that the first road-user leaves the path of the 2nd road-user, and the 2nd road-user reaches the path of the 1st” (Allen et al 1977, cited by Van de Horst et al 2014)

PET: Pose-Encroachment Time is a common conflict measure that examines the difference in time between a first road user leaving a common spatial location and a second road user arriving at that same location (Ismail et al., 2009).

TTC: Time-to-Collision is a common conflict measure that examines the time before two road users (or objects) collide if they were to continue on the same trajectory with no change in speed or direction (Sayed et al., 2013).

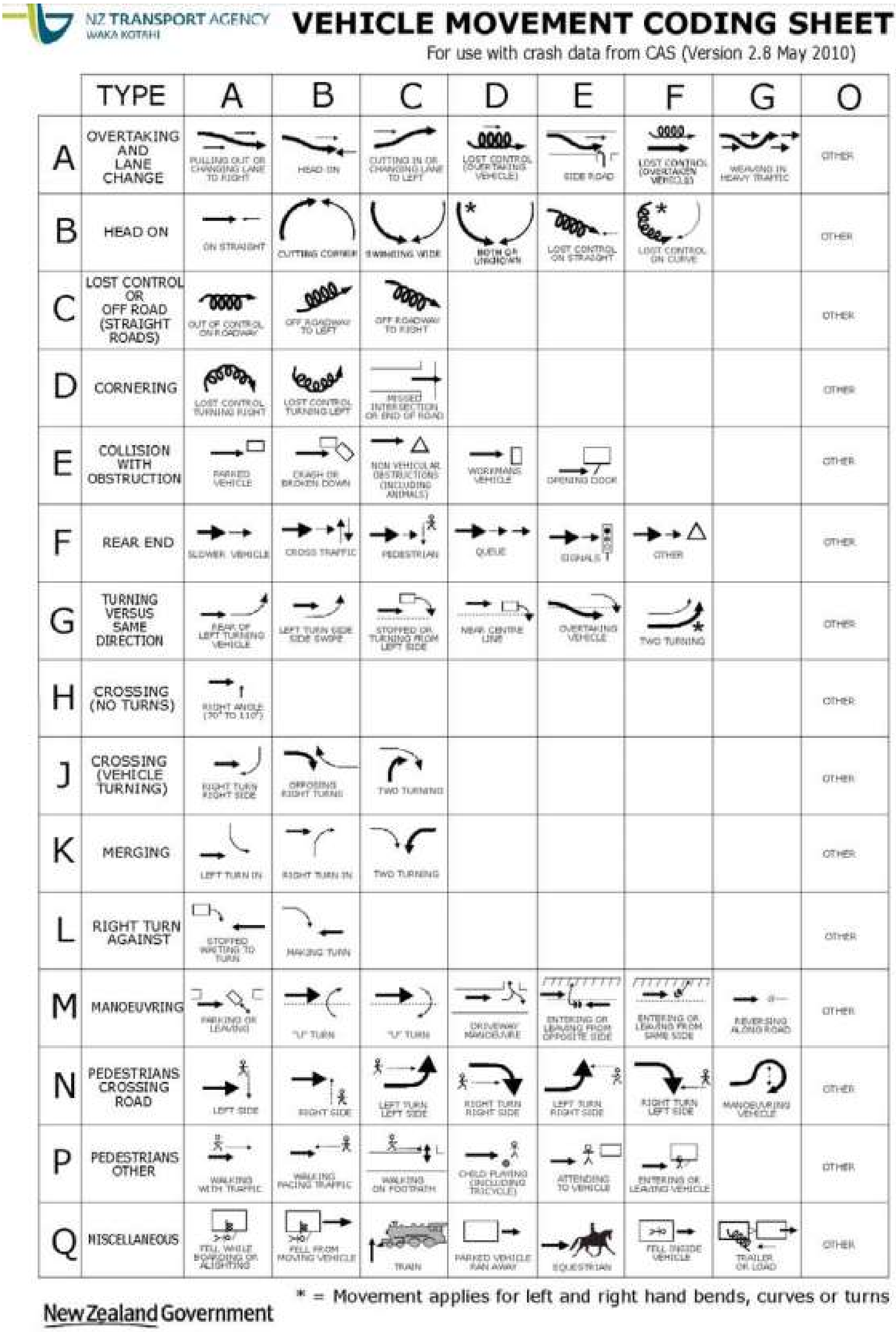
Conflict monitoring success metrics

Collective Risk = Events/hour

Individual Risk = Conflict rate/interaction

Severity = Typically examine a combination of TTC or PET (but do not typically attempt to combine this with speed, which would be a nice addition)

Appendix B: NZTA Vehicle Movement Sheet



NZ TRANSPORT AGENCY
WAKA KOTAHI

VEHICLE MOVEMENT CODING SHEET

For use with crash data from CAS (Version 2.8 May 2010)

	TYPE	A	B	C	D	E	F	G	O
A	OVERTAKING AND LANE CHANGE	PULLING OUT OR CHANGING LANE TO RIGHT	HEAD ON	CUTTING IN OR CHANGING LANE TO LEFT	LOST CONTROL (OVERTAKING VEHICLE)	SIDE ROAD	LOST CONTROL (OVERTAKEN VEHICLE)	WEAVING IN HEAVY TRAFFIC	OTHER
B	HEAD ON	ON STRAIGHT	CUTTING CORNER	SWINGING WIDE	* BOTH OR UNKNOWN	LOST CONTROL ON STRAIGHT	* LOST CONTROL ON CURVE		OTHER
C	LOST CONTROL OR OFF ROAD (STRAIGHT ROADS)	OUT OF CONTROL ON ROADWAY	OFF ROADWAY TO LEFT	OFF ROADWAY TO RIGHT					OTHER
D	CORNERING	LOST CONTROL TURNING RIGHT	LOST CONTROL TURNING LEFT	MISSED INTERSECTION OR END OF ROAD					OTHER
E	COLLISION WITH OBSTRUCTION	PARKED VEHICLE	CRASH OR BROKEN DOWN	NON VEHICULAR OBSTRUCTIONS (INCLUDING ANIMALS)	WORKMANS VEHICLE	OPENING DOOR			OTHER
F	REAR END	SLOWER VEHICLE	CROSS TRAFFIC	PEDESTRIAN	QUEUE	SIGNALS	OTHER		OTHER
G	TURNING VERSUS SAME DIRECTION	REAR OF LEFT TURNING VEHICLE	LEFT TURN SIDE SIDE SWIPE	STOPPED OR TURNING FROM LEFT SIDE	NEAR CENTRE LINE	OVERTAKING VEHICLE	* TWO TURNING		OTHER
H	CROSSING (NO TURNS)	RIGHT ANGLE (70° TO 110°)							OTHER
J	CROSSING (VEHICLE TURNING)	RIGHT TURN RIGHT SIDE	OPPOSING RIGHT TURNS	TWO TURNING					OTHER
K	MERGING	LEFT TURN IN	RIGHT TURN IN	TWO TURNING					OTHER
L	RIGHT TURN AGAINST	STOPPED WAITING TO TURN	MAKING TURN						OTHER
M	MANOEUVRING	PARKING OR LEAVING	"U" TURN	"U" TURN	DRIVEWAY MANOEUVRE	ENTERING OR LEAVING FROM OPPOSITE SIDE	ENTERING OR LEAVING FROM SAME SIDE	REVERSING ALONG ROAD	OTHER
N	PEDESTRIANS CROSSING ROAD	LEFT SIDE	RIGHT SIDE	LEFT TURN LEFT SIDE	RIGHT TURN RIGHT SIDE	LEFT TURN RIGHT SIDE	RIGHT TURN LEFT SIDE	MANOEUVRING VEHICLE	OTHER
P	PEDESTRIANS OTHER	WALKING WITH TRAFFIC	WALKING FACING TRAFFIC	WALKING ON FOOTPATH	CHILD PLAYING (INCLUDING TRICYCLE)	ATTENDING TO VEHICLE	ENTERING OR LEAVING VEHICLE		OTHER
Q	MISCELLANEOUS	FELL WHILE BOARDING OR ALIGHTING	FELL FROM MOVING VEHICLE	TRAIN	PARKED VEHICLE RAN AWAY	EQUESTRIAN	FELL INSIDE VEHICLE	TRAILER OR LOAD	OTHER

* = Movement applies for left and right hand bends, curves or turns

New Zealand Government

Appendix C: Manual coding protocol

Coding protocol...

Two analysts to initially code independently of each other and after 10 cases, to check each other's coding to determine how much data has been coded the same. If there are substantial differences, discuss where these exist and why and refer back to the coding guidelines. Continue this sense-checking process until a level of agreement is reached.

Code site and date.

Code time for each cyclist for when they appear in the frame.

Code the cyclist for each time they move into a new zone (specific to a site and specific to a user).

If a cyclist is riding mid-block and a car passes them – but there is no visible change in direction or speed by either road user – this is a no interaction.

Information about the cyclist and their location

Cyclist type:

- Group (2 or more)
- Solo (note, the quality of the footage and camera angle did not allow us to accurately determine the approximate age of the cyclists)

Cyclist location (Between zones ascribed to the intersection)

- The zone that the cyclist is in when they enter the intersection
- Intermediate location (if relevant)
- The zone that the cyclist is in when they exit the intersection
- Cyclist location in the lane entering the intersection (left, centre, right)
- Cyclist location in the lane exiting the intersection (left, centre, right)

Information about the cyclists and other road users

Traffic density:

- No other traffic
- Light (free flowing)
- Busy (free flowing)
- Bumper to bumper (moving)
- Standstill

Cyclist signalling turn? (yes, no, not applicable)

Road obstacles:

These were identified from the video frame to be part of the road environment that may cause discomfort to cyclists. The discomfort may present itself in the cyclist changing direction or braking to avoid them. These obstacles included man-hole covers, pot holes, a pedestrian build-out, and a side median. Obstacles such as these usually go unnoticed by vehicles with four wheels.

- Were there any obstacles that affected comfort levels?
- Comment about the obstacle

Vehicle behaviour:

Where relevant (at the T-intersections), noted about vehicles turning right into and out of the main leg.

Event details

Interacting user: (car, van, bus, truck, motorcycle, pedestrian, another cyclist)

Conflict interaction type:

- **No interaction:** Definition: No cars present or no evidence of an intersecting movement, or road users adapting their behaviour in response to the other.
- **Standard encounter:** Interacting road user gives-way, no evidence of sudden movements and obvious slowing behaviour to give-way. This could include 'courtesy' give-way behaviour, where user does not legally have to give-way. Behaviour is controlled.
- **Close encounter*:** No obvious action taken by motor vehicle or cyclist, but evidence of discomfort or close proximity (e.g. "whoosh effect"). Not an avoidance, but close- within 3 second time to collision.
- **Avoidance*:** A noticeable change in speed or direction by either the cyclist or interacting user to avoid the other (e.g. minor braking by the vehicle). Less severe avoiding behaviour compared to a near-miss/conflict. Note that an avoidance is based on the proximity of the cyclists and vehicle in that the event
- **Near-miss*:** Rapid or evasive manoeuvering to avoid each other, evident by a sudden change in speed or direction by the pedestrian or interacting user to avoid the other (or both users) (e.g. major braking by the vehicle or swerving).
- **Collision:** Physical contact between users

Event movement code: (from NZTA Vehicle Movement Coding Sheet)

Open-ended questions: (when relevant)

- What happened? Who was at risk?
- What are some causal factors?
- Why were there those causal factors?
- What are some solutions?

Action of interacting user - not cyclist: (brake, carry on as normal, swerve)

Action of cyclist: (brake, carry on as normal, swerve)

Location of interaction: (based on locational zones)

** Please note that the conflict events 'close encounter', 'avoidance' and 'near-miss' are defined around proximity as well as action. Therefore, a cyclist changing their course in preparation for a vehicle's movement is only counted as an event if their proximity is within a 3 second TTC or PET.*

Appendix D: Coding calculations

Table D-1 below provides indicative data to highlight how many hours of data may be required at different intersections for the most in-depth analyses to be run. The minimum hours required was calculated based on the manual events recorded by intersection per hour assuming that you would need about 35 events recorded at a simple intersection (i.e. with one major movement code) through to 140 events being recorded at a complex intersection (i.e. with four major movement codes). This would allow for before-after analysis based on movement codes to see not only that there was a change, but that there was a change in the desired behaviour.

Table D-1. Example intersections with indicative minimum time periods to examine based on the complexity of conflict-related movements and cyclists through an intersection.

Example intersections	Hours	Cyclist/hour	Manual Events	Minimum hours based on number of common movement types (from 1-4 movement types)			
				1	2	3	4
Riddiford (High likelihood/high cyclist rate)	12	83	25	17	34	50	67
Tamaki (Med likelihood/high cyclist rate)	8	120	10	28	56	84	112
Anzac (High likelihood/low cyclist rate)	12	14	3	140	280	420	560

Appendix E: Camera setup lessons

Camera equipment lessons and minimum requirements

- **Visual angle and zoom:** Proximity to the key interactions was far more relevant to conflict detections than footage quality. In terms of ease of data collection this is very positive, as it means that existing cameras (even if they have lower resolution and a lower frame rate) can be effectively utilised as long as they are able to zoom and examine specific parts of an intersection where conflict is occurring.
- **Footage quality:** CCTV footage quality in terms of resolution and frame rate appears to be reasonably accurate. This means that even at 12fps, as opposed to 30 or more fps typically collected for computer vision cyclists and motorists can be accurately detected.
- **Existing CCTV camera stock:** Existing cameras are often already future-proofed, and have a higher quality capability, but it is reduced intentionally. A key limitation right now is capture (bandwidth limitations across the network) and storage of video footage across multiple sites. This is a limitation that should reduce over time. In terms of conflict analysis, a consideration here is to examine more intersections with lower quality footage rather than few intersections with higher quality footage.
- **Lens setup:** Ensuring a standard lens is used is important. A fish-eye lens or anything that allows capture of a wider perspective also means calculations around distance and speed may be altered. It is possible to mitigate fish-eye footage through specialist software.

Benefits of different camera setups

This study mainly focussed on existing fixed cameras (CCTV cameras) compared with mobile, pole-mounted cameras. Another mobile camera setup commonly used is a trailer-mounted camera, where RCAs often purchase their own trailer setup.

Example Camera setups

Fixed cameras: Existing cameras are often already fixed to hard infrastructure such that their locations are less mobile, but they can benefit from limited movement (e.g. due to wind) and can enable a higher placement location.

Pole-mounted cameras: Such as those used in this study, enable attachment to existing infrastructure that enabled height, can be set up in minutes and do not require much roadside space to set up effectively.

Trailer-based cameras: Such as those used in other councils, have the benefit of being mobile, can be set up quickly and without existing infrastructure, but do require space in the location.

Some considerations are outlined below and also summarised in Table E-1:

- **Quality control on visual angle:** A CCTV benefit is automatic return of camera setup to exact same angle and zoom (these locations can be stored in memory in many setups, so there is no human error when repeating footage of the same site). As seen in these findings the visual angle and zoom are critical to accurate analysis.

- **Single purpose video collection:** The benefit of targeted collection via pole or trailer mounted provides consistent data capture (i.e. camera not pulled away by other purpose, such as congestion monitoring). They also allow for flexibility in intersection coverage (as most existing CCTV cameras are located in high use areas that also monitor congestion).

- **Wind conditions:** During data collection the pole mounted approach meant that we lost about half of our data that was acceptable for computer vision. This also would have made manual coding more difficult and slightly more time consuming.

Table E-1 Camera considerations

Data considerations	**Fixed camera (e.g. CCTV)**	**Pole-mounted camera**	**Trailer-mounted camera**
Visual angle and zoom quality control	★★★	★★	★
Flexibility of intersection	★	★★★	★★
Consistent data capture (i.e. not pulled away when events occur)	★	★★★	★★★
Wind conditions	★★★	★	★★
Quality of footage	★	★★★	★★★
Cost	★★★	★★	★
Automatic data upload	★★★	★	★
Data storage	★	★★★	★★★

Note: High quality = ★★★ Med quality = ★★ Lower quality = ★