UNIVERSITY OF TECHNOLOGY SYDNEY

INSTITUTE FOR SUSTAINABLE FUTURES

Institute for Sustainable Futures

INTERSECTION INTERACTIONS: CYCLIST BEHAVIOUR AT SYDNEY CBD CYCLEWAY INTERSECTIONS

2012

ABOUT THE AUTHORS

The Institute for Sustainable Futures (ISF) was established by the University of Technology, Sydney in 1996 to work with industry, government and the community to develop sustainable futures through research and consultancy. Our mission is to create change toward sustainable futures that protect and enhance human well-being, social equity and the environment. We seek to adopt an inter-disciplinary approach to our work and engage our partner organisations in a collaborative process that emphasises strategic decision-making.

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1 INTRODUCTION

The prevalence and role of cycling within the City of Sydney and surrounding LGAs is currently undergoing a transition. Until recently, the City's road network has been dominated by private motor vehicle and motorised public transport traffic, often moving at high speeds. But in recent years, a discernable shift has been taking place in the composition of road traffic whereby people riding bicycles are becoming more common.

This transition has come about in response to several factors, some of which are external and independent of the transport system — such as increases in the price of petrol — while others changes are internal to the transport system and travel behaviour — such as increases in the demand for public transport that create overcrowding, triggering a shift to riding bicycles by some people. Other factors, such as deliberate policies on the part of the City of Sydney to improve amenity and safety for people riding bicycles by providing dedicated cycleways and other bicycle infrastructures such as on-street and off-street bicycle parking are also responsible for increases in the proportion of people who want to ride bicycles.

The transition to greater bicycle riding in the City of Sydney has triggered the need for adjustments in a range of different areas of transport and road network operations. The research results recorded in these research notes are largely the product of the need to make adjustments to signals at intersections that incorporate dedicated cycleways.

In June 2011 the NSW Roads and Traffic Authority (now Roads and Maritime Services) in conjunction with the City of Sydney, contracted the Institute for Sustainable Futures (ISF) at the University of Technology Sydney (UTS) to conduct research into cyclist behaviour at three cycleway intersections within the Sydney CBD. The research was carried out in parallel with an analysis by Bitzios Consulting — *Sydney CBD cycleways: traffic signals optimisation*.

The general aims of the research that were identified before monitoring started were to examine:

1. **Road space allocation and traffic signalling at intersections incorporating cycleways,** including operational procedures such as signal phasing, signage and intersection configuration.
2. **Intersection user behaviour and conflict resolution at intersections incorporating cycleways**, including pedestrians, people riding bicycles, private cars and buses.

Once the project started, the role of induction loops embedded in the road surface used to trigger the bicycle specific signals was found to be a particular area of interest. In response, the RigidMount and ISF/UTS team added video cameras to their initial monitoring proposal to specifically examine the stopping positions of cyclists relative to the position of detection zones for induction loops used to trigger bicycle signals.

There were no collisions or incidents involving potentially dangerous behaviour recorded during the study period. Issues relating to the detection zones for induction loops were found to be the primary area of concern and so much of the work carried out focuses relating to their use, safety and compliance issues surrounding this aspect of behaviour.

The formal conclusions arising from the analysis undertaken by both Bitzios Consulting and ISF/UTS is contained in the final report submitted by Bitzios. These notes are intended to document specific aspects of the work carried out by ISF/UTS before the publication of research results in academic journal publications.

2 LITERATURE REVIEW

ISF conducted a literature review of cyclist behaviour at intersections as background to the research on cycleway intersections within the Sydney CBD for the RTA and City of Sydney. The search revealed relatively little research that focuses specifically on cyclist behaviour at cycleway intersections and so a more general search of behaviour change in response to infrastructure provision was carried out including:

- Cycle policy and infrastructure described in Section 2.1.1.
- Cyclist safety and interactions with motorists in Section 2.1.2.
- Cyclist behaviour in Section 2.1.3.

Broadly, the review found that the provision of dedicated cycleways and bicycle infrastructure is linked to increased safety for people riding bicycles and higher mode-splits to cycling.

In relation to cyclist safety, a key factor is cyclist visibility where it has been found that measures which raise driver awareness of the presence of people riding bicycles is crucial to improving safety. Another key element is clear delineation of road space ownership — motor vehicle drivers were shown to engage in potentially risky driving behaviour when they were uncertain about where cyclists were supposed to ride on the road and who had precedence.

The cycleways implemented by the City of Sydney improve both cyclist visibility and clearly define ownership of road space.

Korve and Niemeier (2002) found the use of dedicated bicycle signalling was found to have dramatically reduced the number of accidents between cyclists and motorists at an intersection in California, USA and that the benefits of providing signalling far outweighed the costs.

An analysis by Wu, Yao and Zhang (2011) showed that there was high levels of red light running by cyclists however a great deal of this was ‘opportunistic’, that is cyclists were crossing on a red light when traffic volumes and the risk of accident was low. Studies in Australia have suggested that red light crossing by cyclists is lower than in China but still higher than the level of motorists. ISF was not able to find an example of research into levels of compliance with dedicated bicycle signalling by cyclists.

2.1.1 Cycling policy and infrastructure (general)

This section reviews three relatively recent papers on bicycle policy and infrastructure provision. The first two comprise reviews of the wider literature in this area, and so capture a broad appraisal of various results, while the last focuses on the specific benefits of augmenting cycleway infrastructures with traffic signal phases for bicycles.

Pucher, J., Dill, J., Handy, S. 2010, 'Infrastructure, programs and policies to increase bicycling: an international review' in *Preventive Medicine* 50 Supplement (January): S106–S125.

This paper presents a review of international research into measures designed to increase cycling such as the provision of dedicated cycleways and other bicycle infrastructures, safety improvements and education and marketing programs. These specific measures have been investigated for the purposes of assessing the general benefits to health that arise from increased rates of bicycle use.

Several studies link the provision of dedicated cycleways (similar to the Sydney cycleways) with increases in cycling rates. For example, a Danish study linked a 20% increase in cycling and a 10% decline in motor vehicle traffic within the study area to the provision of a cycleway while a UK study showed a 58% increase in cyclists in its study area over 3.5 years after opening of a dedicated cycleway. The review criticises some studies for selecting narrow study areas and not carrying out a more extensive assessment of surrounding streets to determine whether or not this growth was a product of trip reassignment — existing bicycle trips shifting from existing routes to the new dedicated cycleway — or a more general mode-shift to cycling within the defined study areas.

The installation of dedicated bicycle traffic signals had greatly improved safety at a Californian intersection with 10 auto/cycle collisions in the 35 months prior to installation as opposed to 0 in the 35 months after. Several studies from Europe found significant increases in cycling levels following the installation of traffic calming strategies.

Marketing strategies such as individualised marketing and campaigns such as Ride to Work Day and events that temporarily close streets to cars have been linked with long term increases in the levels of cycling.

The implementation of helmet laws in Australia was linked to declines in the level of cycling in Melbourne, Sydney and Perth with estimates for declines ranging from between 20 – 36%.

The authors concluded that benefits of individual infrastructure or policy interventions can be increased dramatically if they are combined with other interventions to create a comprehensive package of cycling improvements. Cities that have undertaken comprehensive strategies have seen rapid increases in cycling numbers with trip numbers doubling or more in the following cities: Portland, Bogota, Berlin, Paris, London and Barcelona.

Pucher, J., Garrard, J., Greaves, S. 2011, 'Cycling down under: a comparative analysis of bicycling trends and policies in Sydney and Melbourne' in *Journal of Transport Geography* 19 (2): 332–345.

This paper examines several different data sets that show the general level of cycling in Melbourne is about twice that of Sydney and that cycling in Melbourne is growing faster than in Sydney — although it should be noted that these datasets are reporting on growth prior to the introduction of dedicated cycleways in the Sydney CBD.

The paper found that as the overall numbers of cyclists increased the proportion of female cyclists also increased. In Melbourne, 25% of journey-to-work trips by bicycle are being made by women as opposed to 17% in Sydney — this relationship was also observed within different local government areas within a city. In Sydney, over half of all cycling trips were made for sport or recreation purposes whereas in Melbourne cycling predominantly serves the more utilitarian functions like the journey-to-work and education.

Melbourne has some underlying advantages over Sydney with regards to cycling; Melbourne is flatter, has less rainfall (especially torrential rainfall) and wider streets in a more permeable grid formation. All of these factors contribute to making Melbourne a more attractive city for cyclists, however these factors do not account for the more rapid growth of cycling in Melbourne.

A possible explanation for the differences in cycling levels between Melbourne and Sydney is the level of cyclist safety. Despite Sydney having around half the general level of cycling that Melbourne has, the number of injuries within the two cities is similar, suggesting that Melbourne is a much safer city for cycling.

Both Sydney and Melbourne suffer from a limited and discontinuous dedicated cycleway network. However Melbourne has made more progress with introducing cyclist friendly intersection modifications such as advanced stop lines, special turning lanes and traffic signals for cyclists. The 22 cycling experts interviewed as part of the study suggest that in general relevant traffic and transport policies were more favourable to cyclists in Melbourne than in Sydney.

The authors conclude that although both Melbourne and Sydney have undertaken some bicycle friendly measures much more could be done and that the best results would be achieved via an integrated program of interventions. They also state that in the future cycling is likely to remain a marginal transport mode (unlike in parts of Northern Europe) unless politicians are willing to implement policies that reduce the adverse impacts of cars travelling at high speeds on active transport users (pedestrians and cyclists) including reduction of speed limits to 30km/h on local roads and implementation of some car free zones in city centres.

Korve, M.J., Niemeier, D.A., 2002, 'Benefit–Cost Analysis of added bicycle phase at existing signalised intersection' in *Journal of Transportation Engineering* 128 (1): 4–48.

This study examined the effects of introducing a bicycle phase at a T-intersection in Davis, California. The intersection was near the entrance to the University of California Davis campus and was relatively heavily trafficked by cyclists using a cycle lane. Prior to the introduction of the bicycle phase the traffic signal ran on a 3-phase 90-second maximum cycle, which was adjusted to a 4-phase 111-second maximum cycle.

In the 35 months prior to the addition of the bicycle phase to the signalling at the intersection there had been 10 cyclist-auto accidents. In the 35 months following the intersection alteration there were no cyclist-auto accidents.

The authors conducted a Cost–Benefit Analysis of the alterations considering the savings due to reduced accidents, extra delays for motorists, increases in carbon monoxide emissions and the infrastructure costs of the project. The study did not consider whether the changes had created any mode-shift towards cycling. The study found that the alterations had a Benefit–Cost Ratio of 8:1, however this was sensitive to changes in traffic forecasts and injury valuations. The authors noted that the BCR did not fall below 1.0 (indicating value for money) unless unrealistic traffic forecasts and injury valuations were used.

2.1.2 Cyclist safety and interactions with motorists

This section reviews three papers that investigate cyclist and motor vehicle driver behaviour in relation to each other and in relation to different conditions. The research carried out in the first and third paper was primarily motivated by the need to answer research questions in relation to safety considerations.

Johnson, M., Oxley, J., Cameron, M., 2009, *Cyclist bunch riding: a review of the literature*. Monash University Accident Research Centre.

This report analyses the behaviour of cyclists riding in large groups or 'bunches' on public roads.

Beach Road in South Eastern Melbourne is a very popular circuit for weekend recreational riders who often ride in bunches and this has created conflicts with pedestrians, motorists and residents. There have been safety concerns expressed by cyclists, in the five-year period prior to the report there had been 89 accidents involving injuries to cyclists including one cyclist fatality. The most common cause of the accidents was collisions with parked vehicles, in particular car doors being opened into the cycle lane. A major concern for residents of the area is the safety of pedestrians attempting to cross Beach Road, an issue that received significant media attention in 2006 when an elderly pedestrian was hit and killed by a cyclists riding in a bunch.

As well as conducting a literature review, this study undertook analysis of video footage of bunch riders riding along Beach Road prior to and after the 2006 fatal pedestrian accident. In 2005 footage showed a bunch of around 100 cyclists who regularly ran through red lights. The 2007 footage showed a smaller group — 30-40 — who more closely followed the road rules. It was not possible for the authors to determine whether this was a response to the increased attention placed on group riders in the aftermath of the accident, whether it was a characteristic of smaller bunches or whether this was due to the limited sample size. The report states that reasons for red light running may include an unwillingness to stop due to a loss of momentum and the desire to avoid a split in the bunch. The report recommends education campaigns for bunch cyclists and attempts to create a register of bunch riding groups and the installation of advanced signalling equipment that would warn cyclists at the start of a bunch of an imminent signal change.

Basford, L., Reid, S., Lester, T., Thomson, J. & Tolmie, A. 2002, *Drivers' perceptions of* cyclists. Department for Transport, UK.

This report uses a mixed methods (qualitative and quantitative) approach to study drivers perceptions of cyclists in a range of road contexts, including those where dedicated cycling facilities have been provided. The study found that cyclists were viewed as an 'out-group' that was different to other road users and were considered as having a low status among road users.

The research found that drivers perceived cyclist behaviour to be unpredictable and that this perceived unpredictability limited driver's ability to behave successfully in the way that felt ideal and this caused frustration amongst drivers. They found that drivers preferred to only pass cyclists when it was entirely safe but that they felt pressure not to delay other drivers so that the majority of drivers would pass a cyclist even when it was not entirely safe to do so.

The research found that where a driver encountered a cyclist within a context that required a driver to slow down or deviate, drivers' assumed cyclist's were being discourteous regardless of the cyclist's actual behaviour. The research tested driver behaviour within a number of virtual reality worlds and found that road conditions that bring cyclists and drivers into potential conflict (for example pedestrian refuges obstructing the left hand side of the road where cyclists tend to ride), can cause drivers to engage in more risky behaviour when passing cyclists. The research concluded that it was beneficial to provide infrastructure such as dedicated cycleways that clearly defined ownership or priority use of road space.

Johnson, M., Charlton, J., Oxley, J., Newstead, S. 2010, 'Naturalistic cycling study: identifying risk factors for on-road commuter cyclists' in *Annals of Advanced Automotive Medicine* 54: 275-283.

An Australian review of police and coronial reports found that in 60% of collisions between cyclists and drivers, a major contributing factor was that they did not see each other. Further studies have assessed driver behaviour and visual scanning strategies but few have concentrated on the *looking behaviour* of cyclists.

The study used helmet-mounted cameras to investigate the looking behaviour of cyclists and its role in cycle/motor vehicle incidents. The cameras recorded 12 hours of footage for each of the 13 participants over a four-week period, yielding 127 hours of footage that was analysed and included two collisions, six near collisions and 46 incidents.

Over 70% of the events (collisions, near collisions and incidents) occurred at an intersection/intersection-related location. However in over 87% of these cases the intersection had no form of traffic signals or controls. Drivers were found to be at fault in 87% of cases, with the most common cause being drivers turning left across the path of a cyclist. The study also found that on road cycle lanes often ended abruptly forcing cyclists into competing with motor vehicular traffic or riding illegally on the footpath.

2.1.3 Cyclist behaviour

This section reviews five papers that focus on cyclist behaviour taking into account differences in behaviour according to age and gender and how these affect responses to cycleways and traffic signals.

Bernhoft, I.M., Carstensen, G., 2008, 'Preferences and behaviour of pedestrians and cyclists by age and gender' in *Transportation Research Part F* 11(2): 83–95.

Two groups of pedestrians and cyclists in Denmark, the first group in the 40–49 age bracket and the second in the 70+ age bracket, were surveyed to help understand the differing perceptions of traffic safety by different age groups and genders. Both groups reported that the existence of cycleways was important to their comfort, however 71% of older cyclists as opposed to 52% of younger cyclists felt that cycling in an area without a cycleway was dangerous.

A significantly higher proportion of women than men felt that dedicated cycleways were important to their cycling comfort. The presence of signalised crossings was considered more important by older than younger cyclists. Amongst the younger riders, most women would choose a route that contained a dedicated cycleway and signalised crossings while most men would choose the fastest route.

Johnson, M., Newstead, S., Charlton, J., Oxley, J. 2011, 'Riding through red lights: the rate, characteristics and risk factors of non-compliant urban commuter cyclists' in *Accident Analysis & Prevention* 43(1): 323–328.

This study investigated red light infringements by cyclists at ten Melbourne intersections located on heavily used commuter cyclist routes. All of the roads analysed featured cycling lanes, although in many cases these ended at the approach to the intersection. The study filmed a total of 4,225 cyclists all during peak hour. Unlike the ISF behavioural study, this study did not examine cases where cyclists were provided with dedicated traffic signalling and phasing, instead cyclists were expected to use the same traffic signals as motorists.

The research found that around 7% of cyclists did not comply with the traffic signals, almost all cases of red light running involved cyclists who were turning left, which was approximately 28 times more common than cyclists continuing straight ahead. As with other studies, this suggests that cyclists were assessing the danger and concluding that turning left is a low risk manoeuvre under light traffic conditions in the cross street. Neither bike nor clothing type (bicycle sports or casual) was found to be significant in predicting non-compliance. Women were less likely to infringe than men and that the presence of other road users had a deterrent effect on all infringement.

Johnson, M., Charlton, J., Newstead, S., Oxley, J. 2010, 'Painting a designated space: cyclist and driver compliance at cycling infrastructure at intersections' in *Journal of the Australasian College of Road Safety* 21(3): 67–72.

This research used concealed cameras to record cyclist and driver compliance with dedicated cycling infrastructure at a range of Melbourne intersections. The study focussed on three types of cycling infrastructure:

1. Continuous green cycle lanes travelling right up to the intersection.
2. A discontinuous cycle lane followed by bicycle storage zone (head start zone) placed on the centre lane.
3. A discontinuous cycle lane followed by a bicycle storage zone in front of the left lane.

The research found that both cyclists and motor vehicle drivers were compliant with the cycle lane. However there was significant non-compliance with bicycle storage zones with just over half of observed motor vehicle drivers encroaching into the storage zone. The non-compliance with the storage zone by cyclists (i.e. not travelling all the way to the front of the traffic queue and into the storage zone) was also relatively high — 35% for left lane storage zone, 47% for centre lane storage zones. The research also found that compliance was higher, for both groups, in the morning rather than in the afternoon.

Hunter, W. 2000, *Evaluation of a combined bicycle lane/right turn lane in Eugene, Oregon.* Highway Safety Research Center, University of North Carolina

This study filmed cyclists behaviour at two differing bicycle lane designs in the approach to a United States intersection. The first was a standard width right turn lane — the equivalent of an Australian left turn lane — that required cyclists to cross from the right side of a lane to the left in the approach to an intersection. The variant design was a treatment that could be used in the case of narrow width intersections where there is not room for both a full width cycle lane and a right turn lane. In these cases the driver was expected to give way as they crossed the cycle lane and the cyclist continue straight ahead.

The cyclists were surveyed after they had passed through the intersection. The results of this survey were ambiguous with 17% of cyclists feeling that the narrow width lane treatment provided more safety, 27% the standard width design and the rest that there was no difference.

The analysis found that there was a much higher occurrence of drivers giving way to cyclists in the narrow width intersection — 93% as opposed to 48%. The author suggests that this may be due to the fact that in the narrow width intersection the cyclist continues straight ahead whereas at the standard width intersection they are expected to cross to the opposite side of the lane. Despite the ambiguous results of the survey, the author recommends the use of the narrow width design for retrofitting intersection approaches where space is constrained.

Wu. C., Yao, L., Zhang, K. 2011, 'The red-light running behaviour of electric bike riders and cyclists at urban intersections in China: an observational study' in *Accident Analysis & Prevention*

Bicycles and electric bikes (e-bikes) are an important urban transportation mode in China, making up more than 50% of urban transport trips in some major Chinese cities. However these road users also face safety concerns with over 13,000 cyclists being killed in 2004 and the number of e-bike deaths rising by 400% in the years 2004-2007.

The practice of red light running is one of the primary causes of traffic accidents for cyclists and e-bikers, being responsible for as much as 77% of injuries to e-bikers in one study from Haikou.

The study filmed cyclist behaviour at three intersections and then analysed and coded the resulting footage. Two-wheeled riders were categorised as either:

- Law abiding (stopping at an intersection and waited for the green signal).
- Opportunistic (stopped at the red signal but then crossed through the intersection before the signal turned green).
- Risk-takers (they did not stop at all).

Overall red light crossing was higher amongst e-bikers (62%) than cyclists (50%) and men (59%) than women (48%). Older riders tended to be more law abiding than younger riders. Amongst cyclists, 49% were considered law abiding, 28% risk-taking and 23% opportunistic.

Red light running happened more commonly at the beginning and at the end of the red light cycle and was more common when the rider was waiting alone at an intersection or when other riders had crossed in front of them.

3 METHODOLOGY

The methodology used to undertake the research comprised the following five steps:

1. Site and time selection.
2. Intersection filming.
3. Video coding workshops.
4. Analysis of results.
5. Workshop with project partners.

3.1 SITE AND TIME SELECTION

The RTA and the City of Sydney jointly decided on three intersections (see Figures 1 and 2) for the study:

- Bourke and Albion Streets (Bourke St Cycleway).
- Union and Edward Streets (Union St Cycleway).
- King and Kent Streets (Intersection of King St Cycleway and Kent St Cycleway).

The ISF behavioural study was conducted to coincide with a study of traffic signal operations on cycleway intersections undertaken by Alan Finlay of Bitzios Consulting. In order to be able to align results, both studies examined the intersections during the same time periods.

Behaviour was observed and recorded for three one-hour periods at each intersection, including one in the AM peak, the inter-peak and PM peak.

To establish which time periods were most representative of the peaks, SCATS counts for cars and bicycles were analysed and the peak bicycle times identified. These were found to comprise 07:00–08:00am and 17:00–18:00pm. The inter-peak period was chosen as 11:00–12:00am for all three intersections.

Figure 1: Union St facing west towards Edward St (left) Bourke St facing south towards Albion St (right).

Photos courtesy of Bitzios Consulting.

In some cases, due to difficulties with equipment, the study periods did not align completely. For example, video footage for the morning peak analysis of the King and Kent Street intersection begins at 07:15 and so does not cover the entire time period when details SCATS data were collected.

Figure 2: Kent St facing south towards King St (left) King St facing west toward Kent St (right).

Photos courtesy of Bitzios Consulting.

3.2 INTERSECTION FILMING

Nathan Besh from RigidMount undertook the filming of the intersections with the assistance of ISF and volunteers. Filming took place on Tuesdays and Wednesdays, as these days are the least affected by variable work patterns. At the Bourke/Albion and Union/Edward Street intersections four cameras were used. Two were used to record cyclists travelling on the cycleway through the intersection (one in each direction) and the traffic signals. The other two cameras were directed at the detection zone in the cycleway to record where in relation to the signal detector zone cyclists were waiting.

Figure 3: Camera equipment on Bourke St

At the King/Kent Street intersection two cameras were used to record cyclists travelling along the King Street cycleway, two cameras were used to record detector zones on King Street, one camera recorded cyclists travelling along Kent Street and one camera recorded the detector box on Kent Street north of the intersection.

3.3 VIDEO CODING WORKING GROUPS

ISF undertook an initial analysis of the video footage and developed a series of 24 codes to categorise the different behaviours of cyclists (see Table 1). Subsequently two coding working groups were held using volunteers from ISF and Sydney Bicycle User Groups to apply the codes to the video footage. Each volunteer coded the information for a single intersection in a single direction using an Excel spread sheet to record the time and behaviour. ISF then undertook re-coding of a sample of the footage to ensure that the coding had been undertaken accurately.

Table 1: Coding categories used in video transcription

Code Number	Behaviour description
1	Stops at intersection; in detection zone; goes with green signal.
2	Stops at intersection; in detection zone; goes with red bike/green car signal.
3	Stops at intersection; in detection zone; goes with red bike/red car signal.
4	Stops at intersection; in detection zone; red bike signal - continues on footpath.
5	Stops at intersection; in detection zone; red waits for green signal.
6	Stops at intersection; in front of detection zone; goes with green signal.
7	Stops at intersection; in front of detection zone; goes with red bike/green car signal.
8	Stops at intersection; in front of detection zone; goes with red bike/red car signal.
9	Stops at intersection; in front of detection zone; red bike signal - continues on footpath.
10	Stops at intersection; in front of detection zone; red waits for green signal.
11	Stops at intersection; next to detection zone; goes with green signal.
12	Stops at intersection; next to detection zone; goes with red bike/green car signal.
13	Stops at intersection; next to detection zone; goes with red bike/red car signal.
14	Stops at intersection; next to detection zone; red bike signal - continues on footpath.
15	Stops at intersection; next to detection zone; red waits for green signal.
16	Stops at intersection; behind detection zone; goes with green signal.

17	Stops at intersection; behind detection zone; goes with red bike/green car signal.
18	Stops at intersection; behind detection zone; goes with red bike/red car signal.
19	Stops at intersection; behind detection zone; red bike signal - continues on footpath.
20	Stops at intersection; behind detection zone; red waits for green signal.
21	Doesn't stop; goes with green bike signal.
22	Doesn't stop; goes with red bike/car green signal.
23	Doesn't stop; goes with red bike/red car signal.
24	Doesn't stop; goes with red bike; continues on footpath.

3.4 ANALYSIS OF RESULTS

ISF undertook an analysis of the raw data collated from the coding working groups to identify key patterns and specific behaviours of interest. The results were summarised in a series of comparative charts to communicate the key findings. This analysis is presented in Section 4.

3.5 WORKSHOP WITH PROJECT PARTNERS

On Thursday 10 November, a workshop was held at the City of Sydney. It was attended by representatives from the City of Sydney, the Sustainable Transport and Signal Operations teams at Roads and Maritime Services (formerly RTA), Bitzios Consulting, Bike North and ISF.

ISF and Bitzios presented the results of their linked studies and ISF facilitated a discussion on ‘perspectives, roles and responsibilities’ in relation to the provision of bicycle infrastructures. The discussion attempted to increase appreciation of the diverse roles and consequent viewpoints of different people in the group that are relevant to the operations of cycleways and develop a series of shared solutions to issues occurring on the cycleways. After a wide-ranging discussion of possible options the groups split into two and developed a series of recommendations. Outcomes from these discussions informed the recommendations presented by ISF.

4 RESULTS & ANALYSIS

The distribution of cyclists across all of the 24 codes is shown below in Table 2. Codes 11 to 15 denote cyclists whose stopping position is primarily between the detection zone and the element/street treatment that delineates the cycleway from general road space. These can be seen in Figure 2 for example where cyclists stop to the left of the detection zone and use the kerbside between the cycleway and the footpath to place their foot and support the bicycle while stopped at the intersection. In Figure 3, a raised street treatment that uses a garden bed to separate the cycleway from the general road space becomes the elements used by cyclists to place their foot and support their bicycle while waiting at the intersection.

Table 2: Distribution of coding results

Code	% of all cyclists	Behaviour description
1	8.9%	Stops at intersection; in detection zone; goes with green signal.
2	3.2%	Stops at intersection; in detection zone; goes with red bike/green car signal.
3	0.6%	Stops at intersection; in detection zone; goes with red bike/red car signal.
4	0.3%	Stops at intersection; in detection zone; red bike signal - continues on footpath.
5	0.2%	Stops at intersection; in detection zone; red waits for green signal.
6	5.9%	Stops at intersection; in front of detection zone; goes with green signal.
7	7.4%	Stops at intersection; in front of detection zone; goes with red bike/green car signal.
8	2.0%	Stops at intersection; in front of detection zone; goes with red bike/red car signal.
9	0.4%	Stops at intersection; in front of detection zone; red bike signal - continues on footpath.
10	0.3%	Stops at intersection; in front of detection zone; red waits for green signal.
11	0.3%	Stops at intersection; next to detection zone; goes with green signal.
12	0.4%	Stops at intersection; next to detection zone; goes with red bike/green car signal.
13	0.1%	Stops at intersection; next to detection zone; goes with red bike/red car signal.
14	0.1%	Stops at intersection; next to detection zone; red bike signal — continues on footpath.
15	0.0%	Stops at intersection; next to detection zone; red waits for green signal.
16	5.3%	Stops at intersection; behind detection zone; goes with green signal.
17	0.4%	Stops at intersection; behind detection zone; goes with red bike/green car signal.
18	0.6%	Stops at intersection; behind detection zone; goes with red bike/red car signal.
19	0.1%	Stops at intersection; behind detection zone; red bike signal - continues on footpath.
20	0.0%	Stops at intersection; behind detection zone; red waits for green signal.
21	10.6%	Doesn't stop; goes with green bike signal.

22	42.8%	Doesn't stop; goes with red bike/car green signal.
23	9.5%	Doesn't stop; goes with red bike/red car signal.
24	0.9%	Doesn't stop; goes with red bike; continues on footpath.

Each intersection was analysed for three hours across the day. The total number of cyclists crossing the intersections during the observation periods is shown in Table 3.

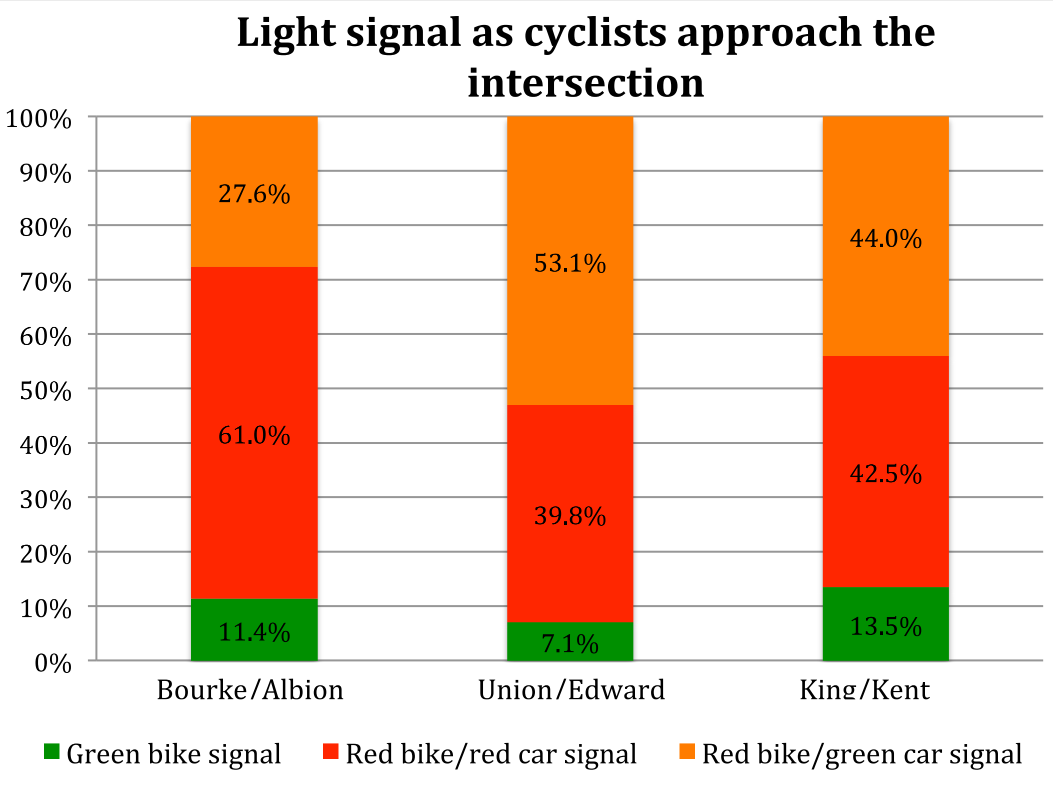
Table 3: Cyclist counts at intersections

Intersection	AM Peak	Noon	PM Peak	Total
Bourke/Albion	151	22	135	308
Union/Edward	224	16	167	407
King/Kent	251	9	140	400
Total	**626**	**47**	**442**	**1,115**

4.1 SIGNAL PHASE ALLOCATION AT INTERSECTIONS

At a traffic signal there are always competing demands for time within the signal phase. A cyclist approaching an intersection (unless that intersection uses coordination or advanced detection) will therefore always be more likely to encounter a red bike light than a green bike light. Nevertheless even considering the competing demands of other road users, the percentage of cyclists encountering green bike lights at the three intersections is low for trunk cycling routes (see Figure 3).

Figure 4: The signal that cyclists are encountering as they approach the intersection.



At the Bourke/Albion intersection there is heavy eastbound traffic on Albion Street heading towards Flinders Street and at King/Kent, the short block lengths require coordination along King Street in order to reduce heavy congestion. At both these intersections the opportunities to increase the green bike phase at the expense of other phases is limited. In order to increase the number of cyclists encountering a green light alternative measures would need to be considered such as splitting the bicycle phase (on King St) or introducing a new ‘flashing yellow’ bicycle signal. Both of these measures are discussed in Section 6.

Conditions at the Union/Edward Street intersection are different from the other two intersections. This intersection has the lowest number of cyclists encountering a green bike light (7.1%) despite having the least car traffic and the least influence on the surrounding road network. Car traffic on both Edward and Union Streets is relatively light. During the AM peak the number of cyclists on Union Street is greater than the number of motor vehicles (during the PM peak there are slightly more motorists; Bitzios 2011). Despite these relatively similar peak volumes, only 7% of cyclists approaching the intersection have a green bike light whereas 53% encounter a green car light (with red bike), this suggest that motorists are gaining a far larger proportion of the signal cycle than cyclists despite their numbers being roughly the same.

The Union Street Cycleway is a trunk route for cyclists on the west side of the city and is particularly important for cyclists commuting into the Sydney CBD. It has seen significant growth in use since its introduction and it is at least plausible that this rapid growth will continue. For motorists neither Union Street nor Edward Street is of particular significance to the overall road network. Given its network significance and that cyclist and motor vehicle numbers are relatively similar (during peak times), there is a strong argument for the cycleway being given priority at the intersection and being allocated the stretch phase[1] of the signal cycle. This would potentially greatly increase the number of cyclists encountering a green bike light as they approached the intersection.

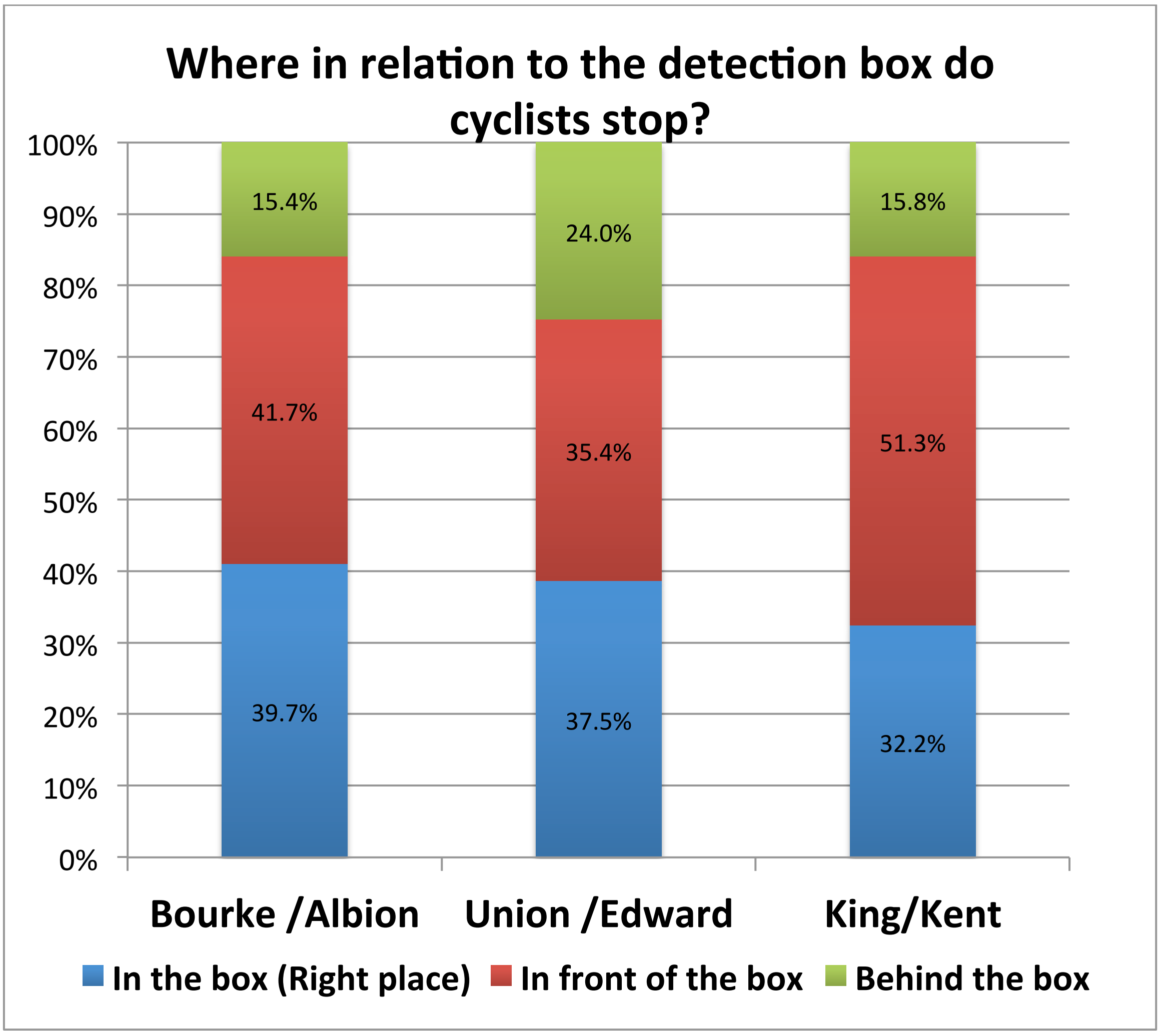
4.2 CYCLISTS USE OF DETECTION ZONES

There appears to be a very low level of knowledge of the correct usage of detection zones for induction loops that trigger signals by cyclists. Only 30–40% of cyclists are stopping in the correct location to trigger the bicycle signal phase, it is probably reasonable to assume that a fair proportion of these are doing so by ‘accident’, that is they are stopping there by chance rather than because they are aware of the method of triggering the signal change.

The video footage shows the majority of cyclists are stopping ahead of the detection zone, most likely because this conforms to cyclist’s behaviour at non-cycleway intersections where cyclists tend to roll through traffic waiting at a red light to reach the front of the intersection. This has a number of benefits for cyclists: they increase their visibility and thus safety and avoid vehicle exhausts. This behaviour has been legitimised through the creation of ‘advanced stop lines’ at intersections with cycling facilities in many countries (see for example Johnson *et al.* 2010).

[1] The stretch phase is allocated to the major road at an intersection; unlike the other phases the stretch phase must always be called during a signal cycle and never terminates early. If other phases are not called or terminate early (due to lack of traffic) the extra time in the cycle will be allocated to the stretch phase.

Figure 5: Cyclist stopping position in relation to detection box

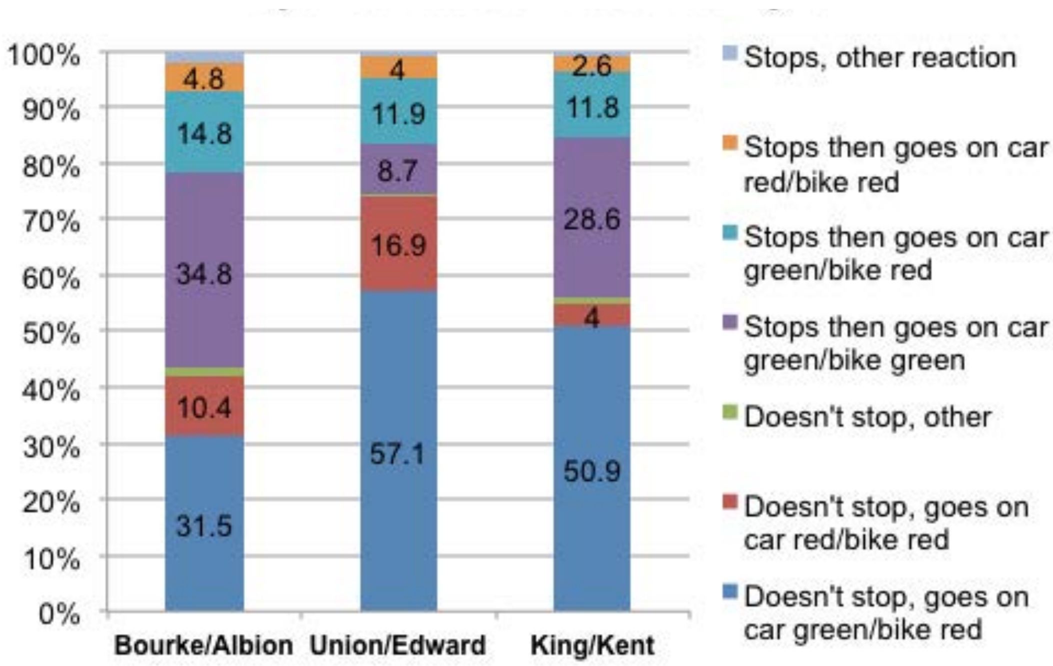


None of the intersections analysed had any marking showing the location of detection zones for cyclists. A clear result of this research is that cyclists are unaware of the correct usage (and in many cases existence) of signal detection equipment. There is a clear need for improved markings of detection zones and communication to cyclists of how to use them to trigger signals. These recommendations are discussed further in Section 6.

4.3 CYCLIST BEHAVIOUR AT RED LIGHTS

At all three intersections less than half of all cyclists who encountered a red bike light stopped and waited for the light to turn green. However it should be noted that in the vast majority of cases cyclists are following the directions of the car traffic signals as they would when riding on a non-cycleway road (See Figure 6). To use Wu *et al.* (2011), categorisation most cyclists running the red lights appear to be ‘opportunistic’ rather than ‘risk takers’. Cyclists appear to be making their own assessment of danger based on their understanding of the car signals and using this to guide their decision of when to cross through the intersection. This assessment is supported by our observation that the vast majority of cyclists check for cars behind them to see if any are turning left before entering the intersection.

Figure 6: Cyclist reaction to a red light

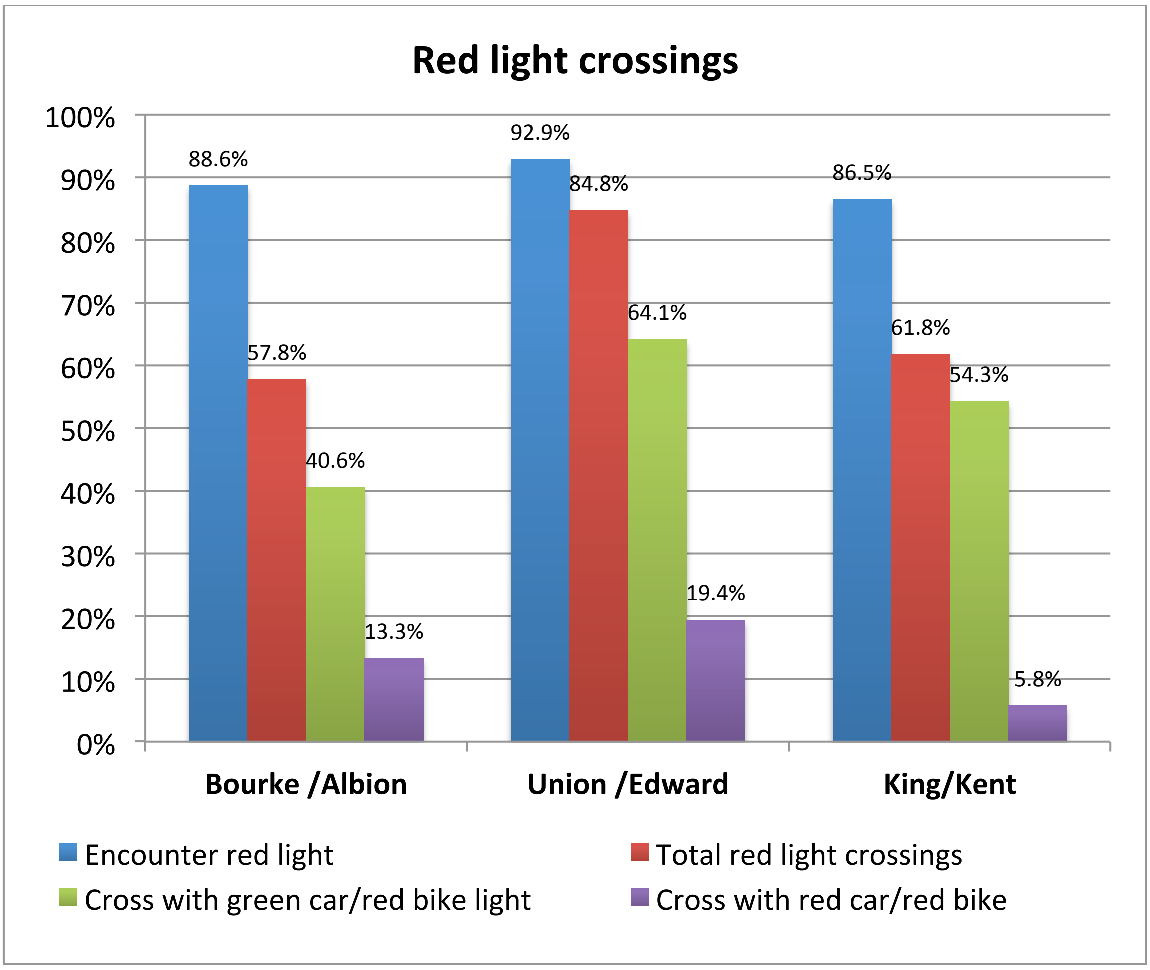


Nevertheless despite the fact that cyclists are assessing that crossing at a red bike light is relatively safe it still does involve some risk. There is the risk of being hit by a car travelling through the intersection perpendicular to the cyclist, however in this case both cyclist and driver are relatively visible to each other and so the incidence of this type of accident should be relatively small. Probably the greater risk to the cyclist is from cars that are behind them and in the lane to their right who wish to turn left across the cycleway. In this case it is quite possible for the cyclist not to be visible to the driver and left turning drivers were found by Johnson *et al.* (2009) to be the most common cause of accidents between cyclists and drivers.

There are a number of options available to attempt to lower the number of cyclists engaging in red-light running. One option would be to increase enforcement of signal compliance by cyclists. However if this were undertaken before any changes were made to signalling along the cycleways, travel times for cyclists would appear unduly long and lead to high levels of dissatisfaction. If cyclists feel they are always having to stop at intersections (due to a low share of the signal time), are not able to trigger the bicycle phase (because they have not been informed as to how to do this) and are being fined even in low traffic conditions, the generalised travel cost of using the cycleway would far outweigh the benefits and many may transition back to riding on the roads despite the decreased safety.

The use of a flashing yellow bike signal may help to increase compliance with dedicated cycleway signals. This would show cyclists when they may proceed with caution but would also act to highlight the high risk potential of the red bike light for cyclists. Cyclists would know that the red bike signal no longer represented periods of low and high risk but now only was present at periods of high risk. This option is discussed further in Section 6.

Figure 7: Red light crossings by cyclists



5 RECOMMENDATIONS

ISF worked closely in conjunction with Bitzios Consulting who were undertaking the ‘Sydney CBD Cycleways: Traffic Signals Optimisation’ study, sharing results and numerous discussions relating to the options for these intersections. ISF believes that the recommendations developed by Bitzios can potentially generate significant improvements in compliance and the conditions for cyclists at the three intersections.

ISF would also like to add some further brief commentary to some of these recommendations where we feel that key results of this study significantly strengthen the justifications for the recommendations. In general however the results of this study concur with all the recommendations developed by Bitzios.

ISF would also like to make some further recommendations arising from suggestions made during a stakeholder workshop held on the 10th November 2011 at the City of Sydney.

5.1 BITZIOS CONSULTING'S RECOMMENDATIONS

The recommendation by Bitzios Consulting are listed here for easy reference.

RECOMMENDATIONS

As a result of this study, Bitzios Consulting submits the following recommendations:

CYCLEWAYS IN GENERAL

1. The specification for the installation of bicycle loop detectors should be modified to ensure that the loop wires are installed as close as possible to the kerb (or the left hand side of the cycleway lane) and are installed at the minimum feasible depth.
2. RMS and Council should conduct a trial of cyclist handrails at several intersections where there is currently no automatic introduction of bicycle phases, to assess the effectiveness of handrails in encouraging cyclists to stop and remain within the bicycle detection zone.
3. RMS and Council should jointly develop and deploy an education and awareness campaign targeted at cyclists likely to use cycleway signals. Such a campaign should explain the benefits of the cycleways but also the cyclist's responsibilities and the different riding techniques required to get the best experience.
4. RMS should investigate the legal, technical and policy issues associated with flashing yellow bicycle signals for potential use in situations where there is minimal conflict with cyclist movements.
5. RMS and Council should jointly analyse the relative volumes of cyclists and motor vehicles at all of the cycleway intersections, with a view to exploring the potential for providing either more green time for the bicycle phase or better coordination for major cyclist movements between adjacent intersections.

TCS 283 – KING AND KENT STREETS, SYDNEY CBD

6. RMS, in consultation with Council, should consider, and possibly trial, an additional phase in order to adjust the timing of the King Street bicycle phase and provide eastbound coordination for cyclists (as described in detail in Section 8.2 and Figure 8.1).

TCS 26 – ALBION AND BOURKE STREETS, SURRY HILLS

7. RMS and Council should conduct a trial of cyclist handrails at this intersection.

TCS 3202 – UNION AND EDWARD STREETS, PYRMONT

8. RMS should trial the automatic introduction of the bicycle phase (C phase) during the periods of peak cyclist flows (typically 0730 to 0900 and 1630 to 1930 on weekdays)
9. RMS and Council should conduct a trial of cyclist handrails at this intersection.
10. RMS should trial the automatic introduction of the 'P1' pedestrian feature (on the northern side of the intersection) during the AM and PM pedestrian peak periods.
11. RMS should investigate the potential for coordination of this intersection with the Union and Pyrmont Streets intersection in the AM peak, and with the Pyrmont Bridge Road/Murray Street/Darling Drive intersection in the PM peak period – for eastbound and westbound cyclists, respectively.

5.2 COMMENTS ON BITZIOS CONSULTING'S RECOMMENDATIONS

ISF would like to add these comments in relation to the Bitzios Consulting's recommendations:

Recommendation 3: ISF would like to specifically add that the 'different riding techniques' taught in the education campaign should include information on the use of detection equipment.

Recommendation 4: ISF understands there are potentially regulatory and legislative barriers to the implementation of this recommendation in the short term. However the results of this study suggest that this may be potentially among the most beneficial of the recommendations in the medium to long term.

The high incidence of red light crossing may be a result of a perception amongst cyclists that the current bicycle signals on cycleways is overly cautious. There is always a trade off between safety and efficiency in traffic signalling and it may be that the benefits of increased safety are being outweighed by the costs of increased travel time. Cyclists appear to be making their own assessment of danger, and while risk in most instances is low, there is always a possibility that individuals will misjudge low and high-risk situations. The creation of a yellow flashing signal would serve to re-legitimise and emphasise the full red signal in the eyes of cyclists highlighting the dangers of crossing on a red bike light.

Recommendation 5: ISF agrees that the results of the ISF and Bitzios Consulting studies suggest a more thorough examination of cycleway traffic needs to be undertaken with consideration given to increasing green signal phase time for cyclists on key routes. This point is discussed further below under ISF Recommendation 4.

5.3 ISF RECOMMENDATIONS

On 10 November 2011 a stakeholder workshop was held including participants from RMS, City of Sydney, Bike North, UTS and Bitzios. This workshop discussed the preliminary findings of the ISF and Bitzios studies and possible options for improving intersection conditions along the cycleways. Based on the intersection analysis and the stakeholder workshop ISF would like to propose the following further recommendations, which are discussed further below:

1. Implement more effective marking of bicyclist detection zones at cycleway intersections.
2. Trial confirmation of detection equipment on key cycleway intersections.
3. Explore the potential of using flashing yellow left turn arrows for cars at King/Kent and Union /Edward Street intersections.
4. Develop criteria for assessing when bicycles will be given signalling priority.
5. Develop a monitoring strategy to investigate whether implemented changes have resulted in a positive impact on cyclist compliance with signals.

The expected time frame for implementing recommendations are graded as follows:

- Short term – Up to 12 months.
- Medium term – 1 to 3 years.

- Long term – More than 3 years.

1. **Implement more effective marking of signal detection zones for cyclists at cycle ways intersections (using existing markings short term and designing new markings for short to medium term).**
The intersections studied did not have any marking of the detector zones during the study period. Effective markings of the detector zone is considered an essential requirement of educating cyclists in the use of detection equipment and should be considered a requirement at all intersections where detection equipment is installed. The current marking used to indicate the presence of a bicycle detector is a diamond, however the stakeholder workshop identified that a symbol with a more obvious meaning would be preferable (e.g. bike symbol, traffic symbol or wording such as 'stop here'). It is recommended that further investigation into the ideal design for detector zone marking be undertaken.

2. **Trial confirmation of detection equipment on key cycleway intersections (short term).**
The City of Sydney representatives at the stakeholder workshop considered the use of confirmation of detection equipment at key cycleway intersections particularly important. The CoS representatives felt that faulty detector equipment had caused the cyclist community to lose trust in the workings of the signalling systems and that the use of detector confirmation equipment would help to rebuild this trust. An important secondary benefit of this equipment is that it would help to educate the cycling community in how to successfully use the detection equipment. It is not necessary for confirmation equipment to be installed at all intersections but its installation at a number of key intersections would probably bring significant benefits.

3. **Explore the potential of using flashing yellow left turn arrows for cars at King/Kent and Union /Edward (medium term).**
The use of flashing yellow car lights at King/Kent and Union/Edward Street intersections would indicate to cars that they are only able to turn left with caution. This would increase their awareness of the presence of cyclists travelling through the intersection along the cycleway. Further investigation of the legal and regulatory implications of this option would be necessary prior to trialling.

4. **Develop criteria for assessing when bicycles will be given signalling priority (medium term).**
SCATS is a real-time traffic management system that is designed to optimise traffic flows to increase safety and minimise congestion. In order to achieve these objectives it is necessary for it to prioritise movements based on existing traffic conditions and loads.

   However most agencies now accept that there are a number of reasons why the greater use of sustainable modes of transport, such as public transport and cycling, would be beneficial. The optimisation of movement of existing traffic loads, which are currently car dominated, may in some instances suppresses the growth of active transport modes like cycling

   There is already in many jurisdictions precedence for buses and trams receiving prioritisation at intersections but, as far as we are aware, no guidelines for when cyclists could receive prioritisation. Prioritisation could include automatic phase calling, longer and/or more bike signals and allocation of the ‘stretch’ phase[2] to cyclists in some cases. The criteria could assess such factors as overall car and bike numbers, optimal use of road space, the effects of delays on other parts of the road network, infrastructure provision, projected growth and the assignment of certain roads as ‘trunk routes’ of a cycling network.

5. **Develop a monitoring strategy to investigate whether implemented changes have resulted in a positive impact on cyclist compliance with signals (short to medium term).**
   As options are trialled on the cycleway it is important that these are monitored to see what effect they are having on cyclist compliance, safety (of all road users) and travel times for cyclists on the cycleway.

6. **Develop guidelines for the choice of cyclist detection technologies at intersections.**
   Loop detector technology, when installed close to the kerb and at the minimum depth and highest controller sensitivity feasible, is the most reliable technology for the detection of cyclists currently available. However in some cases specific road conditions or physical constraints (such as drainage pits) at intersections can reduce the effectiveness of loop detectors. In these cases the use of alternative detection equipment may be more appropriate. CoS and RMS should continue to trial other technologies to find reliable alternative detection technologies that can be installed where loop detectors are not appropriate.

[2] Each traffic signal runs on a cycle that includes a number of phases. Each phase gives the opportunity for a different set of vehicles to move through the intersection. The stretch phase is allocated to the primary, or trunk road, at an intersection. Unlike the other phases, the stretch phase must always be called during a signal cycle and never terminates early. If other phases are not called or terminate early (due to lack of traffic) the extra time in the cycle will be allocated to the stretch phase.