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AN ANALYSIS OF CYCLISTS CRASHES TO IDENTIFY ITS-BASED INTERVENTIONS

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ABSTRACT

Cycling provides a number of health and environmental benefits. Cyclists are more likely to suffer serious injury or be killed in traffic accidents than car drivers and the estimated cost of crashes in Australia is $1.25AU billion per year. Current interventions to reduce bicycle crashes include compulsory helmet use, media campaigns, and the provision of cycling lanes, as well as road user education and training. It is difficult to assess the effectiveness of current interventions as there is no accurate measure of cyclist exposure in South East Queensland (SEQ). This paper analyses cyclist crash characteristics in Queensland with the view to identifying appropriate Intelligent Transport Systems (ITS) based intervention to reduce cyclist injury and death. The inappropriateness of some ITS interventions to improve cyclist safety is highlighted and a set of ITS interventions are identified, based on Queensland crash data 2002-2006.

Key words: Cyclists, ITS

INTRODUCTION

There are a number of benefits associated with cycling. Regular physical activity provides significant health benefits, reducing the risk of chronic illness such as cancer, cardiovascular disease (1). Countries where active transport is a popular option have lower obesity rates (1). Pollutants generated by cars also have health impacts and are associated with respiratory cancer, asthma, cardiopulmonary disease and irritation of the eye, nose and throat (1). Noise pollution, linked to vehicle traffic, can contribute to hearing loss, heart disease, sleep disruption and decreased mental wellbeing (1). There are environmental benefits in addition to the health benefits. Approximately half the greenhouse gases generated by an average Australian household are produced through transport (2) with petrol-fuelled passenger cars produce 0.3kg of CO₂ per kilometre travelled while a cyclist has negligible emissions (2). Vehicles also produce significant indirect pollution (manufacture, delivery, infrastructure required). The construction of one medium-sized car creates 41 tonnes of CO₂ equivalents, while a typical commuting bicycle requires 0.75 tonnes of CO₂ equivalents (2).

Safety is considered an important factor in limiting the number of trips made by bicycle (3). In the UK cyclists account for 1% of road users, but represent 5% of all road fatalities and 7% of all serious injuries. Per kilometre, cyclists are 14 times more likely to be killed or seriously injured in road accidents compared with car drivers.
The cost of bicycling injuries and fatalities in Australia for 1997 was estimated at $1.25AU billion (4). The social cost of bicycle crashes in Queensland for 2006 was estimated at $35.4AU million and $20.9AU million for SEQ (5). Bicycle crashes and injuries are underreported. The underreporting is more extensive than any other transport mode (6). It is acknowledged that relying solely on reported motor vehicle crash data will underestimate the magnitude of the cyclist injury problem, but it is likely to be highly representative of crashes that require hospitalisation and those that are bicycle-vehicle collisions (7).

Analysis of UK data shows common characteristics of bicycle crashes (Stone & Broughton, 2003). Crash incidence is higher in daylight hours, although fatality rates are highest at night on unlit roadways. Bicycle crashes are most likely to occur at intersections (8, 9) followed by mid-block. Fatalities are most likely to occur at slip road junctions followed by mid-block. Initial impact is most likely to occur at the front of the bicycle while fatalities are most likely to occur when the cyclist is struck from behind (8). Speed of collision is an important factor. A cyclist has 95% chance of survival following a crash with a car travelling at 32kph, survival rate is reduced to 15% when car speed is doubled (3). North American crash data shows that 96% of reported bicycle collisions involved another type of vehicle (9). 93% of police-reported bicycle crashes in Western Australia involved at least one other vehicle. To highlight the underreporting in police data, West Australian hospital admission data found 16% of cyclists treated were involved in bicycle-vehicle collisions (10).

When questioning benefit of improving cyclist safety, it is important to note when roadways approach or exceed capacity, every additional vehicle adds to travel time for all vehicles. Replacing vehicles with even a small number of bicycles reduces demand and creates benefits for all users (11). Cyclists’ gain more from road safety than other road users, and research indicates more people would cycle short journeys if cycling was made safer. Where safety programs have been introduced, limiting traffic speed, bicyclist casualties have been reduced by 10-30% (3).

The aim of this paper is to explore the characteristics of Queensland metropolitan bicycle crashes. Crash data from Queensland Transport was analysed to identify characteristics and major factors contributing to cyclists crashes. The analysis allowed us to identify the most relevant ITS interventions.

**REVIEW OF CURRENT CYCLING INTERVENTIONS**

**Helmets**

Compulsory bicycle safety helmets laws were introduced in Queensland in 1991. Research indicates that helmets offer protection against head and brain injury but not neck or facial injury, with some indicating higher rates of neck injury for helmet wearers (12). The reported use of helmets increased following the introduction of the legislation (for children and commuter cyclists) (13). There was a strong relationship between increased helmet use and a reduced percentage of skull fractures and head wounds. However, the proportion of individuals suffering brain injury or concussion remained constant (14) and the proportion of cyclists admitted to hospital with head injuries only declined by 13% (14). There was a greater reduction in the
percentage of cyclists presenting with head injuries following bicycle-vehicle crashes, although this was attributed to other initiatives targeting speeding and drink driving. Australian research in the few years following showed that while there was an increase in helmet usage there were fewer people cycling (15), although this did not occur in Canada (16). Canadian researchers indicated the need to consider the impact of alternative activities on cycling rates (16). The effect of introduction of helmet laws on current generation may differ, as the laws are already in place and it was not necessary to change attitudes and behaviours. Helmet usage influences driver behaviour, with a study finding that drivers treat non-helmet wearers with more caution (17).

**Media Campaigns**

In Queensland, the State Government produced the “Share the Road” campaign, designed to educate motorists and cyclists on safe road behaviours and legal responsibilities. The campaign featured in various forms of media: television, newspaper, radio and promotional items (t-shirts, driver trainer promotion, bumper stickers and reflector stickers) (18). The authors are not aware of any evaluation of this program.

**Cyclists Visibility**

Research into reflector use has demonstrated that all configurations of reflectors have been shown to increase visibility of vulnerable road users at night, with recognition distances 60-80% greater when reflectors attached to limbs compared with torso (19). Investigations have shown that the benefit of static or moving reflectors does not transfer to high clutter environments (20). Research also indicates that the use of visibility aids improve detection during daylight hours, specifically fluorescent materials (yellow, red, orange) enhancing detection and recognition (21). It is not yet known the effect that visibility aides have on cyclist safety.

**Bicycle Facilities**

Research on the efficacy of specific bicycle facilities has been centred in Europe. Following the construction of cycle lanes, as a lane between the curb and parked cars, there was a fall (10%) in total number of crashes. There was a 4% reduction in crashes in road sections between junctions, while there was a significant increase (18%) in crashes and injuries at intersections (22). This data also includes mopeds restricted to cycle paths when top speed is 30kph. The provision of cycle lanes reduced the following types of incidents: car and cyclist travelling in the same direction (63%), cyclist turning across traffic (41%), cyclist and parked car (38%). The following types of crashes increased after the construction of cycle lanes: multiple cyclist collisions (120%), right turning car against cyclist (129%), and left turning car against cyclist (48%) (22).

It has been shown cyclists feel safer when using cycle lanes compared to riding in mixed traffic. It has been shown in Europe that cycle traffic increased and car traffic decreased following the construction of cycle paths, while additional cycle lanes increased cycle traffic but had no effect on car traffic (22). It has been assumed that cyclist safety improves when segregated paths are constructed, as it reduces interaction with motorised traffic. Research indicates that it is not ultimately safer to ride on segregated paths, just generates in different safety issues (11).

**Skills and Knowledge of Road Rules**
To date there has been limited training to develop skills and knowledge of road rules for both drivers and cyclists. The Amy Gillett Foundation Australia has implemented the “Road-Right” program (23), a web-based road rules education program for learners. The program was implemented in August 2007 and is being trialled for 3 years. As yet there is no data to identify the effectiveness of such a program. To date Queensland has only produced an information sheet that listed ways driver trainers could educate learner drivers about sharing the road with cyclists as part of the “Share The Road” campaign (18). Currently the Amy Gillett Foundation is developing a national bike education program to improve cyclist skills and knowledge (23).

**Difficulties in assessing interventions**

Most methods to evaluate the effectiveness of road safety interventions on exposure have some knowledge of the kilometres travelled, or the number of vehicles on the road. Currently there are no systematic counts of bicycle numbers in SEQ. Unlike motor vehicles, bicycles do not require registration., Riders do not require a license and insurance is not compulsory. It is therefore difficult to gather accurate numbers of bicycles in this way. It may be possible to assess bicycle usage by secondary data such as bicycles sold. This data is collected by Bicycle Industries, Australia. The primary issue with the use of existing data is: Does it accurately count the total number of bicycles in use? It does not account for single owners of multiple bikes, or those who purchase a bicycle but do not ride. And this information does not provide information about the facilities cyclists used or how far the cyclist travelled.

The Australian Bureau of Statistics monitors bicycle usage throughout Australia. The most recent survey estimates 46.6% of Queensland households had at least one bicycle in working order, with approximately 37.4% of cyclists riding once a week (8.3% daily) while 40.2% rode less than once a month (24). This survey does not provide sufficient accurate information regarding the number of trips, the facilities used, or distance travelled to determine exposure. This survey also excludes approximately 25% of the population involved in reported crashes (those 16yrs or younger). A survey of Queensland residents was conducted on behalf of BCM Partnership and Queensland Transport to determine bicycle usage, gathering specific data about distance travelled. SEQ respondents (53) gave the following as the most frequent distances travelled: 4-5km (22%), 9-10km (21%), 6-7km (11%), with 2-3km and 20+km equal on 10% (25).

**Increasing use of technology to protect vulnerable road users**

There are three broad categories of ITS designed to enhance road safety: vehicle-based systems that usually combine sensors to collect data and units that process data and convey messages or warn the driver; infrastructure-based systems with roadside units that collect data to provide information to the driver through roadside equipment; and cooperative technologies that gather information from infrastructure and/or other vehicles and convey information to the driver. Systems may be “passive”, “active” or combined active and passive (“CAPS”). Passive systems minimise crash severity at impact, usually of the vehicle occupants. Some systems have been designed to improve pedestrian safety. For example Honda has designed a pedestrian protection system, such as a wiper system and other hood features designed to cushion the force if struck by the head of a pedestrian. However the effect on cyclist safety is not yet understood. Active systems are designed to prevent crashes occurring while CAPS systems serve both functions.
To date there has been limited research into ITS and bicycles. The vehicle type that is the most comparative to the bicycle is the motorcycle. Unique vehicle properties of motorcycles (27) that require particular consideration are: size, which makes it more likely they will be obscured by other vehicles and objects, and are more difficult to detect in high-glare conditions; stopping distances are different and also difficult and dangerous in slippery conditions; indicators are not self-cancelling and for cyclists indicating requires the removal of hands from the steering system which is difficult when cornering or for those less skilled.

Violations of motorcycles right of way is often the cause of crashes, and is often attributed to a failure by other road user to notice the motorcyclist. Such characteristics are also common for cyclists. Detection can be affected by shape, luminance from environment, headlights, shadows, sound, movement and colour of motorcycle. It can also be a result of a failure in the perception or poor judgement of other road users. Drivers are not expecting objects other than cars on the roads. While the majority of ITS applications have been developed with car safety in mind, the following have been identified as beneficial for motorcycles: ABS, vehicle diagnostic systems, rollover threshold warnings, advance lighting systems, blind spot monitoring, intersection collision warnings, driver status monitoring systems, adaptive cruise control, traction warnings, weather warnings, curve speed warnings, active headlights, night vision, emergency brake indicators and driver fatigue systems (27). The issue of practicality and viability of adapting ITS interventions to bicycles has yet to be considered. The cost of installing technology on bicycles, cyclists’ acceptance and the Human Machine Interface (HMI), will remain the main issues.

When considering interventions applied to other vehicles to improve cyclist safety, it is important to view the limitations of current technology. Current sensor technologies (radars, cameras) relevant to vulnerable road users are unable to view behind obstacles, and have limited lateral and longitudinal scope. The primary constraining factors in detecting vulnerable road users are the limited visual acuteness of drivers and in-vehicle sensor systems (28).

Several EU projects such as PROTECTOR, SAVE-U and WATCHOVER have worked on vulnerable road users’ protection. The WATCHOVER FP6 project is designing and developing a cooperative ITS system to prevent crashes involving vulnerable road users. It has developed a system that has wider coverage to include blind spots. This has a simple, low cost on-board system with flexible architecture. Cars are fitted with video sensors and a communication device, with the vulnerable road user fitted with communication device (motorcycles have additional unit that provides an operator alert when risk exceeds threshold). The use of ITS to protect cyclists is still in its infancy, with no real application. There are currently no passive or active safety devices installed on bicycles. As yet there has been no serious research into the benefits of ITS-based intervention.

**Increasing number of cyclists due to health and green house issues**

It is difficult to establish the effect of recent media attention regarding health and environmental benefits on cycling numbers in SEQ. Bicycle sales have increased Australia wide, with sales averaging 795,000 per year for 1998-2001 1.1 million per year for 2002-2005 (29), and reaching 1.4 million in 2007 (30). Bicycle census data from Melbourne for 2007 shows an average increase of 10% for cyclists riding on the road and 20% on off-road routes for all times of the day
from the previous year. Cyclists’ accounted for almost 8% of morning peak vehicles, an increase from 4% the previous year (31). Accurate historical data specifically for Queensland is difficult to obtain, with the most recent research indicating that there has been an increase in bicycle uses in Inner Brisbane (12km radius of CBD) in the decade to 1996, with an overall increase from 0.5%, as the share of transport mode, to 3.0% (26). In addition to the previously outlined difficulties, there are limited bicycle usage counts available. There is some count data available for segregated bicycle facilities, but as yet there are no counts available for the number of cyclists on the road network sharing with other vehicles. In the absence of reliable count data, calculating risk exposure is problematic.

CRASH CHARACTERISTICS

Analysis was conducted on reported road traffic crashes in Queensland from (2002-2006), that are completed by Queensland Police Service officers attending traffic incidents. Crashes recorded in the Queensland Crash Database must have occurred on recognised roads (or bicycle facilities), governed and maintained by Local or State governments. It does not include crashes that occurred on private property. Reported crash features property damage greater than 2500 AUD, or at least one vehicle was towed away, or resulted in minor injury, medical treatment, hospitalisation or fatality.

**Location**

Crashes involving bicycles occurred at intersections (54.01%), with the most common being at T junctions (Figure 1). The majority of on-road reported crashes occurred in mixed traffic conditions, where there is no bicycle facility.

**Time**

There are two peak times for bicycle crashes: 3pm to 6pm when 31% of crashes occurred, and 6am to 9am when 27.4% of crashes occurred (Figure 2). This corresponds with Main Roads bicycle counts, where greater numbers are recorded at these times (32). The majority of crashes
(81%) occurred in daylight conditions and 12% occurred in night conditions (88% of night conditions occurred in areas with street lighting), which correspond to time of day results.

Road users involved in reported bicycle crashes

Of the reported bicycle crashes, most (93.3%) incidents involved a cyclist and one other motorised vehicle. Five percent were single vehicle accidents, while 1% of reported crashes were multi-bicycle incidents. Less than 1% of crashes involved pedestrians (Figure 3). When examining cyclist serious injury (hospitalisation and fatality) rates with vehicles involved: crashes with 4WD 30.7 serious injuries per 100 collisions; 46.7 serious injuries occurred for every 100 crashes involving trucks, and 33.3 fatalities for every 100 bicycle-car collisions. This demonstrates that vehicle type has impact on fatalities, although it should be noted that 4WDs are no more of a threat to cyclist safety than passenger cars.

Crash Type

Two types of crashes accounted for over 40% of crashes. Intersections with vehicles approaching from adjacent directions had the highest with 26%, with a vehicle leaving driveway 17% second (Figure 4). Of the crashes that occurred at intersections, 48.9% had traffic control. With other accident types, 82.2% occurred with no traffic control. Overall, 68% of crashes occurred where there was no traffic control, 15% where there was a give way sign, 11% where there were traffic lights, 4% where there were stop signs, and 1% occurred at pedestrian crossings.

Who is at fault?

For the majority of crashes (56.6%), the cyclist was not at fault. For crashes involving children aged 0-16, they are more likely to be the at fault vehicle (74.2%). Crashes involving cyclists 17yrs and older, cyclists were at fault in 27.6% of the incidents. Passenger vehicles were most likely to be at fault in of bicycle-vehicle crashes (Figure 4 & 5).

Crash Severity

There are five levels of crash severity in police reports. Of the crashes reported to police, 25 (1%) cyclists were killed in road crashes, 852 (34.3%) were admitted to hospital, 999 (40.2%) required
medical treatment, 607 (24.4%) received minor injury that required no treatment and there were no reported property damage only crashes. Cyclists are more likely to be at fault in more severe crashes (at-fault in 56% of fatal crashes, 51% of crashes resulting in hospitalisation), although in crashes requiring medical treatment and minor injuries cyclists were at fault 37% and 43% of the time respectively (Table 1).

Figure 3. Road users involved in police-reported bicycle crashes.

* = motorcycle, car, 4WD, utility/panel van, † = truck, bus, articulated vehicle, ‡ = special purpose vehicle, rolling railway stock, animal, wheeled recreational vehicle.

Figure 4. The percentage of bicycle crashes where the cyclist was deemed at fault.

Figure 5. Road user at fault in bicycle crashes, cyclist 0-16yrs (L) and cyclists 17+yrs (R).

**Contributing factors**

Typical crash factors such as alcohol, speed and fatigue do not feature in bicycle crashes, identified in only 3% of all crashes. For crashes where cyclists are at fault, negligence (33%) and inexperience (17%) are the most common factors. Combined other circumstances (lighting, atmospheric conditions, vehicles entering driveway, animal uncontrolled on road) are third highest (9.5%), with disobeying traffic lights or sign contributing to 7% of crashes. When other road users are at fault, inattention (18.6%), disobey traffic lights or signs (16%) and disobeying other road rules (14%) are the three most frequent contributing factors. When specific factors are examined, traffic violations account for the largest number: disobey give way sign, undue care and attention, turn in the face of oncoming traffic, inexperience/lack of expertise and opening a car door causing danger (218, 341, 191, 101 and 98 crashes respectively).

Table 1. Cyclist fault in crashes and associated crash severity.
The majority of crashes involving bicycles occur on dry sealed roads (96.1%), with few accidents reported on unsealed roads. The horizontal alignment of locations where bicycle crashes occurred was investigated, with 97% occurring on roads with open view (straight road, open view curves). This indicates that visibility should not be an issue in the majority of crashes involving bicycles. Most bicycle crashes (96%) occurred in clear conditions, with only 3.5% occurring in rain.

**Severity of crashes based on speed limits**

Major transport corridors in urban areas, and areas that have high residential populations have speed limits between 50-70kph. Therefore it is logical that following the analysis of crash data the majority of crashes (92.1%) occurred in these speed limits, and exceeding the speed limit was a minor contributing factor (Table 2). While crashes were reported in speed zones between 10kph and 30kph, no fatalities were recorded and few hospitalisations, indicating that at low speeds result in greater safety for cyclists. At speed limits of 80kph and 100kph, fatality rates increased. Fatalities as a percentage of the number of crashes increased as speed increased, with 0% for 0-30kph, 0.7% for 40-70kph and 11% for 80-110kph.

**DISCUSSION**

Our analysis on time (daylight) and location (intersections) of cyclist crashes are consistent with European findings (ref WATCHOVER). As most of crashes occur in daylight, ITS interventions aiming at increasing cyclists night conspicuity would have limited impact. The large proportion of cyclists hit by a vehicle in face of on coming traffic and hit from behind are also consistent with EU trends. The EU SAFETYNET project (2002) analysed bicycle crashes in 14 EU countries and found that 39.35% of pedal cyclist fatalities were related to lateral collision with another vehicle and 17.98% with chain or rear collision with another vehicle.

In most of the reported crashes (EU and Australia), the cyclist was in the driver’s field of view (97% on open view). ITS interventions based on vision processing or radar technology would be
suitable to locate the whereabouts of the cyclist and warn the driver accordingly. GPS devices are not appropriate to locate potential cyclists at intersections due to their inaccuracy (5m). Theoretically, cyclists could wear cheap technology such as RFID tag or wireless device such as Bluetooth to allow in-vehicle receptors or readers to pinpoint cyclists using some triangulation mechanisms. However preliminary research findings from WATCHOVER did not recommend such technology based on robustness, accuracy and portability.

Caution must be used when transferring ITS approaches from motorcyclists to cyclists as variation in crash and injury characteristics, vehicle size, conspicuity and speed are different. Scooters and moped riders might have similar profiles and travel pattern to cyclists but is very limited research in such a field. There is a need to assess the difference between cyclists’ and motorcyclists’ psychological profile, trip purpose and ITS user acceptance. Factors influencing cycle and motorbike use are likely to be different, as health and wellbeing are among the top factors motivating cyclists but not necessarily the case for motorbike riders. Riders are usually reluctant to adopt any ITS technology that would alter their speed. The majority of bicycle trips are recreational, although many are for training or commuting (24).

Cyclists were not at fault in 56% of crashes involving other vehicles, indicating that ITS intervention on cars is likely to have an impact. Installing ITS technology on cars would not be burden to drivers in terms of relative cost whereas the cost of the technology may exceed the cost of a bicycle. Recent ITS research on cooperative systems based on Vehicle to Vehicle (V2V) or Vehicle to Infrastructure (V2I) network can be applied to increase the awareness of crash risks between road users on intersections. Intersections could be fitted with sensors (e.g radar, camera, RFID reader) that would locate the whereabouts of cyclists and wirelessly transmit the information to the relevant vehicle (V2I). Such information could also be gathered from vehicles and transmitted to the infrastructure or other vehicles for analysis.

The EU SAVE-U project found that 48.9% of cyclists’ crashes occurred in the initial vehicle speed range of 50-80 km/h. Our analysis in SEQ found that fatalities as a percentage of the number of crashes increased as speed increased. Exceeding the speed limit (cyclist or vehicle) is not an issue having much impact on the safety of cyclists, however road speed limits influences crash severity. It is likely that the reduction of speed limits could improve cyclist safety, as well as having benefits for other vulnerable road users and all road users in general.

**Study limitations and strengths**

The absence of comprehensive information such as bike counts or kilometres travelled, the fact crashes are underreported limits the validity of our analysis. We do not have access to advanced crash investigations that would help deepen our understanding crash circumstances.

By using police-reported crash data we narrowed the analysis to crashes that result in significant injury or bicycle-vehicle crashes. While these may not wholly representative of crashes, they are the crashes that involve the most cost and are crashes where ITS interventions could be applied.

**CONCLUSION**
This paper examined the characteristics of bicycle crashes that occurred in urban areas and identify potential ITS interventions, or inadequacies in current interventions. Research in this field is new. There is debate over the effectiveness of other interventions (helmets, provision of cycle lanes). With ITS a developing field, we should investigate new ways which may improve road user safety. In all new areas of research it is important to gain an understanding of fundamental factors underpinning an issue to advance knowledge, though identifying and redressing gaps. This current analysis provided some, but not definitive, support for the relevance of ITS to improve cyclist safety. The following conclusions can be drawn. In-vehicle technology should help reduce bicycle crashes, as most reported crashes involved a second motorised vehicle. Inattention, or failure to notice the cyclist, is a contributing factor frequently reported. Vision-based or radar ITS interventions would assist the driver to locate cyclists and avoid collisions. And as most crashes occur at open view locations, the benefits should be maximised. As the majority of crashes involving bicycles occur in daylight the benefits of night-specific ITS interventions (night vision camera) would be limited. Future research is needed to identify and quantify personal, economic, cultural and environmental factors that would characterise cyclists to determine the most appropriate ITS based intervention.

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