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Enhancing safety for cyclists through infrastructure design

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Abstract

Cycling is likely to be an increasingly popular transport mode. Motivating factors include our outlook on sustainability, health effects, environment and resource issues. However, cycling is perceived to be, and remains, a relatively unsafe mode. An important objective of this research is to develop a catalogue of technologies for improving bicycle safety and to prescribe guidelines for implementing most suitable treatments in the Townsville-Thuringowa urban area in Queensland, Australia. The assessment of locations requiring special treatments is undertaken through an analysis of bicycle crash data over the last five years using the Queensland Transport software WebCrash 2. Other key inputs into this research include an inventory of bicycle infrastructure in the Townsville region, a report on the condition of the bicycle facilities and perceived deficiencies. Improvements to physical road features are proposed. Bicycle Compatibility Index, a measure of cyclists' comfort, has been estimated at various locations in the region. Continuing work will deal with the effect of various treatments on cyclists' comfort levels.

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Introduction

Cycling performs an important transport role and it is essential that planners, designers and managers should provide necessary facilities for cyclists. Cycling is likely to be an increasingly popular transport mode. Motivating factors include our outlook on sustainability, health effects, environment and resource issues. The efficient transportation of goods and people requires a balance between vehicular transport and other means in order to "…improve living conditions for both road users and urban residents". This aim cannot be reached unless safety conditions cease to be a deterrent to walking and cycling" (OECD, 1998, p.4). The trend of placing the rights of cyclists and pedestrians second to vehicles has given rise to a mind-set of inferiority from the vulnerable road users. The safety of vulnerable road users such as pedestrians and cyclists has been sporadically investigated since the early stages of transportation design and engineering because of the extreme attention paid to vehicular traffic since the sixtees.

However," . vulnerable road users are only now being taken into account on a larger scale" (OECD, 1998, p.186). In addition, the identification of contributing factors is hoped to provide an objective insight into selecting appropriate solutions. Changing motorists' perceptions so that they respect and accept the cyclists' entitlement to their share of the road space is necessary for safer travel. The mission is to ensure the integration of cycling as a valid form of transport within the overall transport network. Treating cyclists as peers on roads will reduce negative attitudes and behaviour that have in the past both led to accidents and discouraged other potential riders. An alternative to this is promoting the cyclists 'road rank' to above that of the motorist, especially at intersections. The increased disturbance to motorists and decreased traffic flows would generally outweigh this as a viable option, but could be of use in specific locations.

An important objective of this research is to develop a catalogue of technologies for improving bicycle safety and to prescribe guidelines for implementing most suitable treatments in the Townsville-Thuringowa urban area in Queensland, Australia. The assessment of locations requiring special treatments is undertaken through an analysis of bicycle crash data over the last five years using the Queensland Transport software WebCrash 2. Continuing work includes the estimation of Bicycle Compatibility Index and the effect of various treatments on cyclists' comfort levels at various locations in the region.

Bikeways

Basically bikeways can be classified into three groups – off-road bike paths (BP), bike lanes including shared bicycle/car parking lanes and exclusive bike lanes (BL) and shared mode lanes such as wide kerb lanes (WKL). Bike paths are physically separated from the roadway, bike lanes have a designated area on the roadway using a painted line, while in wide kerb lanes, the leftmost vehicle lane is extended in width to accommodate cyclists. The guidelines for selecting the type of bikeway are given in Austroads Guide to Traffic Engineering Practice, Part 14 – Bicycles (Austroads, 1993).

Bike Paths

Separate bicycle paths (BP) were recommended in the Netherlands at locations with vehicle speeds over 50 km/h or traffic volumes exceeding 1200 vehicles/h. Diepens and Okkema Traffic Consultants (1995) recommended one-way paths of at least 1.8 m and two way paths of no less than 2.8 m. However, this opinion was contradicted in a report by Ekman and Kronberg (1995) of a study involving experts from Denmark, Finland, Norway and Sweden, which found that while two way paths were cheaper, they were less safe for riders as it rendered merging with vehicles before the junction stop line impossible.

Bicycle lanes

Bicycle lanes (BL) are recommended in roadway situations where a high proportion of cyclists are relatively inexperienced (Wilkinson, Clarke, Epperson and Knoblauch, 1994). Harkey and Stewart (1997) noted that the separation of the bike lane from the vehicle path using a painted line, has resulted in fewer erratic driver manoeuvres and more predictable cyclist behaviour. Also, it had the effect of increasing comfort levels for both user groups. They found that the bike lane users maintained a greater distance (0.8 m) from the roadway edge than wide kerb lane cyclists (0.4 m). Interestingly, this appears somewhat offset by the finding that the passing vehicles allowed an extra 0.4 m for wide kerb lane users, compared to passing the cyclists in the bike lane. Consequently, they found motorists were much more likely to encroach into adjacent traffic lanes when wide kerb lanes were used, as opposed to bike lanes.

Wide Kerb Lanes

McHenry and Wallace (1985) observed that it was important to allow enough wide kerb lane (WKL) width to accommodate shared use but limited to prevent vehicles making two lanes at intersections. Wide kerb lanes are "…sometimes designated when right-of way-constraints preclude the installation of 'full width'" bike lanes (Hunter et al., 1999, p.5). The Florida DOT (1995) advises that wide kerb lanes are to be reserved for last resort use as "only five percent of bicyclists feel comfortable using these facilities."

Combined bicycle and bus lanes

Combined bicycle and bus lanes have been used with success (Hunter, et al. 1999). A popular design requires the cyclists to be located between through traffic lanes and the bus and left turn lane. It enables riders to travel with minimal disruption from stopping or departing buses. Designs incorporate the use of pavement marking to specify potential conflict points cyclists may encounter with passengers from the buses. The measures caused cyclists to slow down if a bus was stopped, and increased the distance for identifying the closest conflict point.

Relative safety of bikeways

Pein (2000) states that the increased pavement required for BLs can become affected by road debris, which compromise cyclist safety. The maintenance aspect is then often neglected. While WKLs may still require sweeping, it is of a greatly reduced level. An interesting side to the ongoing safety debate between the WKLs and BLs is that of funding availability for each option. In a study for Chapel Hill, North Carolina in the US, Pein identifies BLs as being an identifiable bike facility whereas WKLs (and paved shoulders) are not. This situation gives rise to a more limited source for the cycle specific BL funding, while support for WKLs allow the bicycle provision to be snugly placed in the shadow of the greater good of the roadway. That is, WKLs and paved shoulders can be backed using the much more substantial roadway funding. Another point in Pein's article is that BLs are often supported for the perception of safety they provide to inexperienced riders. A BL has the effect of teaching novice riders that they must remain in that space, no matter how unsafe it may be" (Pein, 2000, p.5). This is despite the legal recognition of cyclists as having equal right to use the roadway as motorists. An additional safety facet of WKLs is the reduced incidence of wrong way riding. Pein also supports the finding that motorists allow less distance between BL cyclists than WKL riders when overtaking. He also mentions common anecdotal knowledge from cyclists, that the WKL induces a speed reduction from the motorist due to heightened caution levels in response to the inherent ambiguities of a WKL. The use of BLs (or paved shoulders) is recommended on higher speed roads (70 km/h and above) with few intersections or driveways, limited high speed descents and turning movements for drivers and riders, with maintenance obligations. Too often BLs are used in low speed environments where a WKL could have sufficed.

Hunter et al. (1999) summed up their comparison of bike lanes with wide kerb lanes by crediting both as useful in certain locations and situations. They recommend the use of bike lanes where sufficient space is available, and that BLs would likely result in greater usage than WKLs. In support of this statement, they referred to Harkey, Reinfurt, Knuiman, Stewart and Sorton, (1998) who found BLs gave increased comfort levels, and findings such as in Rodale Press survey of 1992 that cyclists favoured BLs.

Bikeway Treatments

In the last few years, a variety of innovative, on-street treatments have been implemented to reduce bicycle/motor vehicle conflicts. A comprehensive literature search from around the world has revealed a number of treatments provided to improve safety for cyclists. These include bike boxes, raised bicycle lanes, bicycle boulevards, use of paint to delineate paths through intersections, defining bicycle/motor vehicle weaving areas, highlighting paved shoulders, and others. Factors influencing the choice of each treatment have been identified and the impact of these treatments has been examined in before-and-after studies. Public opinions and factual data have been collected to assess the effectiveness of various treatments. Some of these treatments for bikeways are discussed below (intersection treatments in next section):

Red-painted shoulders

This treatment makes the WKL appear no wider and reduces the encroachment of the adjacent traffic lanes by motorists. Hunter (1998) studied the use of 3 feet wide (approximately 1 m) red painted shoulders in Florida. The paint was "intended to offset the widening in a visual sense (i.e., make the road appear no wider)" (Hunter, 1998; p.1). The cost of painting the one mile (1.6 km) section of road on both sides was US$6600 IN 1996. Speed data, video, and questionnaires were used to compare the effectiveness of the treatment. It was found that full time use of the shoulder was about 80%, with a further 6% partially using the shoulder. Motorist encroachment into the other lane was reduced at locations with the red shoulders, and almost 93% of encroachments at the non-painted shoulder site were severe, compared to about 30% at the treated section. No vehicle to vehicle conflicts occurred at the treated locations, but there were eight such conflicts at the site without red shoulders. 80 per cent of survey responses indicated greater comfort levels due to the red shoulders. Importantly, the red shoulders did not promote any increase in vehicle speeds. Hunter concluded "…that the red shoulders have produced operational benefits for both bicyclists and motorists" (Hunter 1998; p.20).

Painting lines on both sides

A BL with painted lines on both sides has been implemented. Hunter, Stewart, Stutts, Huang and Pein (1999), found that if vehicle parking is to be included as part of a BL, a double striped 1.5 m BL that sets the outermost line no less than 0.9 m from the parked cars will "provide the best channelisation of bicyclists" (Hunter, et al., 1999, p.76). The authors specified a minimum of 2.4 m for vehicle parking. They noted that where right-of-way conditions make the double line BL unsuitable, a combination lane for both riders and parking can be used. This lane should have a preferred width of 4.3 m with parking bay corners marked. Comparison between this United States finding and the Queensland Department of Main Roads Manual of Uniform Traffic Control Devices (MUTCD) (2001) stance on combined parking and cycling lanes shows some differences. Firstly, they do not suggest using double stripes to delineate the extent of the bike lane. Either the bike lane extends out to the parking bay width or is narrower than the parking lane. Signage is used to inform riders and motorists of times the lane is for cycling and when it is for parking. Another noteworthy variation is that Main Roads recommend full bay marking to deter moving traffic from using it as a lane. They suggest sheltering the parking-cycling lane from through traffic with extended kerbs at the extremities. Finally, Main Roads place bicycle symbols on the lane, which should be recognised as having "…no legal significance when used on a roadway" (Department of Main Roads, 2001, p.9-15).

Rumble Strip

An extension of the bike lane concept in highway shoulder situations is the introduction of a rumble strip to mark the lane. In this study the strip was positioned on the bike lane side of the line. Khan and Bacchus (1995) observed that the likely frequency on paved highway shoulders of vehicle-bicycle crashes is significantly reduced compared to the sharing of lanes. The rumble strip effectively acts a warning device for drivers who may have veered into the bike lane. They recommend a shoulder width of no less than 1.5 m to allow for both cycle travel and rumble strip, for vehicle speeds up to 100 km/h. This opinion is supported in the Metropolitan Bicycle and Pedestrian Plan (Fargo-Moorhead Metropolitan Council of Governments, 2000) that specified rumble strips were recommended where shoulders are used by bicyclists if there was a minimum clear path of 1.2 m in which a bicycle could operate safely.

Intersection treatments for cyclist safety

According to Hunter, Stutts, Pein and Cox (1996), between 50 and 70 percent of bicycle-motor vehicle crashes can be attributed to intersections and intersection-related locations. Hunter et al (1999) state grade separation is an effective countermeasure to reduce intersection conflicts between bikes and vehicles, but that the associated costs mean the substitute of at grade treatments are more popular.

Bike lanes and wide kerb lanes at intersections

Wayne Pein (2000) identifies the use of BLs at intersections as potentially increasing confusion, while noting WKLs can allow bicycle functions without any greater complexity. He also points out that WKL manoeuvres are "not as formally legitimised as with BLs" (Pein, 2000; p.3), and that BLs can be used in an instructional capacity at intersections by limiting possible movements or using a striped line.

A clinical analysis of high conflict rate sites from crash data undertaken by Hunter, Stewart, Stutts, Huang and Pein (1999a), showed that conflicts can be consistently related to several factors. These are: "(1) presence of parked motor vehicles (either entering or exiting legal parking or illegal parking or stopping) in the BL or WCL, (2) presence of driveways or intersecting streets, and (3) provision of additional (usually turn) lanes at intersections that typically (but not always) resulted in a narrowing of the BL or WCL." (1999a, p.16) Countermeasures for these problem situations were delved into. For incidences involving parked cars, a recognised crisis occurs when there are part-time exclusive bicycle lanes (as in operation in Queensland) that effectively block cyclists outside of cycle-only times. Hunter et al. noted that this arrangement is only effective if prohibited parking times were properly enforced. They go further to recommend eliminating parking in those areas, so that cycle facilities are not disrupted. This measure would ensure total integration of cycling into the transportation network. Signage and enforcement need to accompany good design grounding to be valuable in discouraging illegal motorist movements. When driveways or intersecting streets are present and identified as problematic, signage and painted messages or chevrons to warn both driver and rider about pathway collision dangers are suggested. For road treatments, a tactic can be to provide stop bars for motorists and accompanied signage to warn the driver to be aware of cyclists. By dashing any BL lines, both driver and cyclist can be warned of a potential conflict. Where additional lanes have been provided at intersections. A dashed line to identify the zone of potential conflict from turning vehicles and straight-travelling riders is desirable. Advanced Stop Lines (ASL) are recommended to give riders prominence at intersections. An extremely noteworthy finding from the report is that most conflict cases could *not* be attributed to either a BL or WKL deficiency. The majority of conflicts could *not* have been avoided if the other facility was present. While standard bike facility designs are encouraged in order to foster a consistent approach, the freedom of movement cyclists enjoy requires a degree of design tailoring to properly account for frequent manoeuvres.

The Florida DOT (1995) has joined other American States in suggesting that bike lane stripes become dashed on approaches to intersections, to allow for the bicycles to merge with vehicles. In this way, turning manoeuvres can be completed as part of the flow, and not merely secondary to it. It recommended right-angle bike crossings with suitable sight distances at intersections. This is supported by the opinion that bicycling at intersections is considered safest with both modes combined (OECD, 1998). Austroads (1993) recommends double lined bike lanes that are dashed to intersections and linked to an Advanced Stop Line.

The Danish Road Administration (1994) studied signalised intersections where a white rumble strip separated the reduced-width bike lane from vehicles for about 25 m before the intersection. Analysis focussed on situations of turning vehicles reacting to cyclists ahead. The study found that driver behaviour improved and that the time interval for cyclists leaving potential conflict points increased. Only one quarter of drivers as before continued to turn right in front of a cyclist. It concluded that due to these observed behaviours, the expected safety of riders had improved.

Coloured bicycle crossings

Coloured bicycle crossings were studied at five intersections in Montreal, where pavement was painted blue at bike path crossing points (Pronovost and Lusginan, 1996). Raised awareness of potential conflict areas was expected to come about from the measures. The study found more cyclists remained on designated bike crossings and obeyed stop signs. This superior cyclist behaviour caused a reduction in conflict between riders and vehicles. This proved to be a very cost effective treatment.

European and Canadian cities had previously met with success using blue coloured bike lanes at intersections in order to reduce conflicts. For that reason, Hunter, Harkey, Stewart, and Birk (2000) studied the effects markings and signage at a selection of intersections in Portland, U.S. had on bike crashes. Blue colouring was selected for its non-biased meaning (as opposed to connotations with green or red, for example), its visibility in low light and wet conditions, and the fact that it can be recognised by colour-blind individuals. In addition, public survey results were overwhelmingly in favour of the light blue. Paint and glass beads were applied in the first instance, but in high traffic volumes became too worn in a matter of months. Subsequently, a thermoplastic selected for its weathering resistance and non-slip properties was applied at a greater initial cost than the paint. When consideration was given to the maintenance and re-application costs, the more durable thermoplastic was economically favoured. Both the paint and thermoplastic were not slippery, but were less visible than expected. New signage was used to inform drivers of the need to give way (yield in U.S) to cyclists in the blue lane. Bicyclist comfort was said to be increased when the blue pavement was implemented, and more riders used the marked section to negotiate the conflict area. Significantly more motorists gave way to cyclists after the lane was coloured, and notably fewer cyclists slowed or stopped when entering the area of conflict. The proportion of drivers that indicated their intended manoeuvre was similar before and after the blue lanes were installed. A marked reduction in conflicts after the lanes were introduced was seen. The authors concluded that due to better definition and awareness of the conflict area, the measures could be taken as improving safety for cyclists. They noted instances of cyclist complacency on the coloured lanes, which may indicate a false sense of security from the coloured lane and new signage. More evaluations were called for in order to establish appropriate application guidelines.

Raised and painted bicycle crossings

Raised and painted bicycle crossings at intersections in Sweden resulted in increased cyclist speeds and decreased vehicle speeds (Leden, 1997. Right turning motorist speeds were dropped by 35 to 40 per cent. An estimated reduction of 10 per cent in bike-vehicle crashes was found using a quantitative model. Survey results indicated cyclists believed safety improvements of 20 per cent came about due to the painting and raising of the crossings. Anticipated usage increases of 50 per cent were expected to increase the total number of crashes, but safety was believed to be nonetheless improved. A review of the report combined survey and model results to give an estimate of 30 per cent risk reduction from the raised and painted crossing (Gårder, Leden, and Pulkkinen, 1998).

Profiled pavement markings

Profiled pavement markings, consisting of painted chevrons within the bike lane near a T or four way intersection, were put in place in Denmark to reduce lateral distances between vehicle and cyclist and raise awareness on approaches. The cyclist was guided close to vehicle lanes on approaching, and then led away at the intersection. It was found that cyclists became aware earlier, more drivers slowed to bicycle speed, and drivers were less likely to make a right turn in front of riders (Herrstedt, Nielsen, Agústson, Krogsgaard, Jørgensen and Jørgensen, 1994).

Advanced Stop Lines and Signal Phase Design

By recessing the point where motorists stop at a junction, an Advanced Stop Line (ASL) of up to 5 m for cyclists can be put in place in front of the vehicles. Hunter et al. (1999) saw that an ASL (also called a bike box) was most appropriate at signalised intersections on roads with marked bicycle lanes. The benefit of this simple separation is that riders are visible to the vehicle drivers. Interestingly, the Queensland Main Roads MUTCD Bicycle Facilities section states that the stop line for bikes need only be 2 m ahead of vehicular stop lines

Linderholm (1992) noted that cyclists are at an advantage when the green signal comes because of their promoted position with a 5 m ASL. This visibility advantage thereby greatly reduces risks of appearing unexpectedly, which is a common reason for accidents. Herrstedt et al. (1994) found that ASLs in Denmark significantly decreased the number of accidents between right turning vehicles and cyclists travelling straight. In 1992, Wheeler studied the effects of 5 m ASL at signalised junctions in England, and found that it became easier for right turning cyclists to get into position. Good positioning in Oxford went from 57 per cent to 97 per cent with the ASL in place. A two signal design can also be implemented, as in the United Kingdom, where Zegeer, Cynecki, Fegan, Gilleran, Lagerwey, Tan, and Works, (1994) commented that cyclists are given a special green signal while motorists are stopped with a red light. In 1995, Wheeler monitored nine intersections in the U.K. to conclude that single signal designs were expected to be as valuable as two-signal phases if a mandatory bicycle lane with distinctly coloured road surfaces in cyclist areas was set up.

Roundabouts

Hunter et al. (1999, p.8) found that “many bicycle-motor vehicle crashes at roundabouts occur when motorists cut in front of bicyclists or fail to yield the right-of-way”. It was observed that small roundabouts that have flared entry roads are the most dangerous design, and that cyclists dislike large roundabouts the most. United Kingdom roundabouts have crash rates between two and three times larger than compared with signalised intersections. The smaller, ‘mini-roundabouts’ were said to have a far better crash rates. They attributed the reduction in crashes at roundabouts to a combination of lane markings, warning signs, sharper entry angles and improvements in visibility. Balsiger (1995) recommended the design of smaller roundabouts where it is not possible for vehicles to overtake cyclists.

Studies of Danish, Swedish and Dutch roundabouts concluded that the safest design for large vehicle volume situations was a bike path linked to typical bike crossings. This finding was based on a comparison between a bike lane within the roundabout, and no bicycle provisions (Brüde and Larsson, 1996). It was noted by the authors that results were based on limited data.

The Main Roads (Qld) MUTCD has only two sentences in the Bicycle Facilities section under the heading of ‘Roundabouts’. They are: “Bicycle lanes should not be marked in roundabouts. Alternative arrangements such as shared paths or provision of an alternative route may need to be considered.” (Department of Main Roads, MUTCD, 2001, p.9-17)

Austroads (1993) deals more comprehensively with roundabouts, noting that small radius designs are safest for cyclists, and that larger roundabouts and multi-lane varieties increase rider hazards. The guide states that with regard to large roundabout design safety shortcomings, “…no ready solution seems available” (1993; p.41). Large roundabouts are recommended to accommodate both roadway commuter riders and inexperienced or young cyclists. Austroads prefer to provide a safer option for the latter group by constructing an exclusive bike path or shared path beyond the kerbing. The cyclists can then safely negotiate a branch of the connector roads at right angles using ramps and island shelters, before rejoining the bike lane through to the exit of the roundabout. A design suggested for further evaluation includes BL provisions within the roundabout, but not across the exits. Very large roundabout treatments are listed as either giving an alternative cycle route or “…providing a controlled crossing on the critical approach, or a grade separation where cyclist demand is very high.” (1993; pp.43-44) In locations with high rider volumes or safety problems it is recommended to consider placing warning signs for motorists to give way to cyclists. Clearly the guide acknowledges safer cycling environments come from slower vehicle speeds. The guide also argues that separate peripheral paths have not been shown to heighten cyclist safety.

The bicycle compatibility index

The US Federal Highway Administration has tried to quantify the feelings of cyclists when riding on any specific roadway. This feeling is based on a number of roadway and operating characteristics including the type and dimension of bikeway facility provided, volume and composition of traffic, operating speeds, adjoining land-use, parking lanes, etc. This has been represented in the form of an index that has been linked to comfort level and Level of Service designation. The way cyclists feel on the road is extremely important in their patronage of this mode and their feeling about the safety of cycling. Road designers have a responsibility to make cyclists feel good.

The index is calculated from the relationship

$$BCI = 3.67 - 0.966BL - 0.410BLW - 0.498CLW + 0.002CLV + 0.0004OLV + 0.022SPD + 0.506PKG - 0.264AREA + AF$$

where

BL = 1 if bicycle lane/paved shoulder > 0.9 m is present, 0 otherwise
BLW = bicycle lane (or paved shoulder) width, m (to the nearest tenth)
CLW = curb (kerb) lane width m (to the nearest tenth)
CLV = curb (kerb) lane volume, vph in one direction
OLV= other lane volume, vph, same direction
SPD = 85th percentile speed of traffic, km/h

PKG = 1 if parking lane with>30% occupancy is present, 0 otherwise
AREA = 1 if roadside development is residential, 0 otherwise
AF = adjustment factor = ($f_t + f_p + f_{rt}$)
f_t = adjustment factor for truck volume (0 - 0.5 for volumes from <10 to =120 trucks/hr)
f_p = adjustment factor for parking time limit (0.6 for <15 min. to 0 for >480 min.)
f_{lt}= adjustment factor for left turn volume (0.1 for =270 vph, 0 otherwise)

The BCI index is converted into a LOS (level of service) designation which is an indication of the comfort level felt by cyclists, as shown in Table 1.

Table 1: Relationship between BCI and LOS

LOS	BCI range	Compatibility level
A	< 1.50	Extremely high
B	1.51 – 2.30	Very high
C	2.31 – 3.40	Moderately high
D	3.41 – 4.40	Moderately low
E	4.41 – 5.30	Very low
F	> 5.31	Extremely low

Harkey et al (1998) have used the BCI model for assessing design alternatives for a roadway reconstruction project. It was found that the original plan without bicycle facility resulted in a BCI index of 4.71 (LOS E). Provision of WKL changed BCI to 4.21 (LOS D) while the bicycle lane reduced BCI significantly to a level of 3.24 (LOS C).

Local focus

Nolan (2001) identified bikeways in the Townsville region that required upgrading, in addition to more general recommendations. The broad ranging improvements suggested included access, path width and delineation, path signage, barrier type, drainage grate removal, lighting, maintenance program, surface treatment, hazard (dips, ledges) removal, retro-reflective pavement marker placement, and speed reduction in built-up areas. As mentioned previously, Nolan did not recommend traffic calming measures which obstruct cyclists' access, unless provisions for riders were made. Of important relevance to this research is the recognition that provisions for cyclists at intersections and roundabouts are insufficient.

Nolan listed problem areas in the region with situations of immediate safety concern given high priority. The recommended areas for upgrade are:

- a continuous route along Thuringowa Dr,
- Boundary St, Saunders St and Railway Av intersection,
- access from Nathan St bridge to university, and riverside path to university.

The high priority recommendation for development of a new bikeway is for a bike route along Queens Rd, identified as an issue of cyclist demand. Sections of the road are observed to provide limited space for bikes, and the two roundabouts are also inadequate for safe cycling. Although not listed as high priority, the facilities for cyclists at Nathan St and Ross River Rd intersection are also recommended for upgrading.

It is these high priority locations that will be compared with crash data findings in order to establish any correlations to warrant redesign. Ideally, the sites identified from the crash data analysis can be validated by Nolan's observation-based recommendations, and treatments for each location devised.

Crash data

Queensland Transport has provided crash data for analysis in this project. Data incorporated many factors such as a unique accident identifier, date and time, roadway feature, atmospheric conditions, lighting, traffic control, crash nature, location, landmarks, speed limit, severity, units involved, unit type, blood alcohol, people in units, unit action, major damage, circumstance, injury severity, helmet, restraint, and a description of events. Most of these entries were in code form, requiring a check of code definitions to ascertain details.
During 1997-2001, a total of 278 accidents involving bicycles were recorded in Townsville-Thuringowa urban area. The casualties by severity and age group are shown in Table 2:

Table 2: Bicycle Accidents: Casualty Severity and Age Group, 1997-2001

Age group	Fatal	Hospital-isation	Medical treatment	Minor injury	Total
0-4	0	0	1	0	1
5-11	1	5	17	4	27
12-16	1	16	45	26	88
17-20	0	12	18	8	38
21-24	0	8	12	5	25
25-29	0	2	13	10	25
30-39	0	9	14	8	31
40-49	0	9	16	3	28
50-59	0	4	0	1	5
60-69	0	0	5	2	7
Unknown	0	0	2	1	3
Totals	2	65	143	68	278

The contributing circumstances for bicycle crashes are analysed for each severity level. These are shown in Table 3. Since there may be multiple contributing circumstances in a crash, the total number of entries in Table 3 exceeds the number of crashes recorded.

Table 3: Contributing circumstances, 1997-2001

Contributing circumstances	Fatal	Hospital-isation	Medical treatment	Minor injury	Total
Alcohol related	0	5	5	0	10
Fail to give way or stop	0	15	33	21	69
Disobey traffic light/ sign	0	3	6	0	9
Illegal manoeuvre	0	19	39	15	73
Dangerous driving	0	0	2	0	2
Disobey road rules	0	5	7	4	16
Inexperience	0	14	49	15	78
Other driver conditions	0	1	11	3	15
Age-lack of perception	0	3	1	2	6
Rain/wet road	0	1	3	0	4
Negligence	1	7	14	7	29
Inattention	1	11	15	8	35
Road surface/quality	0	0	0	2	2
Road works	0	1	4	1	6
Other circumstances	1	8	16	15	40
Totals	3	93	205	93	394

An analysis of bicycle crashes by DCA code has also been undertaken with a view to assisting in the identification of infrastructure deficiencies, as shown in Table 4.

Table 4: Crash severity and DCA Code, 1997-2001

DCA Code	Fatal	Hospital-isation	Medical treatment	Minor injury	Total
Vehicles adjacent approach (DCA 100's)	0	30	72	28	130
Vehicles opposite approach (DCA 200's)	1	18	24	9	52
Vehicles same direction (DCA 300's)	0	18	36	29	83
Vehicle manoeuvre (DCA 400's)	2	17	55	22	96
Vehicle overtaking (DCA 500's)	0	0	3	0	3
Vehicles on path (DCA 600's)	0	6	10	4	20
Vehicles off-path (DCA 700's)	0	3	5	1	9
Miscellaneous (DCA 900's)	0	1	0	0	1
Totals	3	93	205	93	394

The locations of crashes are listed as intersections if the conditions at the junction led or significantly contributed to the accident. In other cases the event is listed under streets/roads, or roundabouts as appropriate. Where 'freak' occurrences took place that had no reflection on the infrastructure or design, the statistic is ignored. These chance events included, for example, the instance where a cyclist was injured when trying to avoid a dog. They have been treated as irrelevant to this project in trying to determine infrastructure deficiencies. The results of analysis are shown in Table 5.

Table 5: Crash Data Analysis Results, 1997-2001

Location Type	Total Independent Entries	Number of Locations with 2 or More Crashes
Streets / Roads	52	13
Roundabouts	22	5
Intersections	96	8

The following locations recorded the number of crashes shown in parentheses:

Streets/Roads : Charters Towers Rd (10), Ross River Rd (7), Charles St (5), Dalrymple Rd (4), Thuringowa Dr (3), Sturt St (3), Hugh St (3), Woolcock St (3), University Rd (3), Fulham Rd (2), Flinders St West (2), Bowen Rd (2), Palmerston St (2).

Roundabouts : Bayswater Rd/Kings Rd (3), Thuringowa Dr/Hinchinbrook Dr (3), Canterbury Rd/Kern Bros. Dr (2), Gollogly Ln/Pinnacle Dr (2), Dalrymple Rd/Banfield Dr (2).

Intersections : Nathan St/Ross River Rd (5), Nathan St/Leopold St (4), Morey St/Dean St (2), Nathan St/Fulham Rd (2), Hugh St/Bayswater Rd (2), Nathan St/Bergin Rd (2), Nathan St/Charles St (2), Ross River Rd/Anne St (2).

Also of interest to the analysis of crash data, was the fact that many entries failed to properly define the location of the accident. Several roundabouts were not named, and some streets also not identified. These were subsequently ignored due to lack of information. This finding is supported by Hutchinson (1987) who found that one of the problems with such data compilations as this, was the prevalence of under reporting in various cases including accidents involving cyclists. Discrepancies in location listing within police accident reports were also highlighted by Peled and Hakkert (1993).

During the analysis, a significant proportion of riders in the data were under the age of 12 years. Other frequently occurring factors included; riding the wrong way (into traffic), either motorist or cyclist failing to give way, hitting an opened door of a parked vehicle, and riding at night without lights.

The crash data for the region is by no means exhaustive. Queensland Transport staff estimated the share of bicycle accidents that are reported is in range of 20 to 30 per cent. This means that analysis results are only taken from a small portion of the accidents in the area.

It is clear that action needs to be taken to reduce bicycle accidents in the Townsville region. It is also evident that conflicting arguments and opinions need to be sifted through so that the best solution for this problem can be identified, and implemented. Appropriate treatments at vulnerable sites will be designed in the light of the research on the types, feasibility and effectiveness of various bikeways and intersection treatments as a part of continuing research.

Conclusions

Cycling performs an important transport role and it is essential that planners, designers and managers should provide necessary facilities for cyclists. Cycling is likely to be an increasingly popular transport mode. Motivating factors include our outlook on sustainability, health effects, environment and resource issues. The efficient transportation of goods and people requires a balance between vehicular transport and other means. This aim cannot be reached unless safety conditions cease to be a deterrent to walking and cycling.

Firstly, the choice of bikeway facility is important. Although off-road bike paths which separate vehicular and bicycle traffic, are preferred, these may not always be feasible due to high cost and unavailability of right-of-way. Bike lanes are generally preferred to wide-kerb share lanes from safety point of view.

Secondly intersection treatment is crucial. Between 50 to 70% of bicycle-motor vehicle crashes are attributed to intersections and intersection-related locations (ref). A wide range of treatments have been proposed, tried and implemented in many European cities with several examples from United States and other countries as well. The choice of appropriate treatment depends on a number of physical (geometry, adjoining land use, etc.) and operational (volumes, speed, parking regimes, etc.) characteristics as well as economic considerations. It is prudent that cyclist safety is given supreme consideration in making decisions on intersection treatment.

Finally, the cyclists should feel good and comfortable about riding on the roadway. This feeling depends on a number of traffic and geometric factors including type of facility provided, traffic volumes, speeds, parking lanes, adjacent land-use, proportion of trucks, turning movements etc. Road designers must make it a priority to provide conditions that result in a highly comfortable riding environment i.e. a high level of service and bicycle compatibility index.

References

Allen, J.S. (2001). *Bicycling Street Smarts*, Rubel Bikemaps, Second Edition, Cambridge, UK.

Austroads (1993). Part 14 – Bicycles. *Guide to Traffic Engineering Practice,* Sydney, Australia

Balsiger, O. (1995). Cycling at Roundabouts: Safety Aspects, *Proceedings of the 8th Velo-City Conference*, pp.215-217, Basel, Switzerland.

Brüde, U., and Larsson, J. (1996). *The Safety of Cyclists at Roundabouts - A Comparison between Swedish,Danish, and Dutch Results*, Swedish National Road and Transport Research Institute, Linköping, Sweden.

Danish Road Administration (1994). *Design of urban signalised intersections*, Copenhagen, Denmark.

Department of Main Roads Queensland, Part 9 - Bicycle Facilities (2001). *Manual of Uniform Traffic Control Devices,* Brisbane, Australia.

Diepens and Okkema Traffic Consultants, (1995). *International Handbook for Cycle Network Design*, Delft University of Technology, Netherlands.

Ekman, L., and Kronborg, P. (1995). *Traffic safety for pedestrians and cyclists at signal-controlled intersections*, Lund, Sweden.

Fargo-Moorhead Metropolitan Council of Governments, (2000). *Metropolitan Bicycle and Pedestrian Plan*, Fargo.

Florida DOT, (1995). *Florida Bicycle Facilities Planning and Design Manual*, Final Draft, Florida Department of Transportation, Tallahassee, FL, USA.

Gårder, P., Leden, L., and Pulkkinen, U. (1998). Measuring the Safety Effect of Raised Bicycle Crossings Using a New Research Methodology, *Transportation Research Record 1636*, Washington DC, USA.

Harkey, D., and Stewart, J. (1997). Evaluation of Shared-Use Facilities for Bicycles and Motor Vehicles, *Transportation Research Record 1578*, pp. 111-118.

Harkey, D., Reinfurt, D., Knuiman, M., Stewart, J., and Sorton, A. (1998). *Development of the Bicycle Compatibility Index: A Level of Service Approach*, Report No. FHWA-RD-98-072, Federal Highway Administration, McLean, VA, USA.

Herrstedt, L., Nielsen, M., Agústson, L., Krogsgaard, K., Jørgensen, E., and Jørgensen, N. (1994). *Safety of Cyclists in Urban Areas: Danish Experiences*, Danish Road Directorate, Copenhagen, Denmark.

Hunter, W., Stutts, J., Pein, W., and Cox, C. (1996). *Pedestrian and Bicycle Crash Types of the Early 1990's*, Publication No. FHWA-RD-95-163, Federal Highway Administration, McLean, VA, USA.

Hunter, W. (1998) *An Evaluation of Red Shoulders as a Bicycle and Pedestrian Facility,* University of North Carolina Highway Safety Research Center, Chapel Hill, NC, USA.

Hunter, W., Stewart, J., Stutts, J., Huang, H. and Pein, W. (1999). *A Comparative Analysis of Bicycle Lanes versus Wide Curb Lanes: Final Report*, University of North Carolina Highway Safety Research Center, Chapel Hill, NC, USA.

Hunter, W., Stewart, J., Stutts, J., Huang, H., and Pein, W. (1999a). *Bicycle Lanes versus Wide Curb Lanes: Operational and Safety Findings and Countermeasure Recommendations,* University of North Carolina Highway Safety Research Center, Chapel Hill, NC, USA.

Hunter, W., Harkey, D., Stewart, J. and Mia L. Birk, (2000). *Evaluation of the Blue Bike-Lane Treatment used in Bicycle/Motor Vehicle Conflict Areas in Portland, Oregon,* Federal Highway Administration, McLean, VA, USA.
Hutchinson, TP., (1987). *Road accident statistics*. Rumsby Scientific Publishing, Adelaide.

Khan, A.M., and Bacchus, A. (1995). Bicycle Use of Highway Shoulders, *Transportation Research Record 1502*, pp. 8-21.

Leden, L. (1997). Has the City of Gothenburg Found the Concept to Encourage Bicycling by Improving Safety for Bicyclists?, *Proceedings of Velo City ‘97 - 10th International Bicycle Planning Conference*, pp. 271-274. Barcelona, Spain.

Linderholm, L. (1992). *Traffic safety evaluation of engineering measures - Development of a method and its application to how physical lay-outs influence bicyclists at signalised intersections*, Department of Traffic Planning and Engineering, Lund, Sweden.

McHenry, S.R., and Wallace, M.J. (1985). *Evaluation of Wide Curb Lanes as Shared Lane Bicycle Facilities*, Maryland State Highway Administration, Baltimore, MD, USA.

Nolan, R. (2001). *Townsville/Thuringowa Bikeways Audit*, Townsville/ Thuringowa and Districts Cycle Committee, Townsville, Qld., Australia.

Oregon DOT, (1995). *Oregon Bicycle and Pedestrian Plan: An Element of the Oregon Transportation Plan*, Oregon Department of Transportation, Bicycle and Pedestrian Program, Salem, OR, USA.

Organisation for Economic Cooperation and Development (OECD), (1998). *Safety of Vunerable Road Users*, OECD, Paris, France.

Pein, W., (2000). *Bicycle Lanes vs Wide Outside Lanes,* Retrieved May 30, 2002 from Google search engine on the World Wide Web: http://www.bicyclinglife.com/EffectiveAdvocacy/blvswol.htm

Peled, A., and Hakkert, A.S. (1993). A PC-oriented GIS application for road safety analysis and management. *Traffic Engineering and Control*, Vol. 34, pp. 355-361.

Pronovost, J., and Lusginan, M. (1996). Behavior of Road Users Following the Application of a Special Bikeway Crossing Marking, *Pro Bike/Pro Walk 96 Resource Book*, Bicycle Federation of America and Pedestrian Federation of America, Portland, OR, USA.

Wheeler, A. (1992). *Advanced stop line for cyclists at Oxford, Newark and Bristol*, Crowthorne, Berkshire, UK.

Wilkinson, W., Clarke, A., Epperson, B. and Knoblauch, R. (1994). *Selecting Roadway Design Treatments to Accommodate Bicycles,* (FHWA-RD-92-073) Federal Highway Administration, Washington DC., USA.

Wykle, K.R. (1999). Pedaling into the 21st Century. *Public Roads*, Vol. 63, pp. 30-31

Zegeer, C.V., Cynecki, M., Fegan, J., Gilleran, B., Lagerwey, P., Tan, C., and Works, B. (1994). *FHWA Study Tour for Pedestrian and Bicyclist Safety in England, Germany, and the Netherlands*, Report No. FHWA-PL-95-006, Federal Highway Administration, Washington DC., USA