

Introduction

Pedestrians and cyclists are particularly vulnerable from safety point of view because of lack of protection and speed compared to motorized vehicles. This paper investigates shared space options of cyclists and pedestrians and strategies available to traffic planning purposes. This investigation covers methodological frameworks that account for flow characteristics of cars, bicycles and pedestrians in an attempt to determine an optimum sharing strategy. The main consideration from the design point of view is whether to segregate these traffic streams or not. Space availability is an important consideration included in this design step. The other important question relates to the amount of spacing between users provided when mixed operations are recommended.

Botma et al. (2001) have mentioned five research areas of interest to contemporary researchers in non motorised transport and two of those research areas are directly relevant here. They are (a) analysis of quality of operation for bicycles and subjective danger for pedestrians at shared footpaths and (b) analysis of risk perception of pedestrians due to cars at a narrow urban street.

Experience from Sydney and overseas has indicated that there is a high level of perceived risk associated with non-motorised transport modes. It is also useful to review design standards covered by Austroads, ARRB and Standards Association of Australia, particularly in the context of bicycle and car shared spaces and cyclist pedestrian shared zones. This paper covers methodological aspects related to assessment of perceived level of safety and its application in the design process.

Accident data analysis

Safety analysis is typically approached from accident studies and assessment of preventative measures. These measures may even include specifications on road user attire. For example, compliance problems related to Australian cyclists helmet wearing have been an issue discussed by Smith and Milthorpe (1993).

Interactions between motor vehicles and cyclists or pedestrians could result in serious accidents because of differences of size and speed characteristics. It is generally accepted that bicycle accidents are underreported. Cairney (1992) has suggested that only about 3% of bicycle related accidents are recorded in Australia. Fortunately, according to a survey of cyclist inpatients in NSW it is observed that the number of bicycle accidents with motorised vehicles is relatively low. For example, 78% of cyclist patients did not involve a collision with a vehicle (Arup, 1990).

Corresponding data for USA is provided by a survey conducted by Moitz (1997). It has been established that only 38% of bicycle related accidents are reported to police. About 13% of bicycle related accidents has resulted in legal action. On the other hand about

Safety Perception Issues Related to Pedestrians and Cyclists *Vandebona, Kiyota*

57% of cyclists involved with accidents has required a visit to a doctor. Only 5% has required a hospital stay.

However, the experience in USA shows a higher level of bicycle accidents with cars than in Australia. 59% of bicycle accidents has involved a car. About 30% of accidents involved no other road user.

In Japan, in 1998 there were about 800,000 accidents (all types) resulting in injury or death. Bicycle accidents accounted for 18 percent of all casualties. This is a reflection of the high level of bicycle usage in Japan. A small proportion (0.5 percent) of casualties resulted from bicycle and pedestrian accidents. An alarming observation made by Japanese authorities is that pedestrian-cyclist accident counts are steadily increasing since 1992 (Kiyota et al., 1996). Similar to the experience in Australia and the USA, it is suggested that a large percentage of pedestrian-cyclist accidents and conflicts are not reported at all.

Shared paths

In Australian context, there are two types of shared usage observed. Firstly, there are arrangements for shared use of motor traffic and bicycles. These shared lanes are typically observed in roads with a speed limit of 60 km/h or less. However, Austroads (1999) has documented specifications for applications in 80 km/h zones as well.

In the USA, shared facilities, particularly in recreational settings, are available for a mix of pedestrians, runners, cyclists and skaters. In Japan, shared usage of the footpath is allowed for cyclists and pedestrians. In the Netherlands, cycle paths are a shared facility for bicycles and mopeds.

Shared traffic operations require the adaptation of the cyclist and the pedestrian to the particular operating environment. Cyclists have to maintain relatively low speeds to avoid conflicts with pedestrians. Pedestrians need to watch for cyclists and be ready to take evasive action to avoid collision with passing cyclists. This requires pedestrians to maintain a high level alertness.

The second type of arrangements is for shared usage of space for cyclists and pedestrians. These are named as shared or dual use paths in Austroads (1999). Figure 1 shows a schematic arrangement and desirable dimensions specified. Figure 1 is selected from one of the many diagrams included in Austroads (1999) to cover recommendations for a range of operating conditions. It is important to note that what is meant by 'desirable' in these specifications is probably a compromise and not necessarily a reflection of expectations of a particular road user group. These specifications are a compromise of cyclist, pedestrian and service provider requirements.

Safety Perception Issues Related to Pedestrians and Cyclists

Vandebona, Kiyota

In a space designated for cyclist and pedestrian shared use, the pedestrian is the vulnerable road user. This is because a cyclist speed can be an order of magnitude higher than the speed of the pedestrian. Pedestrians move at about 5 km/h. In contrast, cyclists may achieve 30 km/h on flat terrain. With a moderate favourable gradient, they can achieve 50km/h. This is a cause of anxiety to pedestrians. In shared paths though, the bicycle speeds in the range of 10-15 km/h are more prevalent.

And even within one type of slow traffic, a large variation in relevant speed characteristics may be observed. For example, on Dutch recreational bicycle paths there is a mix of parents with young children, cycling side by side, operating at 10 km/h with much swaying and amateur racing cyclists reaching 30 km/h and more (Botma et al., 2001).

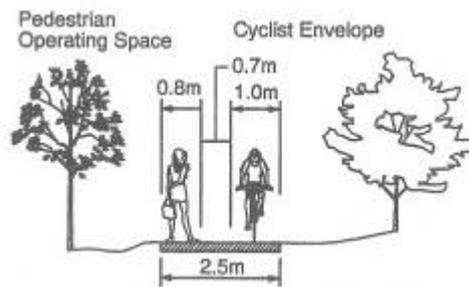


Figure 1. Desirable Minimum Dimensions of Shared Path
Source: Austroads (1999).

Kiyota et al. (2000a) have observed that when densities of pedestrians and bicycles are low, pedestrian cyclist conflicts are infrequent. As these densities increase, potential conflicts among road space users become more frequent. As a result, cyclists are forced to travel on shared road space at low speeds. Pedestrians are also required to be vigilant to take evasive action to avoid collision by passing bicycles. Passing bicycles pose a high level of danger to the elderly and children because of their lack of agility and lack of size, respectively.

The lesson from the above observations is that increased pedestrian density reduces bicycle speeds and hence improves the level of safety. In other words, under certain circumstances, use of low separations between pedestrians and cyclists can increase the perceived level of safety of pedestrians, by sacrificing the ease of mobility of bicycles.

Field survey methods

There is much similarity in the manner research in this field has progressed in Australia, Japan, USA and the Netherlands. In Australia the emphasis has been on data based on

Safety Perception Issues Related to Pedestrians and Cyclists

Vandebona, Kiyota

observations and surveys and video recordings. The Japanese researchers have added the dimension of using medical equipment to monitor physiological symptoms. The study performed in USA (Moitz, 1997), and mentioned earlier in this paper, has also adopted the questionnaire survey method. That particular study has captured nearly 3000 respondents.

In general, questionnaire surveys have been adopted in the four countries considered. Behavioural observation method has been adopted by authors of this paper in joint research work carried out in Japan and Australia.

A study conducted in Saga city in Japan has looked into the level of anxiety felt by pedestrians when bicycles pass by in a shared space (Kiyota et al, 2000a). This analysis is based on video recording of pedestrian and bicycle interactions and later interviewing the pedestrians to assess the level of safety they have associated with each episode. This survey has established that the spatial separation between the pedestrian and cyclist is a primary variable in the formulation of the perceived level of safety (Table 1). When the spatial separation is small, the level of safety was deemed small. As the separation increased, the estimated perceived level of safety also increased. It is acknowledged that the perceived level of safety applicable in the context of Australian public may differ from the values mentioned in Table 1, but it is expected that the general trend observed in this data set is equally applicable here.

Table 1. Effect of spatial separation (cyclist and pedestrian) on perceived level of safety

Minimum separation	Probability considered dangerous
75 cm	0.86
100 cm	0.39
125 cm	0.06
150 cm	0.01

Source: Kiyota et al. (2000a).

The spacing between the pedestrians and cyclists is obtained by establishing a method to record the physical location of pedestrians and cyclists. Five short lines were drawn on the footpath at 5 m intervals and cross marks were made on these lines at 50 cm intervals. These marks were made using masking tape. The spacing between road users in passing could be measured to the nearest 25 cm using these reference lines.

Bicycle speed is calculated based on the time taken by an individual to travel between two successive lines. In this project, however, the spacing and speed have been calculated by an image processor. The automated image processing method increased the level of precision of data while reducing the data retrieval effort. Some trigonometric

Safety Perception Issues Related to Pedestrians and Cyclists

Vandebona, Kiyota

computations are required to eliminate the parallax error due to camera being held at an angle to the subject.

Effect of cyclists on pedestrians

The main impact of presence of cyclists on the path used by pedestrians is that of increased level of apprehension of their personal safety. As mentioned before, growth of bicycle and pedestrian collisions in Japan is a particular problem. It is also important to appreciate that the way risk of collision with bicycles in shared space is perceived by different types of pedestrians is dependent on their physical abilities. In this collaborative research project it has been attempted to investigate the effect of the age group of the pedestrian on risk perception characteristics.

An interview survey of 156 pedestrians, consisting of 38 elementary school students, 35 University students and 83 elderly (age possibly 65 years or more) provided the data required for the analysis (Kiyota et al., 2000a).

An assessment of video segments of pedestrian and cyclist interactions has been performed by the respondents. Their assessment has shown that only 18% of the scenes were deemed dangerous by the University students whereas the elderly group classified 40% of the scenes as dangerous. The young children group also provided similar results, identifying 42% of scenes as dangerous. It is the elderly and young children that feel a high level of risk when using the shared footpath. Understandably, University students have not indicated the same degree of perceived risk.

The difference of risk perception levels related to different age groups poses a significant challenge to the traffic planners. Particularly in societies where the proportion of elderly population is increasing, the application of shared footpaths may need a safety review.

An important extension of the above analysis stems from the observation that there is a difference in the group of scenes classified as dangerous by the elderly and the young children. Further analysis has shown that the average of the minimum spacing of the dangerous scenes is 1 m for the elderly selected scenes, and 0.81 m for the young children selected scenes. Average speed of the bicycle at that minimum separation was 12.5 km/hr for elderly selected dangerous scenes and 11.4 km/hr for the young children selected scenes. This is an indication that the young children are more concerned about the speed of the bicycle than the minimum separation. They are more likely to allow the bicycle to get close to them. On the other hand, the elderly are more concerned with the minimum separation. This may be an outcome of their awareness of lack of agility.

Level of safety experienced by pedestrians

There are several ways to evaluate the pedestrian perception of risk when sharing road space with passing bicycles. One method uses the spacing maintained by pedestrians as

Safety Perception Issues Related to Pedestrians and Cyclists

Vandebona, Kiyota

an indicator of the level of safety. This method is based on the hypothesis that pedestrians attempt to keep away from passing bicycles in response to the perceived level of risk. Therefore, it is possible to estimate the perceived level of risk by means of observing the behaviour of pedestrians against passing bicycles.

Focusing on a single pedestrian, it is possible to model the risk perception of the pedestrian based on the amount of evasive action taken against a passing bicycle. However, in real world experimentation, it is rare to find such one to one interaction. Often, several pedestrians and cyclists pass each other in the shared space. Risky scenes may involve interactions among several pedestrians and bicycles. Therefore, a conflict mode limited to one to one interactions between a pedestrian and a cyclist cannot properly explain the safety of shared road space.

In pedestrian stress level studies carried out in Japan, an attempt has been made to monitor a physiological symptom that would directly relate to stress of the individual. There are number of candidate symptoms that can be pursued. Widely known physiological symptoms of stress are blood pressure, heart beat rate, respiration rate, perspiration and galvanic skin response. A symptom that can be easily measured and does not require large equipment is sought for the purpose of pedestrian stress measurements. After consideration of cost, weight and ease of interpretation, it has been decided to monitor the heartbeat of the pedestrians to understand the level of stress experienced by them.

Pulses are obtained by the count of number of R-waves on an electrocardiogram. The interval between two continuous R waves is measured to compute the heartbeat rate per minute. The device utilised in the experiment reported by Kiyota et al. (1999) can store up to 3.6 hours of heartbeat recording. The device weighs about 170 grams.

Number of volunteers (University students) was equipped with heartbeat monitors and the progress of these pedestrians was video recorded to obtain corresponding data related to separations and speeds.

More than 80% of pedestrians who have a heartbeat rate increase of 10 pulses per minute has taken some kind of evasive action. Thus heartbeat increase by 10 pulses per minute has been adopted as an indication of sensing danger.

Table 2 shows that this methodology allows researchers to account for the effect of spacing between road users and speed of the passing vehicle in the estimation of pedestrian stress. Table 2 also shows that 66% of Japanese pedestrians displays the stress associated with sensing danger when the passing car speed is 40 km/h at 50 cm spacing. When the spacing is 100 cm, (and passing car speed of 40km/h) the corresponding percentage drops to 30%.

Table 2. Effect of the passing vehicle speed on perceived level of risk

Movement type	Car speed	Level of risk at given spacing between car and pedestrian		
		50 cm	100 cm	150 cm
On coming vehicle	40 km/h	0.25	0.07	0.02
	30	0.18	0.05	0.10
	20	0.13	0.05	0.01
Vehicle from behind	40	0.66	0.30	0.09
	30	0.56	0.22	0.06
	20	0.45	0.16	0.03

Source: Kiyota et al. (1999)

Although these measurements may not be transferable to Australian pedestrians, the trend indicated by the overseas pedestrian may well be applicable. An increased spacing aids in the attempt to reduce the level of stress experienced by the pedestrian.

A similar analytical model has been developed for pedestrian cyclist interaction. This model is based on the hypothesis that pedestrians feel the danger of passing bicycles when the level of risk exceeds a certain threshold (Kiyota et al., 2000a). This disaggregate model is a valuable tool in quantifying the degree of perceived risk in a particular road space where the pedestrian densities are known.

Shared footpaths

In Australia there has been some degree of nation wide uniformity adopted since 1999 about the shared footpath usage. With few exceptions, the shared usage of footpath has been banned.

In Japan, an opportunity to study shared usage of street space became available with a revision of traffic regulations in 1978 that allowed the introduction of shared usage of footpaths among cyclists and pedestrians. The amended regulation allowed Japanese planners and traffic authorities to operate without physical segregation of cyclists and pedestrians. These research opportunities have resulted in joint research work in this field by researchers from University of New South Wales and Saga University. Results of such research work have been mentioned earlier in this paper.

A small scale survey was conducted in 1998 in Sydney to investigate the level of public acceptance in the context of using roadside footpaths as shared facilities for pedestrians and cyclists. The sample size of this questionnaire survey was 300. It appears that there is a considerable support for this shared usage of footpaths (Table 3). It is interesting to note that this support mainly stems from motorists who would benefit from the absence of bicycles on vehicular traffic lanes. 66% of motorists have supported the bicycle-

pedestrian shared use of footpaths. On the other hand, cyclists have little support for the proposal. Pedestrians appear to be indifferent about this shared arrangement. In this limited survey, only about 45% of pedestrians supported the shared use of footpath with cyclists.

Table 3. Level of support for the shared use of footpath

	Road user category	Support for shared footpath	
There are some made about the footpath, in the USA	Motorists	66%	Source: Brown (1998). useful observations shared use of by Moitz (1997).
	Cyclists	23%	
	Pedestrians	45%	

He developed a stress index computation for a survey of 3000 cyclists carried over 13 months. For example, major roads with shared car and bicycle facilities scored a stress index of 1.26 and minor streets with similar facilities scored a value of 1.04. This is a reflection of cyclists feeling less stressful in minor road situations. He observed that these stress index values are almost halved by introducing dedicated bicycle lanes. For example, streets with bicycle lanes showed a cyclist stress index of 0.50. This is an important finding that demonstrates the relatively high level of safety and mobility cyclists associate with bicycle lanes. An even more important finding made by Moitz (1997) relates to the stress index computed for shared footpath. Such footpaths score a 5.3, a substantially high level of stress, according the proposed stress index computation. Shared use of footpath appears to be considered extremely dangerous by cyclists in USA.

Bicycle and motor vehicle shared space

It is generally accepted that shared arrangements for bicycles and motor vehicles are quite stressful to the cyclists. In a survey conducted in Sydney, the level of stress is measured through five noticeable physical manifestations. These stress indicators are,

1. Footpath riding
2. Riding on left edge of the lane
3. Frequent change of lane position
4. Looking behind at mid blocks
5. Indication of loss of balance

The above indicators reflect the sudden or frequent need for evasive actions considered by cyclists. Four sites were monitored to compare the level of stress exhibited by cyclists. 255 cyclists were observed during the survey period. Table 4 provides a summary of the conditions observed. Anzac Parade site showed a high level of footpath riding at midblock where as Botany Street site showed large amount of footpath riding at intersections. Furthermore, the parked cars forced cyclists to use the right edge of the kerb lane as shown by the observations at the Botany Street site.

Safety Perception Issues Related to Pedestrians and Cyclists
Vandebona, Kiyota

The stress level computation was performed by associating a weighting factor for each indicator mentioned before. Brown (1998) has already documented the methodological details of the survey and analysis. It is interesting to note that the stress level computed from the observation of physical manifestations of stress of cyclists is much related to the vehicular traffic flow on the kerb lane. The researchers were not able to make an accurate estimate of the traffic flow of one site, and therefore, only three sites were available for this comparison. However, based on the limited data available it appears that there is a low level of stress associated with segments where the traffic on the kerb lane is high (Figure 2). This maybe because of lack of hindrance from parked vehicles and bus stop activities that allowed other traffic to use the lane, also improve the bicycle riding quality. Anyhow, these results also indicate that there is a need to carefully select the weighting factors applied in computation of the stress level.

Table 4. Computation of stress rating in selected roads in Sydney

	Anzac parade Kensington	Botany street, Randwick	King street, Newtown	Oxford Street, Darlinghurst
Bicycle facility	None	Bicycle/car parking lane	None	None
Number of cyclists observed	72	40	58	85
Bicycle volume (bicycles/hr)	46	18	25	62
Left lane traffic volume (veh/hr)	354	N/A	375	458
Clearway/no standing restrictions	Yes	No Parking lane	Yes	yes
Lane width (m)	3.0	3.7	3.0	3.0
Speed limit (km/hr)	60	60	60	60
Footpath riding at intersection	2.8	25.6	3.4	15.8
Footpath riding at mid block	30.6	20.5	19	10.5
Lane other than kerb lane	1.4	10.3	3.4	26.3
Left side of kerb lane	51.4	5.1	50	28
Middle or right side of kerb lane	16.7	64.1	27.6	35.1
Stress rating	57.66	32.31	53.05	38.72

Source : Brown (1998)

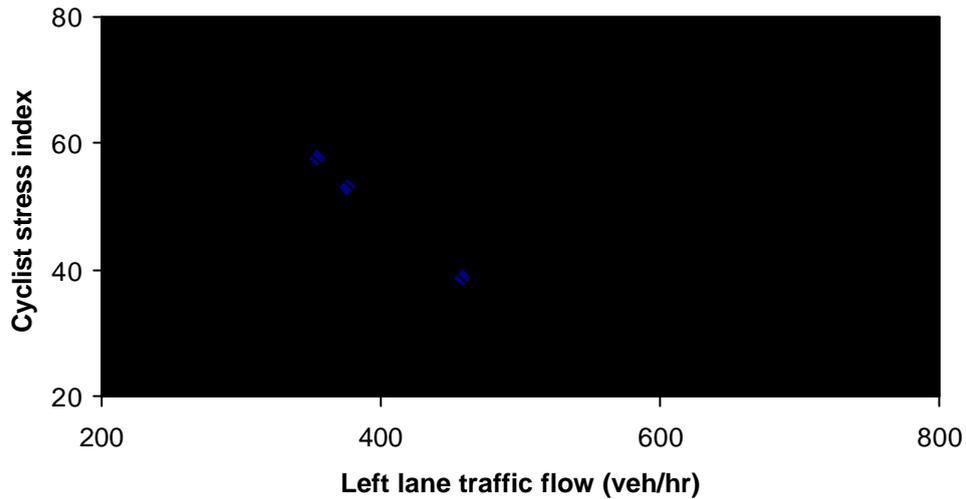


Figure 2. Inverse relationship between level of stress and left lane volume

Bicycle and motor vehicle segregation

Another arrangement for space usage recommended by Austroads (1999) is the segregation of traffic streams. Under what conditions do we recommend segregation of the cyclist and motor vehicle traffic streams? Conceptually, the spatial separation, speed and flow levels are the relevant variables. Figure 3 presents a simplified approach to developing the warrants for segregation.

	Low Flow	Large Flow
Low speed	Shared space	Segregate
High speed	Segregate	Segregate

Figure 3. Warrants for segregation

Safety Perception Issues Related to Pedestrians and Cyclists

Vandebona, Kiyota

Certain researchers are not convinced that segregation policies currently adopted are result of a desire to improve the level of safety of cyclists. Godefrooij (1997) has suggested that typical traffic planning incentives for providing segregated space for cyclists is generally driven by the desire to improve driving conditions of motorists rather than interests of the cyclists.

Main variables involved in selection of the segregation option, as recommended by Austroads (1999) are traffic volume, parking conditions, speed and land availability.

Cyclists and pedestrians segregation

Austroads (1999) recommends segregation of bicycle and pedestrian flows when large numbers of cyclists and pedestrians are present. However, it is difficult to make use of this guideline because numerical values are not provided. Anyhow, in Australian context, these segregated paths are not common and only seen in certain promenades and recreational sites. In its simplest form, this segregation is achieved by a white lane marking. The minimum path width specified is 3.5 m.

Botma et al. (2001) and Vandebona (2000) have pursued a theoretical framework for separation standards. These proposed models adopt vehicle speed and traffic flow characteristics as governing variables.

Conclusions

There is a range of shared and segregated flow arrangements available for provision of transport infrastructure to pedestrians and cyclists. An understanding of effects of speed, density and volume on perceived and actual level of safety is important in development of warrants for different road space management strategies.

Selection of shared or dedicated lane treatment is an important step in the design process and has considerable impact on the overall cost of infrastructure as well as the level of service provided to users. Investigation of methodologies available for this step has been covered in this paper. In particular, methods of accounting for the stress and danger felt by non motorised road users in the facility design process have been investigated.

It has been observed that a range of field survey methods have been adopted in this field of research. As expected, questionnaire survey methods have been widely adopted. Techniques for unobtrusive observation of road user behaviour are also available. Measurement of physiological symptoms has also been attempted.

Lessons learned from this research project are useful for policy development in relation to the infrastructure design and further research. An area of concern is the effect of age of the road user on risk perception. The difference of risk perception levels related to different age groups poses a significant challenge to traffic and transport planners. In

Safety Perception Issues Related to Pedestrians and Cyclists
Vandebona, Kiyota

societies where the proportion of elderly population is increasing, the application of shared facilities needs more attention.

Research work reported here has also covered aspects of the shared use of footpath among pedestrians and cyclists. Shared use of footpath is considered as one of the most unacceptable scenarios by cyclists in the USA. In Australia, there is some support for shared use of footpath but most of this support comes from a third party, i.e. motorists.

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Safety Perception Issues Related to Pedestrians and Cyclists

Vandebona, Kiyota

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