# LATERAL CLEARANCE BETWEEN VEHICLES AND BICYCLES ON URBAN ROADS

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**ABSTRACT**

The clearance motorists allow when they overtake bicyclists is critical to the safety and level of service experienced by bicyclists in mixed traffic. Recent calls for mandatory minimum lateral clearances in South Africa indicate its importance to the bicycling and sustainable transport communities. This study reports on locally measured lateral clearances between bicycles and vehicles on urban roads in Tshwane. An ultrasonic device was used to measure passing clearances under varying traffic and roadway conditions, and the paper reports on the range and variability of the observed clearances. A regression analysis was performed to identify the factors affecting lateral clearance, such as lane width, vehicular speed, and density. Guidance is offered around the combination of vehicle volume and lane width that can be expected to result in given levels of bicycle safety. This guidance might help practitioners to identify pro-actively roadways with high accident potential for cyclists, or to identify suitable roads for inclusion in an area-wide safe bicycle network.

## 1. INTRODUCTION

### 1.1 Background

Recent fatal accidents involving cyclists have focused a considerable amount of media and public attention on bicycle safety, especially with regard to motorist-cyclist interaction. One result is an increasing call for the enforcement of minimum passing distances between motorists and cyclists: a minimum clearance of 1.5 meters is being advocated for vehicles overtaking cyclists (Figure 1). These calls are based on the presumption, probably correct, that larger passing distances improve safety by increasing the manoeuvring space for both cyclists and motorists, and reducing the likelihood of encroachment onto the other's path.


**Figure 1: Promotion of safe passing**
(Source: pedalpower.org.za)

Yet little is known of the actual passing behaviour of motorists in South Africa. Do motorists actually observe safe lateral clearances? If not, how big is the problem? Passing behaviour can furthermore be expected to be related to the geometric and traffic conditions prevalent at the time – to factors such as lane width, traffic volume, and the presence of a bike lane. How is it related? This question is important from a road engineering point of view, as it can help to establish design and operational strategies that promote safer cycling environments, and contribute to sustainable transport in a wider sense.

## 1.2 What affects lateral clearance?

The literature suggests that the clearance motorists allow when they overtake bicyclists – what we term lateral clearance – is critical to the safety and level of service experienced by bicyclists in mixed traffic. While no empirical research was found on the relationship between clearances and cyclist accident rates, there has been some research showing that clearances vary significantly depending on a variety of roadway and traffic conditions. Perhaps the most important factor is the amount of space vehicles have to travel in (Schramm, 2009) – wider lanes promote higher clearances. Pucher et al. (2011) list wider lanes as one of the reasons for higher bike use in some Australian cities.

Some conflicting evidence exists about the effect of lane width in the presence of bike lanes: reducing lane widths by installing bike lanes may decrease lateral clearances but actually *increase* safety as the predictability of vehicle behaviour improves (Kroll and Ramley, 1977). Furthermore, there is evidence that wider lanes promote higher car speeds (e.g. Fitzpatrick et al. 2001) and lower safety (e.g. Noland, 2002), while speed and lateral clearance have a narrow (positive) statistical relationship (Bracher, 1992). Clearances have also been reported to decrease with higher vehicle densities (Harkley and Stewart, 1997). Thus, because of the speed-flow-density relationship, higher flows, lower speeds, and higher densities can all be expected to contribute to narrowing lateral clearances, at least under uncongested flow conditions.

The same roadway and traffic factors also affect cyclists' subjective assessment of the safety and level of service they enjoy while biking (e.g. Dixon's (1996) Level of Service measure; FHWA's (1998) Bicycle Compatibility Index). This suggests that lateral clearance is also an inferred measure of safety and service quality (Schramm and Rakotonirainy, 2009), and is important from a subjective bikeability perspective.

Design guidelines focus primarily on lane width as a means of promoting safe passing of bicyclists. The AASHTO (1999) *Bicycle Facility Guideline* specifies a minimum kerb lane width of 3.6m and a recommended width of 4.2m to safely accommodate both bicyclists and vehicles in mixed traffic. On steep gradients, this should be increased to 4.5m. The South African *Pedestrian and Bicycle Facility Guidelines* (DOT, 2003) follows suit by prescribing wider outside lanes where bicycles and vehicles share lanes, with a minimum kerb lane width of 4.2m (excluding the kerb and gutter), and wide lanes of 4.5 to 5.5m when higher traffic volumes or speeds are present. It also suggests that sharing of traffic lanes should be restricted to roads with (unspecified) low volumes and speeds under 40 to 50km/h – even though lower speeds are associated with smaller lateral clearances.

## 1.3 Objectives and scope of research

The objectives of this research are to collect and analyse data on the actual lateral clearances between vehicles and bicyclists on urban roads in South Africa. An innovative bicycle-mounted ultrasonic device, coupled with visual traffic observations, was deployed on a representative sample of urban roads operating under typical traffic conditions in the City of Tshwane. The paper aims not only to characterise the range of clearances observed, but also to understand how passing behaviour is affected by roadway and traffic characteristics. Finally, a multivariate model of lateral clearances is estimated and used to derive guidance about the conditions under which cycle safety may be compromised, and how it may be promoted.

The paper does not address the question of whether 1.5m is a suitable criterion for safety, nor indeed whether any single clearance is applicable across all road and traffic conditions. Instead, the authors simply measured in-situ clearances and report them in relation to the 1.5m benchmark. The focus is on mid-block sections (i.e. away from intersections) on urban roads with cross sections that exclude paved shoulders, bike lanes, or on-street parking. The results are particular to roads of this type, and do not necessarily apply to higher-order or rural roads.

## 2. DATA COLLECTION

A test bicycle was instrumented with a small portable ultrasonic distance measuring device to measure the lateral clearances between the centre of the cycle and passing vehicles in the kerb lane (see Figure 2). A researcher rode the bicycle in the kerb lane, at a constant distance of approximately 0.3m from the kerb, and used a flexible rod of this length fastened to the cycle's fork to achieve consistency. The ultrasonic device was calibrated to be accurate to the nearest 10mm. Important to note is that, since the measured distance is to the *centre of the cycle*, our definition of lateral clearance includes the approximately 0.3m to the outer envelope of the cyclist. If needed this width can be excluded from the clearance measurement by subtracting 0.3m from the values reported below.

A sample of 13 road sections in the Pretoria area was selected for measurement, spanning a selection of road widths, road types, and traffic volumes (Table 1). All sections were in urban or suburban environments, with one or two lanes per direction. One-way roads and CBD-type streets were excluded from the sample. All roads lacked bicycle lanes and paved shoulders, had relatively flat gradients, and low bicycle volumes. For each section, manual volume counts were used to record the traffic flow in the kerb lane and in the inner lane of the opposite direction. The average traffic speed was measured with a float vehicle across multiple runs during the same time of day. We lacked equipment to accurately measure the spot speed of each vehicle passing the cycle; instead, the observer simply categorised each vehicle's speed as Low (less than 40km/h), Medium (40 to 48km/h), or High (above 48km/h). Lateral clearances were measured for passenger vehicles only, but average speed and flow refer to all vehicles.

**Figure 2: Infrared measuring device mounted on test bicycle**

**Table 1: Characteristics of sample of road sections selected for measurement**

| Street name | No of lanes per direction | Road type | Kerb lane width (m) | Time of day | Average flow (veh/h) (kerb lane) | Average speed (km/h) (kerb lane) | No of observ-ations |
|---|---|---|---|---|---|---|---|
| Pierneef St | 1 | Collector | 4.60 | 7:20-7:35<br>15:40-15:55 | 1024<br>684 | 48.2<br>52.4 | 25<br>15 |
| Michael Brink St | 1 | Collector | 4.30 | 7:40-7:55<br>16:00-16:15 | 620<br>548 | 46.0<br>47.6 | 23<br>20 |
| Codonia Ave | 1 | Collector | 4.70 | 8:00-8:15<br>16:20-16:35 | 396<br>504 | 39.7<br>24.0 | 23<br>16 |
| Collins Ave | 1 | Collector | 5.20 | 8:20-8:35<br>16:40-16:55 | 204<br>280 | 57.1<br>55.6 | 20<br>24 |
| Main St | 1 | Local | 2.75 | 8:40-8:55<br>17:20-17:35 | 296<br>286 | 35.6<br>28.0 | 25<br>24 |
| South St | 1 | Local | 3.80 | 7:00 - 7:15<br>15:20-15:35 | 156<br>408 | 38.8<br>32.1 | 21<br>19 |
| Charles St | 2 | Collector | 2.85 | 7:00-7:15<br>15:20-15:35 | 978<br>420 | 14.8<br>48.7 | 23<br>22 |
| Lynnwood Rd I | 2 | Collector | 3.60 | 7:20-7:35<br>15:40-15:55 | 440<br>374 | 43.2<br>50.5 | 20<br>25 |
| Lynnwood Rd II | 2 | Collector | 3.90 | 7:40-7:55<br>16:00-16:15 | 556<br>1026 | 41.1<br>21.3 | 23<br>25 |
| Atterbury Rd | 2 | Arterial | 4.05 | 8:00-8:15<br>16:20-16:35 | 218<br>378 | 45.6<br>48.5 | 23<br>24 |
| George Storrar Dr | 2 | Collector | 3.70 | 8:20-8:35<br>16:40-16:55 | 534<br>662 | 44.7<br>38.1 | 23<br>17 |
| Duncan St | 2 | Arterial | 3.25 | 8:40-8:55<br>17:00-17:15 | 414<br>466 | 42.0<br>34.5 | 27<br>24 |
| Church St | 2 | Collector | 3.10 | 9:00-9:15<br>17:20-17:35 | 430<br>322 | 48.1<br>51.0 | 24<br>18 |
| TOTAL | | | | | | | 573 |

## 3. ANALYSIS AND RESULTS

### 3.1 Distribution of lateral clearances

The measured lateral clearances spanned a wide range: the minimum clearance was a mere 0.45m, and the largest 2.57m. Clearances were markedly different for one-lane and two-lane roads: at 1.55m the average clearance was 25cm larger on single lane (per direction) than on double-lane roads (Table 2). The average clearance of 1.41m is less than the benchmark 1.5m.

**Table 2: Summary statistics: observed lateral clearances**

| | All sections | One-lane sections | Two-lane sections |
|---|---|---|---|
| Average clearance (m)* | 1.41 | 1.55 | 1.30 |
| Standard deviation of clearances (m) | 0.317 | 0.334 | 0.274 |
| Range (Minimum; Maximum) | (0.45; 2.57) | (0.70; 2.57) | (0.45; 2.39) |
| Percentage less than 1.5m | 65% | 48% | 76% |

*Note: * Average is weighted by traffic volume to correct for differential sampling rates*

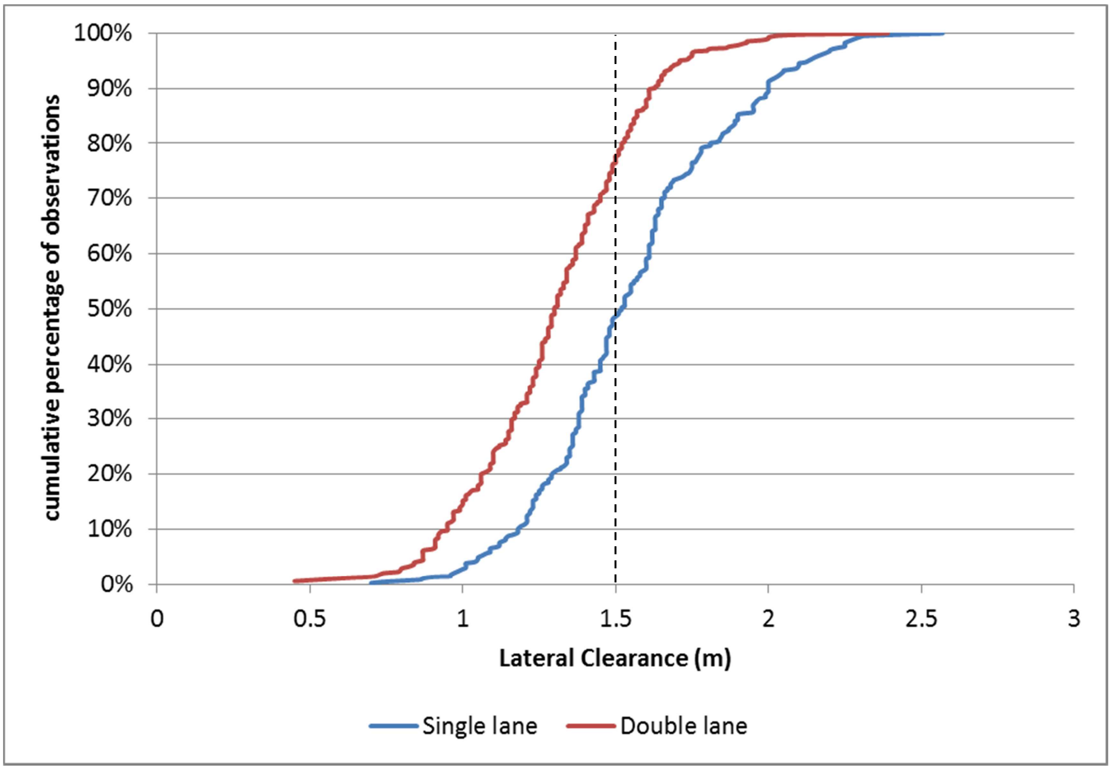


**Figure 3: Cumulative distribution of observed clearances***

*Note: * Distribution is weighted by traffic volume to correct for differential sampling rates*

Figure 3 plots the cumulative distribution of the observed clearances. It can be seen that half of clearances observed on one-lane sections fell below the 1.5m benchmark; on double-lane sections the number is 75%. Overall, two-thirds of motorists did not observe a safe clearance of 1.5m when passing the cyclist (Table 2).

Figure 3 also provides information on the distribution of clearances. Lateral clearances are generally normally distributed, with a slightly wider distribution on one-lane than on two-lane roads (see also standard deviations in Table 2). Motorists' passing behaviour is thus slightly more predictable on two-lane roads.

## 3.2 Effects of lane width

Table 1 indicated that double-lane roadways in the sample tended to have narrower kerb lanes than one-lane sections. Are the different clearances observed above not actually a function of lane widths? Lane widths were plotted against the percentage of observations on each test section that fell below the 1.5m benchmark (Figure 4). There is a clear negative relationship, indicating that clearances tend to increase as the kerb lane becomes wider, as suggested by the literature.

Although the data set is small, there is evidence of a non-linear relationship. There appears to be a critical lane width value around 3.3m, below which more than 80% of clearances are below the benchmark. For lane widths of more than 3.3m, clearances improve, and do so non-linearly. For instance, increasing the lane width from 3m to 4m reduces the number of dangerous passing manoeuvres (i.e. with clearances below 1.5m) by 20% on average, but increasing the lane width by another metre to 5m reduces the dangerous passing by 40%. This phenomenon is related to the shape of the normal distribution. There is thus increasing benefit to increasing kerb lane widths, at least up to a width of about 5m.

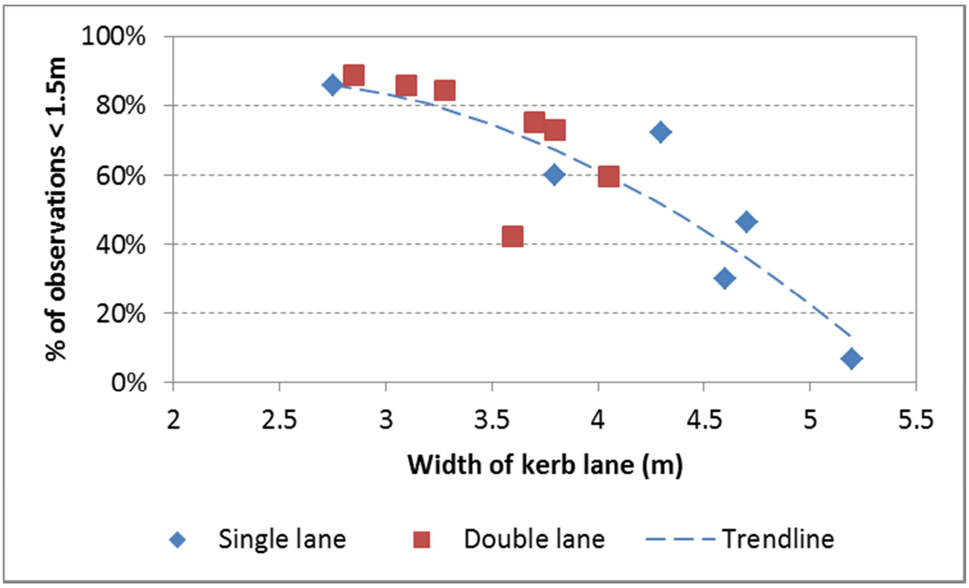


**Figure 4: Lane widths versus % of clearances less than 1.5m**

A second observation is that the lane width-clearance relationship seems to be the same regardless of whether it is a single or double lane section, suggesting that drivers do not necessarily lower their lateral clearances when faced with oncoming traffic in the adjacent lane (as in the case of one-lane per direction), as opposed to with-flow traffic (as with two-lane per direction cases). We can thus use lane width, rather than the number of lanes, as an explanatory variable for lateral clearances.

## 3.3 Effects of traffic conditions

This section examines the sensitivity of lateral clearances to traffic conditions, in terms of the flow, speed and density of vehicular traffic. Let us start with speed. The average clearance was calculated for each spot speed category, and shown in Figure 5. There is a clear relationship: lateral clearances increase with vehicle speed. A one-sided ANOVA test confirmed the statistical significance of this relationship ($p<0.01$).

This might indicate that drivers tend to provide wider clearances to compensate for longer reaction distances at higher speeds. However it might also be an indirect effect of lane widths: if wider lanes promote higher speeds (as will be shown below), then lane widths might explain the variation in clearances, rather than speeds. A multivariate test will be used below to show that speed has an independent effect on clearances.

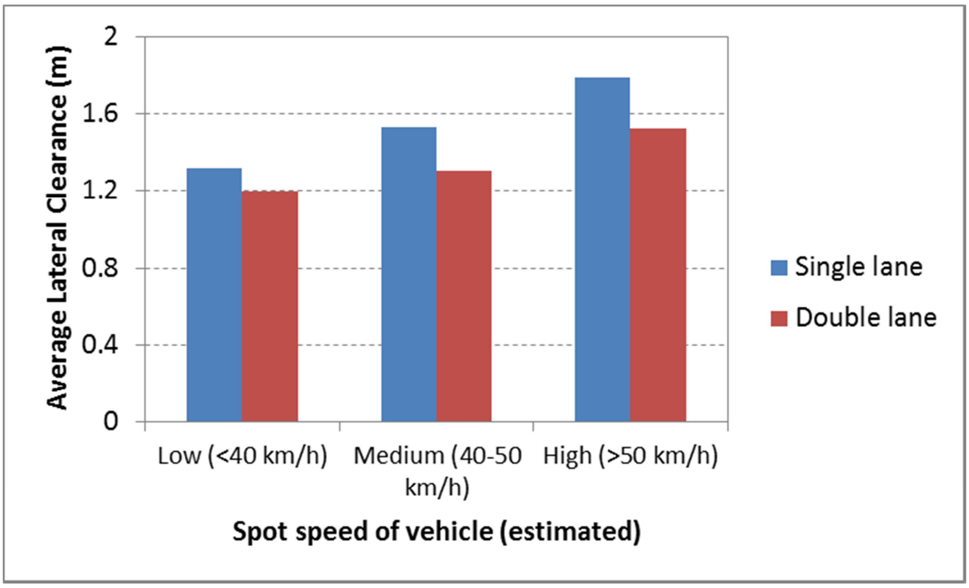


**Figure 5: Average lateral clearance per spot speed category**

The next traffic variables of interest are flow and density. The correlation between the kerb lane flow and lateral clearance is negative – higher flows are associated with lower clearances – but relatively weak: the correlation coefficient is -0.15. There is also a weak correlation between lateral clearances and the flow in the opposing lane (correlation coefficient = -0.25), suggesting that some drivers drive closer to the kerb when faced with more *oncoming* traffic. However this needs to remain an untested hypothesis: in our sample the flows in the kerb lane and the opposing lane were so highly correlated (coefficient of 0.9) that it is impossible to determine if opposing lane flow has an independent effect on lateral clearances.

As an alternative to kerb lane flow, we propose using average traffic density as a variable, on the basis that density is a direct measure of the "crowdedness" of the lane, and might thus directly lead to lower clearances being observed. Density also captures the effects of both flow and speed, through the fundamental relationships, and can be calculated from average speed and flow figures.

Figure 6 plots average lane density against observed lateral clearances, and indicates the existence of a weak negative relationship. A curve fitting exercise showed this relationship to be non-linear: at very low densities of less than 10 vehicles/km, clearances are on average slightly higher than what would be suggested by a simple linear relationship. (The low $R^2$-value of 0.14 shows this relationship to be quite weak – many factors besides density contribute to variations in lateral clearance – but the model still outperforms a null model ($p<0.001$)).

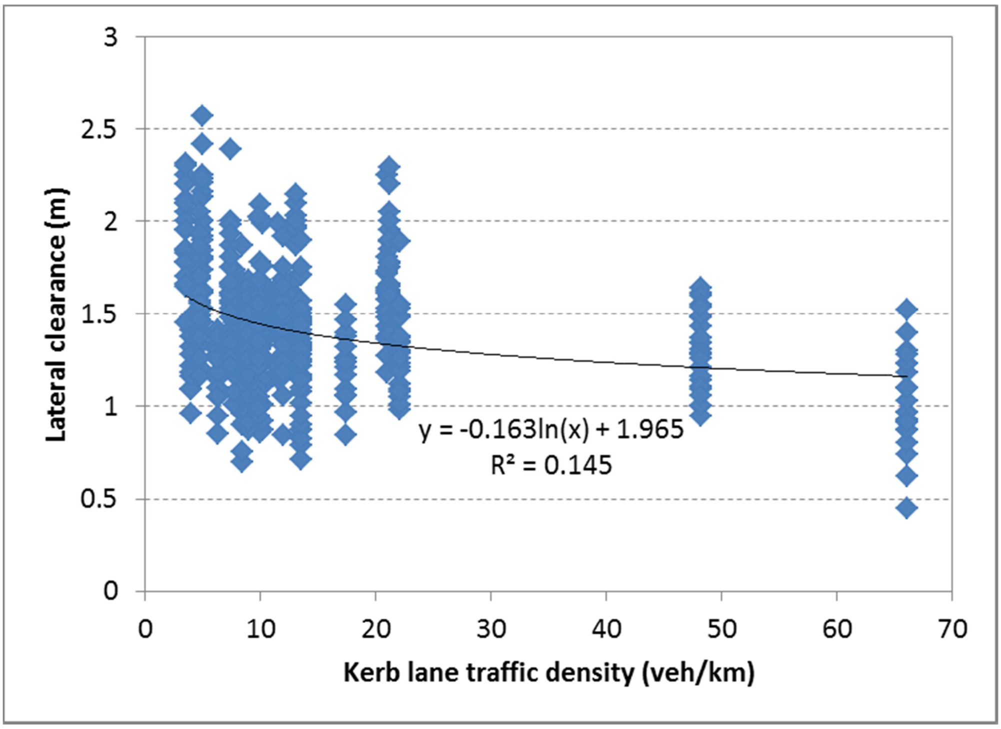


**Figure 6: Kerb lane density versus lateral clearances**

## 3.4 Predictive model of lateral clearances

In order to determine the independent effects of each of the above variables on lateral clearances, a simple linear regression model was estimated with the lateral clearances as dependent variable. The results are shown in Table 3. The best model (Model 1) indicates that the spot speed of vehicles, lane width (entered as the square of the width, following Figure 4), and the average traffic density (entered as the logarithm of the ratio flow divided by speed, following Figure 6) all have a significant independent effect on lateral clearances. We tested the use of average flow and average speed instead of density, and found these to perform worse than the density variable, indicating that density is indeed more closely related to motorists' passing behaviour.

The strongest effect (as indicated by the t-statistics) is that of the lane width. However, even controlling for lane width, there is an independent effect of speed: vehicles passing cyclists at higher speeds tend to allow wider clearances, whatever the lane width.

Model 2 excludes the spot speeds, for comparison. Its much lower adjusted R-square value indicates that it is not just the *average speed* of traffic that determines an individual driver's passing behaviour (the average speed is already reflected by the density variable), but also the *individual* speed of each vehicle that is important.

**Table 3: Linear regression results of lateral clearance models**

| Variable | Model 1 | | Model 2 | |
|---|---|---|---|---|
| | Coefficient | T statistic | Coefficient | T statistic |
| Constant | 1.084 | 21.9** | 1.236 | 22.9** |
| Medium spot speed dummy (40-48 km/h) | 0.168 | 7.45** | -- | |
| High spot speed | 0.339 | 13.3** | -- | |

| | | | | |
|---|---|---|---|---|
| dummy (>48 km/h) | | | | |
| $(\text{Lane width})^2$ | 0.0277 | 16.2** | 0.0295 | 15.1** |
| LN(traffic density) | -0.0994 | 7.03** | -0.1025 | -6.35** |
| N= Adjusted R squared | 573 0.51 | (**=significant at 99%) | 573 0.36 | (**=significant at 99%) |

## 4. IMPLICATIONS: DESIGNING SAFE BIKE ROUTES AND BIKE LANES

The analysis reinforces much of the design guidance already available on the handling of roadways shared by bicyclists and motor vehicles. Most important, from an engineering point of view, seems to be to provide adequate lane widths that can accommodate both wide lateral clearances with bicyclists and safe interaction with traffic in adjacent lanes. The data suggests that kerb lane widths of 3.3m or less are very dangerous as more than 80% of clearances are less than the safe benchmark of 1.5m. Clearances – and by extension cyclist safety – improve significantly at lane widths of more than about 4.5m.

However the interaction between lane widths and traffic speed, and between traffic density and lateral clearances, complicates any design guidance to be given. Wider lanes might promote wider lateral clearances, but they also raise vehicle speeds (e.g. Fitzpatrick et al. 2001). The present data bore this out: controlling for flow, every additional metre of lane width was associated with an increase in average speed of about 5km/h. And higher speeds are generally considered a major threat to cyclist safety. Thus the use of wider lanes might have an offsetting effect on safety by raising the severity of cyclist-vehicle collisions. What is needed is to widen kerb lanes *without* raising speeds – which calls for specific measures such as area-wide traffic calming, or use of visual clues to create an impression of narrow lanes without actually reducing clearances. There is potential here for innovation and experimentation to find perhaps a combination of markings, pavement treatments, and signage that will achieve these goals.

A further important interaction is that between traffic density and passing behaviour. For a given lane width, lateral clearances improve at lower flow levels (which is associated with higher speeds and lower densities, for uncongested conditions). This implies that biking on narrow lanes becomes safer if traffic volumes are low. Using the statistical relationships developed above, it is possible to estimate directly the percentage of passing manoeuvres that falls below a certain threshold – say the 1.5m benchmark – for a given lane-width and traffic flow combination. The values in Table 4 were calculated assuming normally distributed clearances, the best fitting clearance model from Table 3, and the relationship between lane width and average speed observed in our data.

Table 4 provides potentially useful information on the types of roads where safe biking is possible, given current driving behaviour of motorists. For instance, on a road with a kerb lane width of 4.0m and a flow of 350 veh/hr, about half of vehicles will pass a bicyclist with less than 1.5m clearance. To reduce this percentage to, say, 10%, the kerb lane needs to be widened to 5.0m (while maintaining the same flow of about 360 veh/hr). An alternative is to drastically reduce the flow to 35 veh/hr – only at this flow is the density low enough to encourage drivers to pass cyclists with a wide enough clearance 90% of the time. This kind of flow reduction is impossible to achieve, even with volume-reducing traffic calming elements such as one-way chokers. It thus indicates that the chosen level of safety cannot be achieved on this road without further enhancements such as, perhaps, bike lanes.

Table 4 can assist in identifying suitable urban roads for inclusion in a safe biking network. For instance, the table indicates that any road with a kerb lane width of less than about 3.3m and a flow of over 100 veh/hr would expose more than 50% of cyclists to unsafe passing, and might not be suitable for shared bicycle/vehicle operations without further treatment. Or, by selecting a minimum safety level – say that 90% of lateral clearances should exceed the safe 1.5m threshold – the maximum flow-minimum lane width combination can be found that will qualify a road for inclusion in the bike network. It might thus help to prioritise roads for further analysis and upgrading to improve bikeability in an area.

**Table 4: Maximum kerb lane traffic volume for given level of unsafe passing and lane widths (based on data for urban roads in Tshwane)**

| | | Maximum kerb lane traffic volume (veh/hr) | | | |
|---|---|---|---|---|---|
| | | Percentage of lateral clearances <1.5m | | | |
| | | 50% | 25% | 10% | 5% |
| Kerb lane width (m) | 2.75 | 30 | <20 | <20 | <20 |
| | 3.00 | 55 | <20 | <20 | <20 |
| | 3.25 | 95 | 20 | <20 | <20 |
| | 3.50 | 150 | 40 | <20 | <20 |
| | 3.75 | 240 | 75 | 20 | <20 |
| | 4.00 | 350 | 130 | 35 | <20 |
| | 4.25 | 480 | 215 | 70 | 30 |
| | 4.50 | 640 | 330 | 135 | 65 |
| | 4.75 | 820 | 475 | 230 | 125 |
| | 5.00 | 1040 | 640 | 360 | 225 |
| | 5.25 | 1335 | 840 | 520 | 360 |

## 5. CONCLUSIONS

The study investigated the passing behaviour of motorists when overtaking bicyclists on urban roads by measuring the lateral clearance between vehicle and bicycle under typical operating conditions. The data demonstrated firstly the extent of the safety problem faced by cyclists: assuming the international benchmark of 1.5m applies, two-thirds of passing manoeuvres were unsafe. The analysis found that lateral clearances are most sensitive to the lane width, but are also systematically influenced by vehicle speed and average density of traffic in the kerb lane. It was shown that density is a better predictor of lateral clearance than either speed or flow. We derived guidance for practitioners around the combination of vehicle volume and lane width that can be expected to result in given levels of bicycle safety. This guidance might help in pro-actively identifying roadways with high accident potential for cyclists, or in identifying suitable roads for inclusion in an area-wide safe bicycle network.

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