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Road factors and bicycle–motor vehicle crashes at unsignalized priority intersections

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ABSTRACT

In this study, the safety of cyclists at unsignalized priority intersections within built-up areas is investigated. The study focuses on the link between the characteristics of priority intersection design and bicycle–motor vehicle (BMV) crashes. Across 540 intersections that are involved in the study, the police recorded 339 failure-to-yield crashes with cyclists in four years. These BMV crashes are classified into two types based on the movements of the involved motorists and cyclists:

- type I: through bicycle related collisions where the cyclist has right of way (i.e. bicycle on the priority road);
- type II: through motor vehicle related collisions where the motorist has right of way (i.e. motorist on the priority road).

The probability of each crash type was related to its relative flows and to independent variables using negative binomial regression. The results show that more type I crashes occur at intersections with two-way bicycle tracks, well marked, and reddish coloured bicycle crossings. Type I crashes are negatively related to the presence of raised bicycle crossings (e.g. on a speed hump) and other speed reducing measures. The accident probability is also decreased at intersections where the cycle track approaches are deflected between 2 and 5 m away from the main carriageway. No significant relationships are found between type II crashes and road factors such as the presence of a raised median.

1. Introduction

Collisions between bicycles and motor vehicles have caused severe life and property losses in many countries (Wang and Nihan, 2004). The Netherlands is one of the safest countries for cyclists, as crash risks for cyclists are lower in countries with higher bicycle use. In 2007, thirty-four percent of all trips up to 7.5 km were made by bicycle (Ministry of Transport, Public Works, and Water Management, 2009). In spite of this, the numbers of traffic deaths and in-patients among cyclists are substantial in the Netherlands (over twenty percent of all recorded traffic deaths and in-patients). The majority of bicycle–motor vehicle (BMV) crashes occur within built-up areas at unsignalized priority intersections, such as where an arterial road intersects with a local road. Over ninety-five percent of these are failure-to-yield crashes.

This study was issued by the Dutch Ministry of Transport, Public Works, and Water Management in order to develop measures for road authorities. The study is therefore focused on the link between priority intersection design characteristics and BMV crashes. As small crash numbers limit the number of variables that can be included in regression analyses, only those road features were selected for which our literature research (see Sections 1.1 and 1.2) revealed that they were potentially relevant for failure-to-yield crashes with cyclists. Furthermore, only design characteristics were included, e.g. speed humps, while non-design characteristics, like speed, were excluded.

BMV crashes are classified into two types depending on who had priority (i.e. the cyclist in the case of type I crashes; the motorist in the case of type II crashes). Separate analyses are conducted for both crash types as different traffic flows and road features influence each group. For instance, the number of type I crashes is directly related to the amount of motorized traffic on the side road (i.e. the volume of motorists entering or leaving the main road) and only indirectly to the volume of motorists on the main road. Furthermore, most road features affect specific traffic flows. For instance, painting a bicycle track along the main road may have an influence on cyclists on the main road and on motorists crossing the track when entering or leaving the main road. Therefore, this road fea-

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ture may be related to type I crashes while a relationship with type II crashes is less likely.

1.1. Type I crashes and road factors

In type I crashes, the cyclist rides on the priority road and is hit by a vehicle that is leaving or entering the side road. Cyclists on the arterial road have priority over vehicular traffic. An in-depth study of bicycle–car collisions in four Finnish cities showed that cyclists most often noticed the driver before the accident and believed the driver would give way as required by law. However, only a small portion of the drivers noticed the cyclist before impact (Räsäsen and Summala, 1998).

Several priority intersection design characteristics that can be linked to type I crashes have been studied in the last decades. A lot of studies focused on safety effects of bicycle facilities along arterial roads. In their meta-analysis Elvik and Vaa (2009) found a significant increase of bicycle accident numbers due to bicycle tracks at junctions. It is suggested that the crash numbers increase at junctions with bicycle tracks because of a lack of attention due to the physical separation of cyclist and motor traffic. According to Herslund and Jørgensen (2003), drivers who search the road area for possible counterparts may focus their attention on the location where cars usually are. Welleman and Dijkstra (1988) studied the risks (numbers of crashes per passing cyclist) at crossroad branches of priority intersections with different bicycle facilities for cyclists on the main road. In this study, cycle lanes were found to be most risky for cyclists. Cycle paths and mixed traffic on the carriageway did not significantly differ from each other. The risk of bicycle crashes is found to be elevated at priority intersections with two-way cycle tracks along the arterial road, as drivers entering from the side road have difficulties in detecting cyclists from the right (Räsäsen and Summala, 1998; Schnüll et al., 1992; Wachtel and Lewiston, 1994). Summala et al. (1996) studied drivers' scanning behaviour at T-intersections. Drivers turning right from the minor road scanned the right leg of the T-intersection less frequently and later than those turning left. Drivers develop a scanning strategy, which concentrates on more frequent and major dangers but ignores and may even mask visual information on less frequent dangers.

A sight obstacle makes that situation even more hazardous, because drivers cannot even detect cyclists with peripheral vision (Räsäsen et al., 1999). On the contrary, Henson and Whelan (1992) suggested that good visibility at T-junctions was associated with a greater probability of bicycle crashes when a cyclist was riding among cars. They assume that a form of 'risk compensation' operates. When visibility is poor drivers behave cautiously at the junction, counteracting the obvious danger. A wider entry width of the minor road was associated with a decreased safety of cyclists riding on the main road. The extra space may invite vehicles to queue two abreast on the minor road. A left-turning vehicle could screen a cyclist from a vehicle waiting to turn right (Henson and Whelan, 1992).

The results of studies on the effect of markings are inconsistent. The city of Portland studied the effects of blue pavement markings in combination with a "Yield to Cyclist" sign for crossings where the cyclist travels straight and the motorist crosses the bicycle lane in order to exit a roadway, or merge onto a street from a ramp. Significantly higher numbers of motorists yielded to cyclists and slowed before entering the blue pavement areas. However, the blue pavement also resulted in fewer cyclists turning their heads to scan for traffic or using hand signals (Hunter et al., 2000). Jensen (2008) studied the safety effects of blue cycle crossings at signalized intersections. The safety effect depends on the number of blue cycle crossings at the junction. One blue cycle crossing reduces the number of junction crashes by ten percent, whereas marking of two and four blue cycle crossings increases the number of crashes by twenty-three and sixty percent, respectively. Schnüll et al. (1992) did not find bicycle crashes to be affected by the type of marking at priority intersections without traffic lights. Like Gårder et al. (1998), they did show that cyclists riding on the priority road are less at risk if they use raised bicycle crossings as compared to crossings delineated by white painted rectangles. Raising a bicycle crossing leads to somewhat increased bicycle speeds, but significantly reduced motor vehicle speeds (Gårder et al., 1998). A study of cyclist safety at minor priority junctions showed, moreover, that the establishment of speed reducing exit constructions leads to a fall in the number of bicycle crashes of up to fifty percent (Herrstedt, 1979).

To conclude, two intersection design characteristics seem to reduce the complexity of the driving task when giving way to cyclists on the main road, thereby improving cyclist safety. The addition of a left-turn lane or left-turn section on the main road was found to decrease type I crashes, but this is only studied at priority intersections outside built-up areas (CROW, 2002). It enables drivers leaving the main road to slow down and stop without hindering through traffic. Schnüll et al. (1992) studied the safety effect of the distance between the cycle track and the side of the arterial road. A clearance between 2 and 4 m at priority intersections was found to be most favourable. According to Elvik and Vaa (2009), the aim of a bent-out crossing is to give drivers turning into the side road extra time to notice crossing cyclists, and to allow vehicles waiting to exit the side road to do so without blocking the crossing point.

In this section, several factors have been mentioned on how intersection design characteristics affect the behaviour of cyclists and motorists and thereby cyclist safety: visual scanning strategies, risk compensation, and the complexity of the driving task. Drivers' scanning strategies are primarily focused on where motorists are and to a lesser extent on where cyclist are. Therefore, problems may arise if both are physically separated by bicycle tracks. Also, the visual scanning strategy of right-turning drivers who approach the main road is concentrated on the left leg of the intersection, while they may be confronted with cyclists from the right riding along a two-way cycle track. Increasing the conspicuousness of a bicycle crossing by pavement markings or raising the crossing seems to increase cyclists' speed and reduce their visual scanning, while drivers decrease their speed and improve their visual scanning (i.e. risk compensation operates). Drivers also counteract the obvious danger of a poor visibility from the minor road due to sight obstacles as long as it does not hinder an already insufficient visual scanning behaviour. To conclude, it is suggested that left-turn sections and a clearance between 2 and 4 m between the main road and bicycle tracks decrease the complexity of the driving task in that it offers drivers turning into the side road extra time to slow down and notice cyclists.

1.2. Type II crashes and road factors

In type II crashes the cyclist crosses the priority road and is hit by a through vehicle on the main carriageway. These crashes take place at both priority intersections and single separate bicycle crossings (i.e. where a solitary cycle track crosses the priority road). Less is known about these crashes as compared to type I crashes. An in-depth study of bicycle–car collisions in four Finnish cities showed that cyclists rarely did anything to avert these crashes, while drivers often did something. As compared to type I crashes the cyclist victims were more often unfamiliar with the accident location and under eighteen years of age. For cyclists, crossing a major road is more demanding than crossing a minor road (Räsäsen and Summala, 1998). The complexity of the traffic situation seems to play a role in these crashes.