Traffic conflicts on bicycle paths: A systematic observation of behaviour from video

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\textbf{Abstract}
In The Netherlands, on bicycle paths, single-bicycle accidents, bicycle–bicycle and bicycle–moped accidents constitute a considerable share of all bicyclist injuries. Over three quarters of all hospitalised bicyclist victims in the Netherlands cannot be directly related to a crash with motorised traffic. As the usage of bicycle paths steadily increases, it is to be expected that safety on bicycle paths will become a major issue in the coming years in The Netherlands.

A study was conducted into the behaviour of bicyclists and moped riders to improve traffic safety on bicycle paths. By observational data and analysis, mutual conflicts and bicyclist behaviour on bicycle paths were recorded and analysed, among other things by means of the conflict observation method DOCTOR (Dutch Objective Conflict Technique for Operation and Research). The exploratory phase of the study (phase 1), included two research locations, one in the city of Amsterdam and one in Eindhoven. The results gave guidance for a better understanding of the behaviour between different users of separate two-directional bicycle paths. An example includes the relationship between bicyclist–moped rider behaviour and the width of the bicycle path. For a condition with busy bicycle traffic in both directions the width of the bicycle path in Amsterdam (effectively 3.55 m) is relatively narrow, whereas the bicycle path width in Eindhoven (>4.94 m) appears to be sufficient to accommodate large flows of bicyclists. Because of a large flow of crossing pedestrians resulting in (severe) conflicts with bicyclists in Amsterdam, additional countermeasures to better control these interactions are needed.

The DOCTOR conflict observation method from video appears to be applicable for conflicts between intersecting road users and for head-on conflicts on the bicycle path. Conflict situations between bicyclists in the same direction (constituting an important share of injury accidents on bicycle paths) require an additional and more general systematic observation of specific behaviour. Therefore, phase 2 of the project will focus in particular on interactions between bicycle path users in the same direction and underlying processes.

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1. Introduction
The total number of seriously injured (hospitalised) bicyclists in The Netherlands is estimated to be more than 10,000 annually (Schepers, 2010). Single-bicycle accidents, bicycle–bicycle and bicycle–moped accidents constitute a considerable share of all bicyclist injuries. Reurings et al. (2012) conclude that in about half of the injured bicyclist events, the behaviour of another road user (partly) contributed to the occurrence of the event. In a study on the pre-crash phase of real accidents (van der Horst et al., 2007) by means of long-term video-observations at four urban intersections, it also appeared that in almost all cases (16 collisions) another road user was (in)directly involved, either as a distracting or as a contributing element. Over three quarters of all hospitalised bicycle victims cannot be directly related to a crash with motorised traffic (Schepers, 2010). An in-depth study by Ormel et al. (2008), based on 1142 interviews with bicyclists that were taken to the first aid of a hospital, made a further subdivision in the type of accident of the 164 victims that actually were hospitalised, see Table 1.

In The Netherlands, the usage of bicycle paths steadily increases (Slütter and Koudijs, 2007) with a large variety of different type of vehicles (city bike, race-bike, e-bike, carrier bike, light moped, etc.)
Table 1
Percentage of hospitalised bicycle victims by type of accident (N = 164) (Ormel et al., 2008).

<table>
<thead>
<tr>
<th>Type</th>
<th>%</th>
</tr>
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<tbody>
<tr>
<td>With motor vehicle</td>
<td>20</td>
</tr>
<tr>
<td>With moped</td>
<td>4</td>
</tr>
<tr>
<td>Single-bicycle accident</td>
<td>62</td>
</tr>
<tr>
<td>With other bicyclist</td>
<td>12</td>
</tr>
<tr>
<td>With pedestrian</td>
<td>2</td>
</tr>
</tbody>
</table>

and type of users (youngsters, elderly, commuters, recreational users). Therefore, it is to be expected that safety on bicycle paths will become a major issue in the coming years in The Netherlands, especially since the bicycle usage of the vulnerably group of elderly also increases (Ministry of Infrastructure and the Environment, 2012). The number of seriously injured bicyclists in bicycle–bicycle accidents is estimated at about 1150 annually (Van Boggelen et al., 2011). Schepers (2008, 2010) reviewed the literature extensively with regard to bicycle–bicycle accidents. An important finding was that by comparing the number of police-reported accidents (BRON database) with the real number of hospitalised bicyclists (national medical registration), a large under-reporting consists in bicycle accidents without the (direct) involvement of a motor vehicle. Based upon the study by Ormel et al. (2008), Schepers developed a typology of bicycle–bicycle accidents, see Table 2.

Commissioned by the Ministry of Infrastructure and Environment, TNO conducted a study into the behaviour of bicyclists and moped riders by behavioural observations with video to improve traffic safety on bicycle paths. This study was divided in two phases. Phase 1 consisted of an explorative study by observing and analysing bicyclists’ behaviour at two busy two-directional bicycle paths, one in the city of Amsterdam and one in the city of Eindhoven (de Hair & van der Horst, 2012). In phase 2, three urban bicycle paths (in Utrecht and The Hague) as well as two recreational bicycle paths (in Westland township) have been observed. This paper mainly focusses on the method of systematic observing road user behaviour from video, on the results of phase 1, and the implications for conducting phase 2. For the main findings of phase 2, the reader is referred to de Goede et al. (2012).

2. Method

2.1. Choice of locations

Phase 1 of this study was mainly exploratory with an emphasis on conflicts/unsafe behaviour in bicyclist–bicyclist and bicyclist–moped rider encounters (accident types 1, 2 and 3) and less on single-bicycle accidents. From a list of 9 and 19 potential locations in Amsterdam and Eindhoven, respectively, a selection has been made for two locations based upon Google-streetview information and on-site location visits. Criteria for selection included two-directional bicycle paths, heavy bicycle traffic, variety in usage, possibility to install video cameras for unobtrusive observation, etc. Both locations (one in Amsterdam and one in Eindhoven) include two-directional bicycle paths with high volume bicycle traffic in both directions.

2.2. Amsterdam

The main characteristics of the observed location in Amsterdam (Prins Hendrikkade) are (see Fig. 1):

- Relatively narrow two-directional bicycle path, total width is 3.70 m (3.55 m asphalt, 0.15 m gutter at one side).
- Red-coloured smooth asphalt.
- White interrupted centre-line marking.
- Use is allowed for bicycles and light mopeds (speed limit < 25 km/h, no helmet required).
- Many crossing pedestrians.

2.3. Eindhoven

The main characteristics of the selected location in Eindhoven (Neckerspoel) are (see Fig. 2):

- T-junction between two two-directional bicycle paths.
- Width of through-going bicycle path varies between 5.15 and 5.46 m; road width of connecting bicycle path is 4.94 m.
- Cobble stone pavement.
- Wide solid centre-line marking (0.60 m) on through-going bicycle path.

2.4. Video recordings

Fig. 3 gives some examples of the video images as made at both locations. In Amsterdam three black/white CCD video cameras were used, unobtrusively mounted in an existing lamppost, in Eindhoven two black/white CCD cameras were used, mounted on top of an
existing pyramid construction nearby. At each location, a close-up camera was used that provided more details about the type of bicycle and of rider. The video recordings were stored on hard disks of a on-site PC-based system that enabled continuous 24 h/day recordings for 7 days with a time-lapse factor of 4 (12.5 fields/s). The video images were stored as separate JPEG pictures in a time-directory structure (date, hour, minute). Each field had a resolution of 768 × 288 pixels. The on-site video recordings at both locations were made in the period of end of October/early November 2011.

2.5. Analysis method

2.5.1. Selection of analyses periods

For both locations, three 2-h periods (7:00–9:00 h, 12:00–14:00 h, 16:00–18:00 h) of 3 week days of video recordings have been selected for further analyses, so covering the most busy periods.

2.5.2. Traffic counts

To get more insight in the exposure and bicycle path use, traffic counts have been made for bicycles (light) mopeds, and pedestrians during three 2-h periods (see Section 2.5.1). From video, human observers counted the number of a given type of road user in periods of 15 min with a distinction in direction of travelling. Fig. 4 gives the directions of travelling for both locations.

2.5.3. Traffic conflicts

2.5.3.1. Traffic conflict techniques. Traffic conflict techniques (TCT) have been extensively discussed in the literature. With a publication by Perkins and Harris (1967), the TCT was adopted as an operational tool in road safety research. Williams (1981) gave a good overview of the early developments of TCTs. The processes that result in near-accidents or serious traffic conflicts have much in common with the processes preceding actual collisions (Hydén, 1987), only the final outcome is different. Advantages of this approach over the mere use of accident data are apparent. Since near-accidents occur more frequently, observation periods can be much shorter, which, definitely, is advantageous in evaluation studies. Moreover, the preceding process can be systematically observed, which is essential for analysing, diagnosing and solving safety problems (van der Horst, 1990). Since the late seventies, an intensive international cooperation in the field of TCTs started in a first workshop in Oslo with the acceptance of a common definition for a traffic conflict: ‘A traffic conflict is an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged’ (Amundsen and Hydén, 1977). A break-through was the international calibration study of traffic conflict techniques by the ICTCT (International Cooperation on Theories and Concepts in Traffic Safety) in Malmö in 1983 (Grayson, 1984) where eight teams from different countries simultaneously made their conflict observations at three intersections, and a comparison could be made. Hauer and Garder (1986) looked into the issue of the validity of traffic conflict counts (To what extent can serious conflicts be used in order to predict the number of accidents?) and the came up with the approach of looking at the expected number of accidents per unit of time. Based on this approach others could conclude that traffic conflicts are good surrogates of accidents in that they produce estimates of accident frequencies at least as accurate and just as precise, as those produced from historical accident data (Migletz et al., 1985; Svensson, 1998).

2.5.3.2. The DOCTOR conflict observation method. The traffic conflicts in this study have been analysed by using the DOCTOR conflict observation method. DOCTOR stands for Dutch Objective Conflict Technique for Operation and Research. This method was developed in The Netherlands after the international calibration ICTCT study (Grayson, 1984) and applied since then in several traffic safety studies (for example, see Kraay and van der Horst, 1985; van der Horst and Bakker, 2004). A comparison with video-taped conflicts and accidents (van der Horst, 1984) indicated that conflict severity scores, performed by individual observers of existing traffic conflict technique teams at that time, were mainly correlated to Time-To-Collision (TTC) and type of accident. The DOCTOR technique identifies a critical situation if the available space for manoeuvring is less than is needed for a normal reaction (van der Horst and Kraay, 1986). The severity of a conflict is then scored on a scale from 1 to 5, taking into account:

1. the probability of a collision, and
2. the extent of the consequences if a collision had occurred.

Fig. 2. T-junction of two two-directional bicycle paths in Eindhoven phase 1.

Fig. 3. Video images location Amsterdam (left) and Eindhoven (right), phase 1.
The probability of a collision is determined by the Time-To-Collision (TTC) and/or post-encroachment time (PET). In research on traffic conflicts techniques, Hayward (1972) initiated a search for objective measures to describe the danger of a conflict situation and concluded that the Time-To-Collision (TTC) is a dominant one, being 'the time required for two vehicles to collide if they continue at their present speed and on the same path'. TTC at the onset of braking (TTCbr) represents the available manoeuvring space at the moment an evasive action starts. The minimum TTC (TTCmin) as reached during the approach process of two vehicles is taken as an indicator for the severity of an encounter. In principle, the lower TTCmin the higher the risk of a collision will be. As an example, Fig. 5 indicates what happens when a car approaches a stationary object (van der Horst, 1990). Usually, the concave shape of the TTC curves does not show up so nicely since in more complex interactions between 2 moving road users the collision course is often ended before point B is reached. But even then, TTCmin indicates how imminent an actual collision has been. Details of the calculation of TTC can be found in van der Horst (1990). He evaluated the TTC measure in normal and more critical encounters between road users in several empirical observation studies. In general, TTCmin values of less than 1.5 s constitute a potential dangerous situation in urban areas.

The TTC concept can only be applied in case of a collision course. The PET value, as initially introduced by Allen et al. (1977), is a measure that also includes the ‘near misses’. It is defined as the time between the moment that the first road-user leaves the path of the second and the moment that the second reaches the path of the first (see Fig. 6). The PET value indicates the extent to which they missed each other. In urban areas, PET values of one second and lower are indicated as possibly critical.

The extent of the consequences if a collision course had occurred is mainly dependent on the potential collision energy and the vulnerability of the road-users involved. Affecting factors are the relative speed, available and necessary space for manoeuvre, the angle of approach, the type and condition of road-users, etc. The mass and manoeuvrability of the vehicles are very much determining the final outcome. To obtain an unambiguous estimate as possible of the injury severity and for additional information for analysis and diagnosis, several aspects are scored and registered on the observation sheet. For this methodology a manual has been developed in which DOCTOR is described in detail (Kraay et al., 1986).

Conflicts with an overall severity score of 1 or 2 are to be considered as slight conflicts (more dealing with a disturbance in the traffic process, still manageable by at least one of the road users involved), conflicts with a severity score 3–5 as serious conflicts with a more direct link with traffic safety.

Originally, the DOCTOR method was based upon judgments of traffic conflicts by human observers in the field. Later on, the DOCTOR method was applied by making the judgments from video recordings afterwards (van der Horst et al., 2007). The latter approaches has a major advantage over observing conflicts directly at street level by trained observers, viz. you can have repeated looks at an event, score certain aspects of an encounter separately, and identify what actually happened.

For analysing traffic conflicts between road users on a bicycle path, first a pre-selection has been made of potentially dangerous events and potential conflicts. This pre-selection has been conducted manually by human observers from the video recordings. They replayed the recorded data faster than real-time and marked possible relevant situations (the starting time of the scene was stored automatically for further analysis later on). Moreover, time stamps were registered for scenes with (light) mopeds or large groups of bicyclists. This pre-selection data set was the basis for further traffic conflicts analysis with the DOCTOR method by an experienced DOCTOR expert. This analysis has been conducted in two steps:

(1) For a limited period (2 h for Amsterdam and 1 h for Eindhoven) all pre-selected events were judged according to the criteria of

![Fig. 4. Directions of travelling for Amsterdam (top) and Eindhoven (bottom) location.](image-url)
the DOCTOR method including all conflict severity categories from 1 to 5. This step resulted for Amsterdam and Eindhoven in 19 and 20 conflicts, respectively and gave a good insight in what kind of critical behaviour took place.

(2) Because slight conflicts (categories 1 and 2) occur relatively frequently and were mainly of type 2 (crossing), the next step in the conflict analysis consisted of focussing on serious conflicts (category 3–5) for all types and all conflicts of the type 1 (same direction) and type 3 (oncoming). For Amsterdam this resulted in an extra period of 11.25 h, and for Eindhoven in 7 additional hours.

Both periods together resulted in total in 13.25 h of conflict data for Amsterdam and 8 h of conflict data for Eindhoven.

2.5.4. Additional analyses

From the recorded video data, a classification is made on (light) moped behaviour ranging from free riding to overtaking bicyclists on the other side of the bicycle path with oncoming traffic present. For both locations, this analysis was conducted for a 2 h time period. For Amsterdam the speed of free-riding mopeds has been measured from video for 1 h, resulting in 27 cases.

To get a first impression on how well a distinction could be made from video between male and female bicyclists, between type of bicycle, and a rough estimate of bicyclists’ age categories, for both locations a few minutes of all passing bicyclists have been categorised to see how well this could be done from the detailed video images.

A limited analysis had been conducted of bicyclists’ behaviour while riding in groups with the main focus on lateral behaviour in relationship with the available bicycle path width.

3. Results phase 1

3.1. Traffic counts

For each quarter of an hour, the results of the traffic counts for the number of bicycles, mopeds, and pedestrians are given in Figs. 7–9, respectively. In Amsterdam, the maximum number of bicyclists/hour appeared to be 1440 (17–18 h), in Eindhoven, this was much higher, viz. 2420 bicycles/hour and took place in the morning peak (8–9 h) (Fig. 7).

In Eindhoven, the number of mopeds is much higher than in Amsterdam, 805 versus 331, respectively (Fig. 8). One reason may be that in Eindhoven both light (speed limit 25 km/h, no helmet mandatory) and normal mopeds (helmet mandatory, speed limit 30 km/h in urban areas) are allowed to make use of the bicycle path, whereas in Amsterdam only the light mopeds are allowed on the bicycle path (in general, the normal mopeds have to make use of the main road for motorised traffic in The Netherlands).

In Amsterdam, the number of pedestrians that cross the bicycle path is very high compared to the number of pedestrians that cross the bicycle path in Eindhoven (Fig. 9). Most pedestrians cross during the early afternoon period.

3.2. Traffic conflicts

3.2.1. Amsterdam

If we limit ourselves to serious conflicts (severity score 3–5), in total, 40 serious conflicts have been scored in Amsterdam, of which the majority is of type 2 (crossing) (23 in total) and mainly between bicyclists/moped riders and pedestrians that cross the bicycle path, see Table 3. Of this type, two actual collisions took place, both between a pedestrian crossing from direction 4 to 2 and a bicyclist riding from direction 1 to 3 (see Fig. 4).

13 serious conflicts were of the type 3 (conflicts with others in opposite direction), overtaking manoeuvres by bicyclists or moped riders with at the same time opposing traffic present. Type 1 (road users involved travel in the same direction) serious conflicts were relatively rare, 4 in total (all with a severity score of 3).

When we look in more detail into the serious conflicts between crossing pedestrians and bicyclists/moped riders, it appeared that for the total period of conflict counts (13.25 h), the risk for pedestrians crossing from direction 2 to 4 to get involved in a serious
Fig. 7. Number of bicycles by quarter of an hour counts for Amsterdam (top) and Eindhoven (bottom).

Table 3
Location Amsterdam: traffic conflicts by type of conflict (type 1: same direction; type 2: crossing [gray shade column] and type 3: opposing traffic), type of road user (B: bicyclist; M: moped rider; P: pedestrian and C: car) and conflict severity according to the DOCTOR method (1 and 2: slight conflicts and 3–5 serious conflicts [gray shade rows]). The red rectangles reflect the dominant (serious) conflict types.

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<th>1a</th>
<th>1b</th>
<th>1c</th>
<th>1d</th>
<th>1e</th>
<th>2</th>
<th>3</th>
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<tbody>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>1</td>
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<th>1b</th>
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</table>
conflict with a bicyclist/moped on the bicycle path appears to be 0.0022 compared with a risk of 0.0034 for pedestrians crossing from direction 4 to 2, when taking the number of pedestrians and the bicycle path users (quite similar in number for directions 1–3 and 3–1) for the given period into account. Both collisions were with pedestrians from direction 4 to 2 and bicyclists from direction 1 to 2 (for directions see Fig. 4). On one hand, one could say it concerns bicyclists from a for pedestrians less expected direction, if they do not directly expect a two-directional bicycle path. On the other hand, 74% of the serious conflicts between pedestrians and bicycle path users appears to be with the first flow to cross. This yields for both pedestrian directions. So, another explanation may be that pedestrians cross the bicycle path more or less inattentive.

3.2.2. Eindhoven

In Eindhoven, the classification of the type of conflicts according to the taxonomy of Table 2, is a bit more complicated. When the parties involved followed the same direction (for example, direction 1–3, 3–1, 3–2, 2–1, or 2–3, see Fig. 4), the conflict was classified as type 1 (same direction). Conflicts between road users from direction 2 to 3 and from direction 3 to 1 or from direction 1 to 2, and conflicts with crossing pedestrians were classified as type 2 (intersecting), whereas conflicts between 3–1 and 1–3, and between 2–1 and 1–2 were classified as type 3 (opposing).

In Eindhoven, no serious conflicts between bicyclists/mopeds and pedestrians were registered. The majority of serious conflicts were of the type 2 (crossing), conflicts between traffic from the bicycle path connection and bicycle/moped traffic on the through-going bicycle path. Two serious conflicts were of type 3 (opposing traffic), one between a left-turning bicyclist from direction 1 to 2 and a right-turning bicyclist from direction 2 to 1 (see Fig. 4), and the other between a moped rider from direction 3 to 1, who overtakes three side by side riding bicyclists and a moped in opposite direction (from direction 1 to 3; Table 4).

3.3. Additional analyses

3.3.1. Moped analysis

To get a better idea of how moped passages take place, a classification has been made for a 2-h period for both locations.
Fig. 9. Number of crossing pedestrians by quarter of an hour counts for Amsterdam (top) and Eindhoven (bottom).

Table 4
Location Eindhoven: traffic conflicts by type of conflict (type 1: same direction; type 2: crossing (gray shade column) and type 3: opposing traffic), type of road user (B: bicyclist; M: moped rider; P: pedestrian and C: car) and conflict severity according to the DOCTOR method (1 and 2: slight conflicts and 3–5 serious conflicts (gray shade rows). Red rectangles refer to dominant conflict types.

<table>
<thead>
<tr>
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<td>B-M</td>
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<td>M-M</td>
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<tr>
<td>B-C</td>
<td>0</td>
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<tr>
<td>TOTAL</td>
<td>0</td>
</tr>
</tbody>
</table>

| Conflict Type | 1a | 1b | 1c | 1d | 1e | 2 | 3 | Total |
| Conflict Severity |
| 1 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 4 |
| 2 | 0 | 0 | 2 | 2 | 0 | 15 | 4 | 23 |
| 3 | 0 | 0 | 1 | 1 | 0 | 9 | 2 | 13 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| TOTAL | 0 | 0 | 3 | 3 | 0 | 27 | 7 | 40 |
The classification included the distinction between free-riding mopeds (no direct road user in front), following a bicycle with about the same speed, overtaking a bicycle while riding on their own bicycle path side or on the other side without or with oncoming traffic. The position of the wheels is taken as a reference, so it can be that part of the moped (rider) while overtaking on own side, came actually on the other side (maximally, half the width of a moped). Methorst et al. (2011) found an average width of light mopeds including mirrors was 0.78 m (based upon a measurement of 211 light mopeds). The widest light moped was 1.03 m (mirrors included). In Amsterdam, in a 2 h period, 117 light mopeds passed, and were classified as indicated, see Table 5. In Eindhoven, in a 2 h period, in total, 221 mopeds passed by, of which over 74% made a turning movement at the T-junction (from or to direction 2, see Fig. 4). For Eindhoven, Table 5 gives the remaining through-going mopeds (direction 1 → 3 and 3 → 1) and the classification similar to Amsterdam with the inclusion of the crossing category (through-going mopeds that encountered traffic from direction 2). In Amsterdam, 28.2% of moped passages took place while at a given moment with the wheels on the other side of the bicycle path. The potentially most dangerous overtaking manoeuvre by mopeds while oncoming traffic was present, took place in 11% of the passages. In Eindhoven, overtaking while on the other side of the bicycle path took place in only 1.9% of the cases with no one overtaking while oncoming traffic was present.

In Eindhoven, almost 90% more mopeds pass by than in Amsterdam for a 2 h period. In Eindhoven also normal mopeds are allowed on the bicycle path, whereas in Amsterdam only light mopeds are permitted. In Eindhoven, overtaking without oncoming traffic, mainly takes place on the own side of the bicycle path (15.4 versus 1.9%), whereas in Amsterdam overtaking frequently takes place via the other side of the bicycle path (6 versus 17.1%). Also with oncoming traffic, overtaking in Amsterdam occurs relatively frequently via the other side (11.1%). The difference in bicycle path width definitely plays an important role in explaining this difference between both locations. In Amsterdam, the width of the riding strip is 3.55 m, whereas on the through-going bicycle path in Eindhoven, the width is at least 5.15 m. With respect to overtaking mopeds the location in Amsterdam is more risky than the one in Eindhoven.

In Fig. 10, the speed of free-riding light mopeds (without a direct lead bicycle) in Amsterdam is given. The mean speed was 29.4 km/h with a standard deviation of 5.5 km/h. Almost 80% of the free-riding mopeds have a speed above the legal speed limit for light mopeds of 25 km/h. Formally, only light mopeds are allowed on the bicycle path in Amsterdam. From video, it is not always clear whether it was a light moped or a normal one, whereas some light mopeds riders wear a helmet (not mandatory) and some normal moped riders do not (wearing percentage of normal moped riders’ helmet use is between 91% and 96%, according to SWOV, 2010). It can be concluded that mopeds on the bicycle path have a relatively high speed, well above the legal speed limit.

3.3.2. Estimates of gender, age and type of bicycle from video

For both locations, a 3 min period was used to see how well the distinction could be made from video with respect to gender (male or female), age category (<10, 10–15, 15–20, 20–60, >60 years of age), and type of bike (city bicycle, race bicycle, reclining bicycle, mountain bike, etc.).

In Amsterdam, in total, 59 bicyclists and 2 moped riders passed during 3 min. In Eindhoven, 78 bicyclists and 9 mopeds were counted. The distinction between male or female could be made in 96.7 and 96.2% of the cases for Amsterdam and Eindhoven, respectively. The age classes in Amsterdam could be distinguished well, whereas in Eindhoven in 5.1% of the cases it appeared problematic. Ebikes were difficult to identify for both locations.

3.3.3. Behaviour in groups

The conflict analysis results (see Section 3.2) indicated already that the number of serious conflicts of type 1 (same direction) is relatively low. For a bicycle section of 50–100 m this actually cannot be expected because without direct disturbance by infrastructural elements (poles, obstacles) or suddenly intersecting traffic, the process of interactions between bicyclists in the same direction is relatively smooth and anticipatory. In general, the relatively narrow bicycle path in Amsterdam results in more serious conflicts than the more busy and wider bicycle path in Eindhoven. As was the case for overtaking mopeds, also overtaking bicyclists in Amsterdam frequently use the opposite side of the bicycle path, whereas in Eindhoven they usually overtake on their own side.

3.4. Comparison between location Amsterdam and Eindhoven

If we limit ourselves to the serious conflicts (severity score 3–5), then it is remarkable that in Amsterdam, on average, per

![Graph](image-url)

**Fig. 10.** Cumulative distribution of the speed of free-riding light mopeds on the bicycle path in Amsterdam (n=27, November 7, 2011, 16–17 h).
hour 85% more serious conflicts occur than in Eindhoven (3.02/h versus 1.63/h, respectively). If we relate this to the average number of hourly passing road users (Amsterdam 1428/h versus 1605/h in Eindhoven), then the risk to get involved in a serious conflict in Amsterdam is twice as high as in Eindhoven (0.00211 versus 0.00101). In Amsterdam, 19 out of 40 serious conflicts, occur between a bicyclist or moped rider and a crossing pedestrian. This type of conflict did not take place in Eindhoven in the analysed period. In Amsterdam 13 serious conflicts had to do with opposing traffic conflicts (type 3), in Eindhoven only 2. Related to the number of analysed hours and the average amount of bicycle and moped traffic, this results in a five times as high risk of an serious opposing traffic conflict in Amsterdam compared to Eindhoven (0.00104 versus 0.00016, respectively). Serious conflicts of type 1 (same direction) do not occur frequently, but more in Amsterdam than in Eindhoven.

Both locations include two-directional bicycle paths with heavy traffic, but they differ a lot with respect to the type of site (straight bicycle path versus a T-junction of two bicycle paths) and the type of usage (many crossing pedestrians versus only a few; only light moped versus all mopeds permitted). For this explorative phase, the study gave a good coverage of possible interactions between users of a bicycle path and the potential of application of the traffic conflicts technique. But a proper interpretation of the results between both locations is more difficult to make. When we focus on serious conflicts of type 1 (same direction) and type 3 (opposing traffic conflicts) along the main bicycle paths, the results reveal that Eindhoven displays a much lower risk than Amsterdam. An important difference between both locations is the total width of the bicycle path, in Amsterdam the width is 3.70 m overall (including the gutter), in Eindhoven the width is between 4.96 and 5.46 m. Together with the results that in Eindhoven overtaking manoeuvres by mopeds and bicyclists mainly take place on the own site of the bicycle path, whereas in Amsterdam this more frequently takes place via the opposing site, one may contribute this difference to the considerable difference in bicycle path width for both locations.

The conflict analyses in Amsterdam clearly indicate a specific safety problem of crossing pedestrians, with even in the limited analysed period of 13.25 h, two actual collisions between a bicyclist and a crossing pedestrian. A first disaggregation of serious pedestrian conflicts reveals that 74% of the conflicts take place between crossing pedestrians and bicyclist/moped rider flours that are encountered first (in The Netherlands, with right-hand traffic, from the left).

4. Conclusions and recommendations for phase 2

In this explorative phase, the main focus of research was the possibilities for applying the DOCTOR conflict observation technique from video for research of behaviour of bicyclists/moped riders on bicycle paths. First, the scoring of conflicts according to the criteria of the DOCTOR method, from video appeared to be quite well-suited, and even gives advantages over the original approach with human observers on the street, because the scene can be repeatedly reviewed and different aspects judged independently from each other. This phase of the study learned that the DOCTOR technique can be applied well for conflicts between crossing road users, and conflicts with oncoming traffic. Conflict situations between road users in the same direction, occur relatively seldom on a limited road section (with video from one camera one can cover about 50–100 m of bicycle path length). But this type of conflict constitutes an important part of the number of injury accidents on bicycle paths (Schepers, 2010). Methodologically, the second phase should focus more on dangerous interactions between bicyclists travelling in the same direction. To identify possibilities to further improve road safety on bicycle paths, phase 2 should focus more on the interaction between different groups of bicyclists on recreational bicycle paths and on the influence of the infrastructure on the behaviour of, and the interaction between different user groups on busy urban bicycle paths.

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References

Allen, B.L., Shin, R.T., Cooper, P.J., 1977. Analysis of Traffic Conflicts and Collisions. Dept. of Civil Engineering, McMaster University, Hamilton.


