An evaluation of speed management measures in Bangladesh based upon alternative accident recording, speed measurements, and DOCTOR traffic conflict observations

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ABSTRACT

With 21,000 people annually killed in road traffic (estimated figure by World Health Organization), Bangladesh has one of the highest fatality rates in the world. Vulnerable road users (VRUs) account for over 50% of road traffic casualties, and 70% of casualties occur in rural areas. As in many Low and Middle Income Countries (LMICs), the official road accident statistics are incomplete and biased.

Safe Crossings (Netherlands) and the Centre for Injury Prevention and Research Bangladesh (CIPRB) (Bangladesh) received permission from the Bangladesh government in 2014 to design and implement an integrated speed management program (consisting of a combination of small-scale infrastructural measures, active community involvement and road user education) at three locations where a national highway intersects small communities. The infrastructural countermeasures to improve road safety consisted of speed humps, rumble strips, signs and road markings and were designed following the Dutch road design guidelines. In a Before–After study design, we used a combination of three research methods to monitor and evaluate the road safety interventions. We created our own traffic accident recording system with trained local record keepers, we conducted laser-gun speed measurements of motorized traffic (both at intervention and control locations), and we applied the Dutch Objective Conflict Technique for Operation and Research (DOCTOR) for observing serious traffic conflicts at the intervention locations. The latter was based upon DOCTOR scores from video recordings of the behaviour at the three experimental locations Before and After the interventions.

Prior to installing the intervention program, the three locations combined had, on average, about 100 serious accidents, 10 deaths, and 200 injured people on a yearly basis. In April 2015, all infrastructural measures were completed. In the after period (till the end of January 2016), the alternative accident recording system showed a 66% reduction in the number of serious accidents, a 73% reduction in the number of injured people, and a 67% reduction in the number of people killed.

The unobtrusive laser-gun speed measurements resulted in a net reduction of 13.3 km/h (or 20% in relative terms) on average at the intervention locations by taking the general speed development at the control locations into account. According to Nilsson’s power law this would result in a 59% reduction of the number of people killed, well in line with the actual accident figures.
The total number of serious conflicts (only DOCTOR scores 3, 4, and 5) was significantly reduced from 64 serious conflicts per location in a 4.5 h period Before to 29 serious conflicts in the After period, on average (Poisson distributed variable, p < 0.01), or a 55% reduction in relative terms. By including the traffic volumes, the reduction in conflict risk overall is 54%. Moreover, the severity of conflicts was reduced in the After period with only one most severe conflict (DOCTOR score 5) left. Buses represent the largest portion of road users involved in serious conflicts at all three locations, followed by cars and CNGs (Compressed Natural Gas vehicle). By far, the most frequently occurring conflict is of the type head-on conflict between an overtaking bus or car that is encountering a road user in opposite direction (for the greater part a CNG).

All three evaluation measures point to a similar impact of the intervention program and unveil an improvement in road safety between 54% and 60%. The speed-reducing measures indeed considerably reduce the speed of motorized traffic, both the mean speed and 85th percentile values, both the number and severity of serious conflicts are reduced, and the actual number of accidents has decreased. It appears that Nilsson’s power law for the relation between a difference in mean speed and the change in the number of accidents also applies to LMICs.

Speed management measures as common in high-income countries appear to be also effective in LMICs. For evaluation purposes of road safety impacts, a Traffic Conflicts Technique approach (also developed in high-income countries) seems valid and effective as well for application in LMICs.

As there are thousands of traffic black spots with similar characteristics as the three intervention locations in Bangladesh, this integrated approach may well offer similar road safety improvements elsewhere.

1. Introduction

According to the WHO 2015 road safety report, over 21,000 people are killed in road traffic in Bangladesh annually (WHO, 2015), whereas the officially reported number of road traffic deaths of 3196 is clearly incomplete and biased. With a fatality rate of 13.6 per 100,000 population and over 100 road traffic deaths per 10,000 motor vehicles, Bangladesh has one of the highest rates in the world. Vulnerable road users (VRUs; pedestrians and bicyclists) account for 32% of road traffic casualties (WHO, 2015). Hoque (2013) comes with figures of more than 50% VRUs killed in road traffic every year, whereas about 70% of crash fatalities occur in rural areas. Key risk factors include excessive speeds of motorized traffic, the mix of fast and slow traffic, and a high proportion of vulnerable road users on the road. In a road safety study in India, Mohan, Tsimhoni, Sivak, and Flannagan (2009) identify pedestrians, other non-motorists, and slow vehicles on national highways as an area that is likely to bring about substantial improvement in road safety in India. Evidence suggests that a high percentage (about 20–40%) of fatalities on highways consist of pedestrians, bicyclists, other non-motorists, and occupants of slow vehicles.

In high-income countries, speed management measures that reduce vehicle speeds in areas with high proportions of pedestrians and bicyclists are proven to be effective in reducing road traffic injuries (WHO, 2015). In a large-scale Cochrane review of 236 studies on assessing the effects of interventions for reducing road traffic crashes and injuries, Perel, Ker, Ivers, and Blackhall (2007) found only six trials conducted in Low and Middle Income Countries (LMICs), all of which only referred to one review on Helmets for preventing injury in motorcycle riders. Furthermore, most of the research has focused on drivers from high-income countries, yet most of the victims in LMICs are non-drivers—that is, vulnerable road users (such as pedestrians, cyclists, motorcyclists, and passengers of private and public transport). In an evaluation study on traffic calming interventions at eight black spots along truck routes in Ghana, Afukaar (2008) stated that traffic calming may be effective in reducing road crashes although only four sites yielded positive safety effects. Based upon a before study on the potential of traffic calming in an urban setting in Jaipur (India) Hyden and Svensson (2009) conclude that there is an urgent need for speed reducing measures in LIMC cities.

The basic idea behind our project is that speed reducing measures also may be an effective means to improve road traffic safety in LMICs. In 2014, Safe Crossings (the Netherlands) and CIPRB (Bangladesh) got permission from the Bangladesh government to design and implement an integrated speed management program to reduce the number of road crashes at three pilot locations where a national highway intersects small local communities in a rural setting. As in most LMICs the official accident statistics are incomplete and biased, we developed a three stage evaluation programme in a Before and After study design consisting of speed measurements, traffic conflict observations as a surrogate measure for accidents and our own collection of actual accident data by trained local record keepers.
2. Method

2.1. Selection of locations

For the intervention locations we selected three sites on the N2 national highway in Bangladesh (Bangladesh has left-hand traffic) between Dhaka and Sylhet, Nilkuthi, Kunderpara and Namapara. The N2 is a single carriageway two lane asphalt road with a mix of high-speed motorized traffic (buses, passenger cars), slower moving trucks and non-motorized traffic. In a newspaper article (The Guardian, Kelly, 2012) the N2 Highway in Bangladesh was classified as world’s deadliest road. Early 2014, Safe Crossings and CIPRB made a trip along the N2 Highway starting from Dhaka without quantitative knowledge on the number and severity of road crashes at specific locations. We stopped at sites with local exchange of people (bus stops, Compressed Natural Gas vehicles (CNGs)), small settlements, villages with a school nearby, roadside shops, minor road intersections, etc. We selected the three pilot locations based upon our estimate of obvious ‘conflict’ zones and interacting areas between motorized traffic and VRUs but without prior quantitative knowledge on the number and severity of road crashes. In this manner, we minimized the risk of possible ‘regression to the mean’ effects.

All three locations consist of local community settlements with activities at both sides of the road resulting in a mix of fast and slow traffic, crossing pedestrians, and the regular overtaking by high-speed buses and other fast moving motorized traffic of traffic slowing down to embark or disembark people (local buses and CNGs). The intervention locations all had an unpaved minor road connected to the main road. The number of inhabitants is estimated at a few thousand people each. Fig. 1 gives a typical example of traffic overtaking a halted bus (top left), the occasional presence of many CNGs (top right), and roadside activities (below).

For the speed measurements (see hereafter) we selected three control locations along the same N2 highway that were quite comparable in lay-out and traffic characteristics (traffic volume, road user mix) with the three intervention locations. At these locations no measures were taken at all and served as control locations to cover possible general speed effects over time. These locations were Gashirdia, Gabtoli bus stand, and Mahmudabad as controls for the intervention locations Nilkuthi, Kunderpara and Namapara, respectively.

2.2. Infrastructural measures

The infrastructural measures for speed management were designed following the Dutch road design standards (CROW, 2014) corresponding with a ‘before speed’ of 80 km/h and a desired ‘after speed’ of 50 km/h. These measures included two speed humps at both ends of the intervention area (2.40 m in length to get on the hump, a hump height of 0.08 m, a hump length of 7.00 m, and again a sinus-shaped form of 2.40 m in length to get off the hump), a speed limit of 50 km/h, lateral rumble strips, one or two zebra pedestrian crossings, signs, road delineation, and a bus bay at both sides of the road. Fig. 2 gives an overview of the set of infrastructural measures at one of the intervention locations (Nilkuthi).
After the first implementation of the speed humps at Nilkuthi and Namapara, and the first after-intervention speed measurements, it appeared that the through buses, on average, still exceeded the speed limit of 50 km/h. Therefore, the speed humps at Kunderpara were made a bit steeper with a reduction of the sinus-shaped forms on and off the humps to 1.80 m in length. The infrastructural interventions at the three locations were completed in the period January–April 2015.

2.3. Additional interventions

In addition to the infrastructural interventions, also other measures were taken to improve the safety situation. These consisted of educational interventions (safety trainings) for different groups of road users (school children (age 6–9), school children (age 10–16), CNG drivers, and pedestrians). Also, active community involvement was organized, to ensure a long-term impact of the program. For more details about these additional interventions the reader is referred to Vet, Thierry, van der Horst, and Rahman (2016).

3. Evaluation approach

In a Before–After study design, we used a combination of three research methods to monitor and evaluate the road safety interventions. We created our own traffic accident recording system with trained local record keepers, we conducted laser-gun speed measurements of motorized traffic (both at intervention and control locations), and we applied the Dutch Objective Conflict Technique for Operation and Research (DOCTOR) for observing serious traffic conflicts at the intervention locations combined with traffic counts. The after period was chosen about six months after the infrastructural interventions had taken place to ensure a sufficiently long habituation period.

Both conflict observations and traffic counts were made from video recordings that were made on-site at the intervention locations before and after, at each location for about one week (24 h/day). Fig. 3 gives an example of these videos in the Before and After situation at the three intervention locations. Table 1 gives the time periods the on-site video recordings were made at the three intervention locations. The video recordings were stored on hard disk of an on-site PC-based system that enabled continuous 24 h/day recordings for seven days. The video images were stored as separate MPEG-4 files for each quarter of an hour in a time-directory structure (location, date, hour). Each field had a resolution of 768 x 288 pixels.

3.1. Accident database

With the help of trained local record keepers, we created our own accident recording system. After a successful pilot test of this approach in Nilkuthi, this was also implemented for the other two intervention locations. Only, accidents that result in injury or people killed are recorded. Material damage only accidents are not recorded. The definition of an injured person is a person with a physical injury as result of a road crash. The accident data are daily updated by the local record keepers and collected and reviewed on a monthly basis. For all three intervention locations we have an accident data base available for the period from June, 1st 2013 till January 31st 2016. As the Before period we used the period June 1st, 2013–December 31st, 2014 (19 months), and as After period May 1st, 2015–January 31st, 2016 (9 months). The period in-between (4 months) was not included for the Before–After comparison as the implementation of the infrastructural measures had taken place then and road works might have influenced the traffic and crash conditions.

3.2. Speed measurements

We conducted speed measurements before the interventions at the three intervention locations and the three control locations in April 2014 by applying a laser gun operated unobtrusively by people of CIPRB. Based on these baseline measurements, we selected the following intervention-control pairs for speed measurement comparison: Nilkuthi and Gabtoli bus stand, Kunderpara and Gashirdia, and Namapara and Mahmudabad, as these pairs had comparable speed curves for the different types of road users (buses, trucks, passenger cars, CNGs, motorbikes). However, after the implementation of the infras-
tructural measures it appeared that the Mahmudabad control location was too close to the first signs of the nearest intervention location, and therefore we had to decide to remove this control location from our speed measurements. The After speed measurements at the three intervention locations and the two remaining control locations took place in November 2015, half a year after the infrastructural measures were implemented.

3.3. Traffic counts

For the hours the DOCTOR conflict technique was applied (see Section 3.4) the traffic at the three intervention locations was counted by human observers from the video recordings on a quarterly base. A distinction was made between the following categories of road users: buses, trucks, passenger cars/microbuses, CNGs, motorbikes, rickshaws/bicyclists, light motorized vehicles, and pedestrians (adults-children).

Table 1

<table>
<thead>
<tr>
<th>Location</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nilkuthi</td>
<td>March 5–15, 2014</td>
<td>November 5–12, 2015</td>
</tr>
</tbody>
</table>

Fig. 3. Video images of the three intervention locations before and after the infrastructural intervention.

Table 1

<table>
<thead>
<tr>
<th>Location</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
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3.4. DOCTOR conflict observations from video

Traffic Conflict Techniques (TCT) have been extensively discussed in the literature and adopted as an operational tool in road safety research. 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. The TCT enables us to get a sufficient large safety-relevant data set in a relatively short period of time and to analyse road user behaviour in a systematic manner.

Based upon the results of an international calibration study of traffic conflicts techniques by the ICTCT (International Cooperation on Theories and Concepts in Traffic Safety) in Malmö (Grayson, 1984), the Dutch Objective Conflict Technique for Operation and Research (DOCTOR) was developed by the SWOV and TNO in the Netherlands (Kraay, van der Horst, & Oppe, 1986, 2013). The DOCTOR technique is a standardized evaluation method that identifies a critical situation if the available space for manoeuvring is less than is needed for a normal reaction. The severity of a conflict is then scored on a scale from 1 to 5, taking into account (a) the probability of a collision and (b) the extent of the consequences if a collision would have occurred. The probability of a collision is determined by the Time-To-Collision (TTC) and/or Post-Encroachment-Time (PET). The extent of the consequences is mainly dependent on the potential collision energy and the vulnerability of the road users involved. Affected factors are the relative speed, available and necessary manoeuvring space, and whether the avoiding action is judged as controlled or uncontrolled. For further details on the development of the TCT and how conflicts with the DOCTOR technique are scored, the reader is referred to van der Horst, de Goede, de Hair-Buijssen, and Methorst (2014). 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., 2014; van der Horst, Rook, van Amerongen, & Bakker, 2007). This enables repeated looks at an event, scoring certain aspects of an encounter separately, and identifying what actually happened.

In principle, the DOCTOR method requires a total conflict observation period of 18 h. Therefore, we started with selecting 18 h of video recordings at Nilkuthi for scoring conflicts in the before period, spread over 3 days (Monday, Wednesday, Friday (holiday in Bangladesh)), 6 h per day, 8–10, 10–12 and 16–18 h. While analysing the first tapes it became clear that slight conflicts according to the DOCTOR technique (severity category 1–2) were considered as more or less normal behaviour (holiday in Bangladesh)), 6 h per day, 8–10, 10–12 and 16–18 h. While analysing the first tapes it became clear that slight conflicts according to the DOCTOR technique (severity category 1–2) were considered as more or less normal behaviour. Therefore, we decided to focus our analysis on the severe conflicts (severity category 3–5) only. After this analysis (see also Section 4.4.1), it appeared that the number of serious conflicts was relatively high, and it was considered sufficient and time wise more efficient to reduce the number of hours to be analysed with a factor of four, and limit the analysis to 4.5 h in total per location and per period (Before and After). Afterwards, it is always possible to extend the analyses if needed as the video recordings remain available. Table 2 gives an overview of the quarter of hours that were included.

Table 2
DOCTOR observation and Traffic count periods from video for the three experimental locations before and after the infrastructural interventions.

<table>
<thead>
<tr>
<th>Location</th>
<th>Before</th>
<th>Time</th>
<th>After</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Date 2014</td>
<td></td>
<td>Date 2015</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time</td>
<td></td>
<td>Time</td>
<td></td>
</tr>
<tr>
<td>Nilkuthi</td>
<td>March 10</td>
<td>8:00–10:00</td>
<td>November 9</td>
<td>8:00–8:15: 9:1 5–9:30:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10:00–12:00</td>
<td></td>
<td>10:30–10:45; 11:45–12:00;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16:00–18:00</td>
<td></td>
<td>16:15–16:30; 17:00–17:15</td>
</tr>
<tr>
<td>March 12</td>
<td>8:00–10:00</td>
<td>10:00–12:00</td>
<td>November 11</td>
<td>8:15–8:30; 9:30–9:45;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16:00–18:00</td>
<td></td>
<td>10:45–11:00; 11:30–11:45;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8:00–10:00</td>
<td></td>
<td>16:30–16:45; 17:00–17:15</td>
</tr>
<tr>
<td>March 14</td>
<td>10:00–12:00</td>
<td>16:00–18:00</td>
<td>November 6</td>
<td>8:30–8:45; 9:45–10:00;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11:00–11:15; 11:45–12:00;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16:45–17:00; 17:15–17:30</td>
</tr>
<tr>
<td>Kunderpara</td>
<td>March 31</td>
<td>8:00–8:15; 9:1 5–9:30; 10:30–10:45; 11:45–12:00;</td>
<td>November 2</td>
<td>8:00–8:15; 9:1 5–9:30;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16:15–16:30; 17:30–17:45</td>
<td></td>
<td>10:30–10:45; 11:45–12:00;</td>
</tr>
<tr>
<td>March 26</td>
<td>8:15–8:30; 9:30–9:45; 10:45–11:00; 11:30–11:45; 16:30–16:45; 17:45–18:00</td>
<td>October 28</td>
<td>8:15–8:30; 9:30–9:45; 10:45–11:00; 11:30–11:45; 16:30–16:45; 17:15–17:30</td>
<td></td>
</tr>
<tr>
<td>March 28</td>
<td>8:30–8:45; 9:45–10:00; 11:00–11:15; 11:45–12:00; 16:45–17:00; 17:45–18:00</td>
<td>October 30</td>
<td>8:30–8:45; 9:45–10:00; 11:00–11:15; 11:45–12:00; 16:45–17:00; 17:15–17:30</td>
<td></td>
</tr>
<tr>
<td>Namapara</td>
<td>March 17</td>
<td>8:00–8:15; 9:1 5–9:30; 10:45–11:00; 11:45–12:00; 16:30–16:45; 17:30–17:45</td>
<td>November 16</td>
<td>8:00–8:15; 9:1 5–9:30;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8:15–8:30; 9:30–9:45; 10:45–11:00; 11:30–11:45; 16:30–16:45; 17:45–18:00</td>
<td>November 18</td>
<td>8:30–8:45; 9:30–9:45; 10:45–11:00; 11:30–11:45;</td>
</tr>
<tr>
<td>March 21</td>
<td>8:30–8:45; 9:45–10:00; 11:00–11:15; 11:45–12:00; 16:45–17:00; 17:45–18:00</td>
<td>November 20</td>
<td>8:30–8:45; 10:00–10:15; 11:00–11:15; 11:45–12:00; 16:45–17:00; 17:00–17:15</td>
<td></td>
</tr>
</tbody>
</table>

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4. Results

4.1. Accident database

Table 3 shows the accident statistics for the three intervention locations combined. The average reductions in the number of accidents/month and the number of people injured/month are significant at the 1% level ($t$-test ($df = 26$), $t = 3.34$ and $t = 3.55$, respectively), the reduction in the number of people killed/month is significant at the 10% level ($t = 1.53$, $df = 26$).

Using our own accident database, we can zoom in on the accidents with VRUs. Table 4 shows the fatalities in the Before-period at all three intervention locations, categorised by type of road crash. Pedestrians account for 63% of all fatalities (12 out of 19) and motorbikes for 16% (3 out of 19). Table 4 also reveals that pedestrian fatalities in the Before-period resulted from a number of different crash-types (bus, car, truck, and motorbike) of which bus-pedestrian crashes accounted for most fatalities.

Since the completion of the speed hump, there have been 3 fatalities in the intervention locations. All three fatalities resulted from a bus-pedestrian crash. In the first fatality (August 2015), an adult man jumped off a bus that was still driving and his clothes got caught under the wheels of the bus. In the second fatality (October 2015), a bus hit a young boy who was crossing the highway. In the third fatality, a bus hit an adult who was crossing the highway (November 2015).

4.2. Speed measurements

Fig. 4 gives the cumulative speed distributions for the three intervention locations Before and After the infrastructural interventions with all vehicles combined (bus + truck + car). Clearly, the speeds in the After period are much lower than Before with $DIF_{max}$ (maximum difference shifts) of 0.39, 0.42 and 0.29 for Nilkuthi, Kunderpara and Namapara, respectively (Kolmogorov–Smirnov tests, $p < 0.000$). The same yields for the 85th percentile values ($P_{85}$), after the intervention measures $P_{85}$ is reduced with 15.8, 14.9, and 10.8 km/h, respectively.

Vet et al. (2016) present separate cumulative distributions for buses, trucks and cars. It appears that the overall speed reduction as presented here, also applies for these three types of road users separately.

At the control location Gabtoli bus stand both buses and trucks have a somewhat lower speed in the After period, whereas the speed of cars does not differ significantly Before and After (Vet et al., 2016). At the control location Gashirdia buses in the After period have a somewhat lower speed than in the Before period, whereas the speeds of trucks and cars do not differ significantly. Vet et al. (2016) calculate an overall net reduction of 13.3 km/h (or 20% in relative terms) at the intervention locations when correcting for the outcome of the speed measurements at the control locations. By using Nilsson’s power law (Nilsson, 1982), such an average speed reduction would result in an expected reduction of the number of people killed of 59%.

4.3. Traffic counts

We conducted traffic counts for the same time periods (4.5 h in total per location) as we selected for the conflict observations. Table 5 shows the traffic count data for Nilkuthi, Kunderpara and Namapara in the Before and After period. The relative share of buses is similar for the three locations, ranging from 7.6% to 9.2%. Kunderpara has a considerably higher share of pedestrians (around 40%) than Nilkuthi (around 25%) and Namapara (around 24%). For all three locations, the number of CNGs was considerably reduced in the After period, most prominently in Nilkuthi and Namapara, whereas the number of Pick up/Mini truck/tractor had increased considerably. Most likely, these differences were due to a temporary national measure to ban CNGs from the N2 Highway for a limited period of time just before the After measurements took place.

4.4. Traffic conflicts

As indicated in Section 3.4, we focused our DOCTOR analysis from video on severe conflicts only (severity category 3–5). We started with an 18 h DOCTOR observation period for one intervention location in the Before period, Nilkuthi. In Section 4.4.1 this analysis is presented by type of road user involved and by making a comparison with a selection of a limited

<table>
<thead>
<tr>
<th># of accidents/month</th>
<th># of people killed/month</th>
<th># of people injured/month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>9.2</td>
<td>5.3</td>
</tr>
<tr>
<td>After</td>
<td>3.1</td>
<td>1.6</td>
</tr>
<tr>
<td>Reduction (absolute)</td>
<td>61%</td>
<td></td>
</tr>
<tr>
<td>Reduction%</td>
<td>66%</td>
<td></td>
</tr>
</tbody>
</table>
Table 4
Overview of fatalities in the Before-period in the intervention locations by type of road crash (June 2013–December 2014).

<table>
<thead>
<tr>
<th>Road user 1</th>
<th>Road user 2</th>
<th>Number of deaths</th>
<th>Share of total (known) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus</td>
<td>Truck</td>
<td>1</td>
<td>5.3</td>
</tr>
<tr>
<td>Bus</td>
<td>CNG</td>
<td>2</td>
<td>10.5</td>
</tr>
<tr>
<td>Bus</td>
<td>Motorbike</td>
<td>2</td>
<td>10.5</td>
</tr>
<tr>
<td>Bus</td>
<td>Pedestrian</td>
<td>4</td>
<td>21.1</td>
</tr>
<tr>
<td>Truck</td>
<td>CNG</td>
<td>1</td>
<td>5.3</td>
</tr>
<tr>
<td>Truck</td>
<td>Pedestrian</td>
<td>3</td>
<td>15.8</td>
</tr>
<tr>
<td>Minibus</td>
<td>Pedestrian</td>
<td>1</td>
<td>5.3</td>
</tr>
<tr>
<td>Car</td>
<td>Pedestrian</td>
<td>2</td>
<td>10.5</td>
</tr>
<tr>
<td>Motorbike</td>
<td>Motorbike</td>
<td>1</td>
<td>5.3</td>
</tr>
<tr>
<td>Motorbike</td>
<td>Pedestrian</td>
<td>2</td>
<td>10.5</td>
</tr>
<tr>
<td>Total of fatalities</td>
<td></td>
<td>19</td>
<td>100</td>
</tr>
</tbody>
</table>

Fig. 4. Cumulative distributions of speed (km/h) for the three intervention locations Before and After all vehicles (bus–truck–car) combined. (N = number of observations; Avg = Average speed (km/h); S.d. = Standard deviation (km/h); P85 = 85th percentile speed (km/h).)

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set of hours (4.5 h in total). This set of quarters of an hour was analysed for the remaining periods (Nilkuthi After, Kunderpara and Namapara Before and After). In Sections 4.4.2–4.4.4 the intervention measures are evaluated by comparing the traffic conflicts in the Before and After period for the intervention locations Nilkuthi, Kunderpara, and Namapara, respectively.

4.4.1. Nilkuthi Before: 18 h versus 4.5 h observations

De 18 h DOCTOR analysis from video resulted in total in 202 serious conflicts (severity scores 3, 4, 5), whereas the 4.5 h selection resulted in 56 serious conflicts. The 4.5 h periods were selected without prior knowledge of the number of conflicts. This is about 11% more than \( \frac{1}{4} \) of the 18 h number of serious conflicts. With a Chi\(^2\) value of 2.40 (df = 1) this difference is not significant at the 10% level (Chi\(^2\) = 2.71). The relative distribution of conflicts by conflict severity (see Fig. 5 right) was rather similar for both selections. The relative involvement of the different type of road users involved in the serious conflicts did

![Fig. 5. Nilkuthi Before: 18 h versus 4.5 h selection total number (left) and relative frequency of severe conflicts (right) by conflict severity.](image-url)
not differ either for both periods (see Fig. 6). Based on these results we concluded that an analysis period of 4.5 h subdivided in quarters of an hour spread over 3 days (Monday, Wednesday and Friday) would be sufficient to start with for the remaining analyses.

4.4.2. Nilkuthi Before–After

Based upon the 4.5 h period analyses, it appeared that the number of serious conflicts was reduced from 56 to 38 in the After period, see Fig. 7 (left). This reduction in serious conflicts (\(-18\%\), or \(-32\%\)) is significant at the \(p < 0.01\) level (Poisson distributed variable, \(\chi^2 = 5.78, \text{df} = 1\)) (Kraay et al., 2013). When we take the road user volumes into account by the number of conflicts/volume, then we see a reduction in conflict risk of \(-28\%\) (38/5606 After versus 56/6031 Before).

Fig. 7 (right) indicates a shift to the left in conflict severity, implying that the conflicts in the After period are less severe than in the Before period with no conflicts of the highest level 5 anymore.

Fig. 8 shows the relative involvement in serious conflicts by type of road user. It appears that buses (road user type 1) represent the largest proportion involvement (34% Before, 30% After), followed by CNGs (road user type 4) and cars (road user type 3). Pedestrians are represented in 6 and 8% Before and After, respectively. This relatively low number may be partly due to the absence of pedestrian-pedestrian conflicts, whereas buses and cars are also mutually conflicting, of course.

4.4.3. Kunderpara Before–After

In Kunderpara the number of serious conflicts was reduced from 73 to 22 in the After period, see Fig. 9 (left), even more than in Nilkuthi. This reduction in serious conflicts (\(-51\%,\) or \(-70\%\)) is significant at the \(p < 0.0005\) level (Poisson distributed variable, \(\chi^2 = 35.6, \text{df} = 1\)). When we take the road user volumes into account by the number of conflicts/volume, then we see a reduction in conflict risk of \(-67\%\) (22/5645 After versus 73/5724 Before).

Fig. 9 (right) indicates a shift to the left in conflict severity, implying that the conflicts in the After period are less severe than in the Before period with no conflicts in the most severe category anymore. This effect in Kunderpara was also stronger than for Nilkuthi.

Fig. 10 shows the relative involvement in serious conflicts by type of road user. It appears that overall, buses (road user type 1) represent the largest proportion involvement in the After period (40.5%) and 25% Before, followed by cars/microbuses

![Fig. 6](image-url) Nilkuthi Before: 18 h versus 4.5 h selection by relative involvement (%) in serious conflicts by type of road user (1 = Bus, 2 = Truck, 3 = Car/microbus, 4 = CNG, 5 = Motor bike, 6 = Rickshaw/bicycle, 7 = Pedestrian, 8 = Light motorized vehicle, 9 = Other).

![Fig. 7](image-url) Nilkuthi Before versus After: total number (left) and relative frequency of severe conflicts (right) by conflict severity.
(road user type 3) with around 25%. CNGs (road user type 4) have a lower share in serious conflicts than in Nilkuthi. Pedestrians are represented in 6.5% and 12% of the conflicts Before and After, respectively.

4.4.4. Namapara Before–After

In Namapara the number of serious conflicts was reduced from 62 to 36 in the After period, see Fig. 11 (left). This reduction in serious conflicts (−36%, or −58%) is significant at the \( p < 0.0005 \) level (Poisson distributed variable, \( \chi^2 = 20.9, \text{df} = 1 \)). When we take the road user volumes into account (number of conflicts/volume), then we see a reduction in conflict risk of

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As Fig. 11 (right) indicates, also in Namapara there is a shift to the left in conflict severity, but less prominent than for Nilkuthi and Kunderpara, with one most severe conflict (category 5) left in the After period.

Fig. 12 gives the relative involvement in serious conflicts by type of road user. Again, buses (road user type 1) represent the largest proportion involvement, followed by cars/microbuses (road user type 3), and CNGs (road user type 4). Pedestrians are represented in 3.2% and 5.8% of the conflicts Before and After, respectively.

5. Discussion and conclusions

Prior to installing the intervention program, the three locations combined had, on average, about 100 serious accidents, 10 deaths, and 200 injured people on a yearly basis. In April 2015, all infrastructural measures were completed. In the After period (till the end of January 2016), the alternative accident recording system showed a 66% reduction in the number of serious accidents, a 73% reduction in the number of injured people, and a 67% reduction in the number of people killed.

The unobtrusive laser-gun speed measurements resulted in a net reduction of 13.3 km/h (or 20% in relative terms) on average at the intervention locations by taking the general speed development at the control locations into account. For all three intervention locations the 85th percentile speed were also reduced considerably with minus 20.0%, 18.4%, and 14.5% respectively. According to Nilsson's power law a net average speed reduction of 13.3 km/h would result in a 59% reduction of the number of people killed, well in line with the actual accident figures as collected with our own accident collection system.

The total number of serious conflicts (only DOCTOR scores 3, 4, and 5) was significantly reduced from 64 serious conflicts per location in a 4.5 h period Before to 29 serious conflicts in the After period, on average (Poisson distributed variable, \( p < 0.01 \)), or a 55% reduction in relative terms. By including the traffic volumes, the reduction in conflict risk overall is 54%. For Nilkuthi the reduction in serious conflicts is 32%, for Kunderpara even 70%, and for Namapara 58%. Moreover, the severity of conflicts was reduced in the After period with only one most severe conflict (DOCTOR score 5) left. When taking the traffic volumes Before and After into account the reduction in conflict risk is 27%, 67%, and 58% for Nilkuthi, Kunderpara, and Namapara, respectively. The overall speed reduction of motorized traffic is clearly a contributing factor to both traffic conflict effects. It appears that buses represent the largest portion of road users involved in serious conflicts at all three.
locations, followed by cars and CNGs. By far, the most frequently occurring conflict is of the type head-on conflict between an overtaking bus or car that is encountering a road user in opposite direction (for the greater part a CNG). Head-on overtaking conflicts still take place in the After period but at a lower speed, and, therefore, result in a lower conflict severity range.

Although the integrated speed management programme appeared to reduce the road safety problems considerably, the issue of dangerous overtaking by buses is still a concern. In our opinion, additional safety training of drivers of through buses might help to further improve road safety on national highways in Bangladesh.

Conducting traffic counts and scoring traffic conflicts from video recordings afterwards appeared to be a valuable approach. Video recordings that are digitally stored give the possibility to observe events multiple times and count different types of road users separately. In more chaotic traffic situations such as in Bangladesh, working with human observers in the field is difficult and the approach of the intermediate step of analysing video recordings afterwards may be more time consuming but improves the reliability of the observations considerably. The traffic conflict material as available on video also appeared to be very helpful in the training sessions in the educational part of the integrated program. Traffic Conflict Techniques (TCTs) as originally developed in high-income countries, appear to be also applicable in LMICs. We focussed our conflict analyses on serious conflicts (DOCTOR severity category 3, 4, and 5) only, as it became clear that slight conflicts (severity category 1 and 2) should be considered as more or less normal behaviour in the Bangladesh setting. So, in spite a shift in the severity scale, the basic concepts for defining conflicts and their severity (time measures for probability of a collision and extent of consequences based upon potential collision energy and vulnerability of road users involved) are still valid and applicable even in more chaotic traffic settings in LMICs.

All three evaluation measures point to a similar impact of the intervention program and unveil an improvement in road safety between 54% and 60%. The speed-reducing measures indeed considerably reduce the speed of motorized traffic, both mean speed and 85th percentile values, the number as well as the severity of serious conflicts are reduced, and the actual number of accidents has decreased. It appears that Nilsson’s power law for the relation between a difference in mean speed and the change in the number of accidents also applies to LMICs. In our study, we had the opportunity to collect data on the actual number of accidents occurring at the three intervention locations. As our study indicates, it might be sufficient to conduct an evaluation based upon both speed measurements and traffic conflict observations and have a good estimate of the expected safety effects, when no reliable accident data are available.

As there are thousands of traffic locations with similar characteristics as the three intervention locations in Bangladesh, this integrated approach may well offer similar road safety improvements elsewhere in LMICs.

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