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# Safety effects of blue cycle crossings: A before-after study

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**Abstract**

This paper presents a before-after accident study of marking blue cycle crossings in 65 signalised junctions. Corrections factors for changes in traffic volumes and accident/injury trends are included using a general comparison group in this non-experimental observational study. Analysis of long-term accident trends point towards no overall abnormal accident counts in the before period. The safety effect depends on the number of blue cycle crossings at the junction. One blue cycle crossing reduces the number of junction accidents by 10%, whereas marking of two and four blue cycle crossings increases the number of accidents by 23% and 60%, respectively. Larger reduction and increases are found for injuries. Safety gains at junctions with one blue cycle crossing arise because the number of accidents with cyclists and moped riders that may have used the blue cycle crossing in the after period and pedestrians in the pedestrian crossing parallel and just next to the blue marking was statistically significant reduced. Two or four blue cycle crossings especially increase the number of rear-end collisions only with motor vehicles involved and right-angle collisions with passenger cars driving on red traffic lights.


*Keywords:* Blue cycle crossing; Road safety; Pavement marking; Before-after study; Meta-analysis; Denmark

## 1. Introduction

Blue cycle crossings was invented by the Municipality of Copenhagen and marked in 1981 for the first time. The basic idea is to mark the area of conflict between motor vehicles and cyclists blue so road users pay more attention to this conflict and cyclists have a lane marking through the junction area. Today, blue cycle crossings are often used in Denmark. A few other countries also mark cycle crossings in blue, and several countries mark crossings in other colours e.g. red, yellow and green.

Nettelblad (1990) made a before-after study of blue cycle crossings marked in 37 junctions in 1985, both signalised and non-signalised, in Malmö, Sweden. These cycle crossings were located in relation to dual-way cycle paths, meaning that cyclists were travelling in both directions on these blue cycle crossings. Nettelblad found that police recorded bicycle injury accidents fell from 126 to 119, and the rate of bicycle injury accidents per entering cyclist to the junctions were unchanged. Nettelblad did not use a comparison group in order to take accident trends into account.

Linderholm (1992) studied two of the signalised junctions marked in Malmö in 1985 using the Swedish conflict technique (see e.g. Hydén, 1987). In this technique near-accidents are studied. A near-accident is a situation, where road users are less than 1.5 s from a collision but avoid this by evasive manoeuvres. Hydén (1987) describes a relationship between the number of near-accidents and real accidents. Linderholm could neither document any safety effect of these dual-way blue cycle crossings, even though there was a tendency to a fall in rate of severe conflicts between left-turning cars and cyclists going in the opposite direction of the cars in the drive lane next to them.

Jensen and Nielsen (1996) made a before-after study of cycle crossings marked in 47 signalised junctions in the period 1989–1994 in Danish urban areas. They took accident trends into account using a general comparison group, and found that blue cycle crossings reduced the number of accidents involving cyclists/moped riders by 31% from expected 47 to observed 32 in the after period. The number of injuries in these accidents fell by 34%, from 33 to 22. Both results were statistical significant on a 10% level. Other accidents not involving cyclists or moped riders and injuries in these accidents did not change

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significantly. They did not try to relate results to the number of blue cycle crossings marked in the individual junctions. Cycle crossings were with one-way bicycle traffic in 44 of 47 junctions. Jensen and Nielsen also investigated single accidents at junctions among two-wheelers, in order to find out if the change in friction from asphalt to thermoplastic marking could result in single accidents. They only found evidence that two of 734 single accidents may have been caused by slippery markings both cases were zebra stripes in pedestrian crossings.

Hunter et al. (2000) studied road user behaviour before and after the marking of one blue cycle crossings at 10 conflict areas in Portland, USA. They found that significantly fewer cyclists turned their head to look for motor vehicles and fewer cyclists used hand signals after the blue cycle crossing was marked. More cyclists travelled on the "correct path" through the junction after the blue pavement had been marked. Motorists also changed behaviour. Significantly fewer motorists used turn signal, but more slowed or stopped on approach after marking the blue cycle crossings. Overall, the yielding behaviour was markedly changed from 72% yielding motorists before to 92% after. The number of cyclist–motorist conflicts also got lower from 0.95 per 100 entering cyclists before to 0.59 after. A conflict was defined as an interaction where at least one of the parties had to make a sudden change in speed or direction to avoid the other, a rather stringent definition.

Seventy six percent of the cyclists felt the locations in Portland with blue pavement were safer, and only 1% less safe (Hunter et al., 2000). Forty nine percent of motorists thought the junctions were safer with blue cycle crossings, whereas 12 percent thought less safe. In Copenhagen, cyclists feel a lower perceived risk, are more comfortable and more satisfied when blue cycle crossings are present (Jensen, 2006a).

The before-after study of accidents and injuries, which will be presented in the following, include marking of between one to four blue cycle crossings per junction in 65 signalised junctions in Copenhagen, Denmark. The blue thermoplastic pavement was marked during the years 1981–2003. The width of the blue cycle crossing is typically 2 m. The volume of incoming motor vehicles per day to the junction varies from 7000 to 66 000 and volumes of incoming cyclists span from 2500 to 27 500. A report describes the study and results in detail in Danish (Jensen, 2006b). Fig. 1 shows a junction with four blue cycle crossings.

## 2. "Second-best" methodology

Randomized experiments (see e.g. Hutchinson, 2007), where the experimental units like junctions are randomized to treatment like blue cycle crossings, are often viewed as the best way to study effects of safety measures. In our case, a randomized experiment is actually practicable due to the low costs of the blue pavement, but such experiment has not been undertaken.

The safety effects of blue cycle crossings are therefore studied using a "second-best" observational study methodology. The Empirical Bayes method (see e.g. Hauer, 1997) is viewed by many as the best of the non-experimental observational methods. The Empirical Bayes method accounts for three major possible

Fig. 1. Photo of signalised junction in Copenhagen with four blue cycle crossings.

biases in before-after accident studies; regression-to-the-mean effects, accident trends and traffic volumes.

However, the Empirical Bayes method has not been used in this study. The prime reason for this is that the signalised junctions, where blue cycle crossings have been marked, include the most trafficked junctions in Copenhagen in terms of motor vehicles, cyclists and pedestrians, and constitute one sixth of all signalised junctions in the city. The accident models that need to be developed if the Empirical Bayes method were to be used could be of the kind shown in general in Formula 2 later in this paper. Such accident models are relatively reliable to use in order to predict the number of accidents, if the incoming traffic volumes to the junction, where you wish to predict accident figures, are pretty normal compared to the traffic volumes in the junctions that the accident model is based upon. In the Copenhagen case, many of the studied junctions are in the far end of the traffic volume axis, i.e. much trafficked, and we are therefore close to or outside the boundaries of the possible accident models' valid area. The prediction of accident figures for these much trafficked junctions are unreliable, because the beta figures of the accident models becomes crucial for the prediction, and these beta figures change from model to model primarily due to uncertainty, because the models are based on a relatively low number of junctions. The prediction results for regression-to-the-mean effects and figures for expected accidents and consequently safety effects will therefore be relatively unreliable, because most of the accidents in the studied junctions actually take place in the much trafficked junctions.

Instead a stepwise methodology is used. First, a general comparison group is used to account for accident trends. Second, changes in traffic volumes are taken into account. And third, an analysis of long-term accident trends is made in order to check for abnormally high accident counts, i.e. regression-to-the-mean, in the before period. It was chosen to use equally long before and after periods, which for the individual junctions was of 1–5 years duration. The expected number of accidents in the after period is calculated based on a formula, here shown in the general form:

$$A_{\text{Expected}} = A_{\text{Before}} C_{\text{Trend}} C_{\text{Traffic}} C_{\text{RTM}}, \quad (1)$$

where $A_{\text{Expected}}$ is the number of accidents/injuries expected to occur at the junction in the after period if blue cycle crossing(s) was not marked, $A_{\text{Before}}$ is the number of accidents/injuries that occurred at the junction in the before period, $C_{\text{Trend}}$, $C_{\text{Traffic}}$ and $C_{\text{RTM}}$ are correction factors for accident trends, traffic volumes and regression-to-the-mean, respectively.

The study of blue cycle crossings is part of a larger programme including studies of reconstructions, markings, signal-control and traffic calming schemes within the boundaries of the Municipality of Copenhagen. A major effort was made in order to register all physical changes to the road network in the period 1976–2004. Several hundred schemes were identified.

Several junctions and links had undergone more than one reconstruction or other scheme. Only "clean" schemes are studied, meaning that at the 65 signalised junctions, where blue cycle crossings have been marked, no other scheme has been implemented in before and after periods and in the year, when the blue cycle crossing was marked.

Unchanged roads with known developments in traffic volumes were used to set up a general comparison group. The Copenhagen Police District covers the entire area of the Municipality of Copenhagen, and there is no indication that accidents are registered differently in one city quarter compared to another. The general comparison group consists of 110 km of roads with 170 locations, where motor vehicle and bicycle/moped traffic is counted yearly or every fourth to sixth year. A total of 24 369 accidents and 8648 injuries occurred on the 110 km of roads in the period 1976–2004.

Since a general comparison group has been chosen instead of a matched comparison group, an effort was made in order to avoid consequences of larger differences between general comparison group and treated junctions. Trends for different types of accidents and injuries of the general comparison group were analysed and compared. Trends for junction and link accidents are very similar, and hence no need for sub-grouping. However, trends for different accident/injury severities and transport modes exhibit quite different developments, e.g. the average yearly decline in property damage only accidents only with motor vehicles involved is 2.3%, whereas the decline in accidents with severe injuries or killed and only motor vehicles involved is 3.8% and pedestrian accidents with severe injuries or killed is 6.2%. Therefore it was found reasonable to describe trends by seven accident sub-comparison groups and five injury sub-comparison groups. These sub-groups are defined in Table 1.

So the correction factor $C_{\text{Trend}}$ is actually 12 different correction factors, which is the number of accidents/injuries in the sub-comparison group in the after period divided by the number accidents/injuries in the sub-comparison group in the before period. The individual correction factor e.g. $C_{\text{Trend},1}$ is then multiplied with the same sub-group of accidents at the treated junction $A_{\text{Before},1}$ as part of formula 1.

The correction factor $C_{\text{Traffic}}$ is based on changes in traffic volumes at the treated junction and in the general comparison group. The relationship between traffic flow and accidents/injuries is non-linear. Danish accident prediction models for signalised junctions in urban areas are most often of the following kind:

$$E(\mu) = \alpha N_{\text{pri}}^{\beta_1} N_{\text{sec}}^{\beta_2}, \quad (2)$$

where $E(\mu)$ is the predicted number of accidents/injuries, $N_{\text{pri}}$ and $N_{\text{sec}}$ are the incoming motor vehicle flow daily from primary and secondary direction, and $\alpha$, $\beta_1$ and $\beta_2$ are estimated parameters. $\beta_1$ and $\beta_2$ are often close to 0.5 in the many models that have been developed during the last decades in Denmark, whereas $\alpha$ varies between the different types of signalised junctions (Greibe and Hemdorff, 1995; Hemdorff, 1990, 1993, 1996, 2001, 2004; Jensen, 1998). Figures for $\alpha$ varies, because the level of safety depends on the type of signalised junction, e.g. rural versus urban, 3-armed versus 4-armed. In this case, incoming bicycle/moped flow is also known, and here the sparse number of accident prediction models indicates that bicycle/moped flow only influence the number of accidents involving cyclists and

Table 1
Definition of 12 sub-comparison groups (in brackets: number of accidents/injuries 1976–2004)

| | Bicycle/moped[a] | Pedestrian[b] | Motor vehicle[c] |
|---|---|---|---|
| Accidents with killed/severe injuries | 1 (2 197) | 2 (1 445) | 3 (1 584) |
| Accidents with minor injuries and no killed/severe injuries | 4 (1 289) | 5 (1 228) | |
| Property damage only accidents | 6 (3 316) | | 7 (13 310) |
| Killed and severely injuries | 8 (2 235) | 9 (1 477) | 10 (1 907) |
| Minor injuries | 11 (1 359) | 12 (1 670) | |

[a] Accidents involving cyclists/moped riders and injuries in these accidents.
[b] Accidents between pedestrians and motor vehicles and injuries in these accidents.
[c] Accidents only with motor vehicles involve and injuries in these accidents.

moped riders. Eq. (2) is then used to set up formulas for $C_{\text{Traffic}}$:

$$C_{\text{Traffic,pmv}} = \left(\frac{\text{MV}_{\text{pri,after}}/\text{MV}_{\text{pri,before}}}{\text{MV}_{\text{CG,after}}/\text{MV}_{\text{CG,before}}}\right)^{0.5} \times \left(\frac{\text{MV}_{\text{sec,after}}/\text{MV}_{\text{sec,before}}}{\text{MV}_{\text{CG,after}}/\text{MV}_{\text{CG,before}}}\right)^{0.5}, \quad (3)$$

$$C_{\text{Traffic,bike}} = \left(\frac{\text{MV}_{\text{pri,after}}/MV_{\text{pri,before}}}{\text{MV}_{\text{CG,after}}/MV_{\text{CG,before}}}\right)^{0.5} \times \left(\frac{MV_{\text{sec,after}}/\text{MV}_{\text{sec,before}}}{MV_{\text{CG,after}}/\text{MV}_{\text{CG,before}}}\right)^{0.5} \times \left(\frac{\text{BM}_{\text{pri,after}}/\text{BM}_{\text{pri,before}}}{\text{BM}_{\text{CG,after}}/\text{BM}_{\text{CG,before}}}\right)^{0.5} \times \left(\frac{\text{BM}_{\text{sec,after}}/\text{BM}_{\text{sec,before}}}{\text{BM}_{\text{CG,after}}/\text{BM}_{\text{CG,before}}}\right)^{0.5}, \quad (4)$$

where $C_{\text{Traffic,pmv}}$ is the traffic correction factor for pedestrian and motor vehicle accidents/injuries (see Table 1), $C_{\text{Traffic,bike}}$ is the traffic correction factor for bicycle/moped accidents/injuries, $\text{MV}_{\text{pri}}$ and $\text{MV}_{\text{sec}}$ are motor vehicle daily flow at the treated site on primary and secondary direction respectively, $\text{BM}_{\text{pri}}$ and $\text{BM}_{\text{sec}}$ are bicycle/moped daily flow at the treated site on primary and secondary direction respectively, and $\text{MV}_{\text{CG}}$ and $\text{BM}_{\text{CG}}$ are motor vehicle flow and bicycle/moped flow in the general comparison group respectively. Flow data from the entire before and after period are used, hence, increases and decreases in traffic volumes from before to after are accounted for. The change in incoming motor vehicle traffic to the junctions varied from −21% to +14% , however, most junctions experienced a minor increase. Similar the change in incoming bicycle traffic was between −38% and +27%, also most junctions experience a minor increase.

The analysis of long-term accident trends is made in order to check for abnormally high accident counts, i.e. regression-to-the-mean, in the before period. The analysis is made using a before-before period, which is a 5-year period 8–12 years before the marking of blue cycle crossings. The before-before period is chosen because it most often will be prior to an eventual black spot identification period or other type of systematic accident investigation period that may have lead to the marking of blue cycle crossings. A fact is that systematic accident investigations of accidents that occurred 2–7 years before the marking of blue cycle crossings were part of basis for decisions to make the markings in 54 of the 65 junctions. The before-before period is used to calculate an expected number of accidents and injuries in the before period of the treated junctions by making corrections for accident trends and traffic volumes:

$$A_{\text{Expected,Before}} = A_{\text{Before-Before}} C_{\text{Trend}} C_{\text{Traffic}}$$

The $C_{\text{RTM}}$ correction factor is then calculated as the expected number of accidents in the before period divided by the observed number of accidents in the before period, and likewise for injuries. However, because not all junctions can undergo this type of analysis, the $C_{\text{RTM}}$ is set to be the same for all junctions and is only used, if there are statistically significant differences between the expected and observed numbers of accidents and injuries in the before period.

Table 2
Expected and observed accidents and injuries in the before-before and before period in 30 of the 65 junctions, where blue cycle crossings have been marked

| | Observed before-before | Expected BEFORE | Observed BEFORE | Development (percent) |
|---|---|---|---|---|
| Accidents | 696 | 233 | 231 | −1 |
| Injuries | 188 | 95 | 93 | −2 |

Of the 65 treated junctions it is possible to make this calculation for 30 junctions. Twenty four junctions have been excluded of this analysis because they have been changed by other schemes in the period between 12 years before the marking of the blue cycle crossings and the before period. Eleven junctions have been excluded of the analysis because accident records only are available back to 1976.

The results of the analysis of long-term accident trends, which are shown in Table 2, indicate no general abnormally high or low accident counts, i.e. regression-to-the-mean effects, in the before period. The reason to a major difference in observed accidents and injuries in the before-before period compared to the before period is that the before-before period always is of 5 years duration, whereas the duration of the before period varies from 1 to 5 years from site to site. Results from breakdowns into different accident/injury severities and transport modes do neither indicate abnormal accident counts in the before period. The general correction factor for regression-to-the-mean effects is then set to 1.

The overall product of correction factors for accident trends and traffic volumes varies from 0.46 to 1.67 in the individual junctions, meaning that the expected number of accidents in the after period ranges from 0.46 to 1.67 multiplied by accidents in before period. Corresponding figures for the overall product of injury trends and traffic volume correction factors varies from 0.42 to 1.74. Due these major differences in correction factors and that the blue cycle crossings have been marked over a long time span it is founded reasonable to use meta-analysis rather than simple sums of accidents and injuries in order to describe mean safety effects and the variance of these effects. The meta-analysis methodology used is described by Elvik (2001). Fixed effects models have been used for homogeneous mean effects, i.e. only random variation in estimated effects for the junctions. Random effects models are adopted to heterogeneous mean effects.

## 3. Results of before-after accident and injury study

Table 3 presents the overall figures of observed and expected accidents and injuries along with the weighted mean percent changes or best estimates for safety effects and 95% confidence intervals. No results given in Table 3 are statistically significant at the 5% level, because the best estimates are very close to zero. There is a substantial variation in effects in the individual

Table 3
Safety effects of blue cycle crossings by accident and injury type

| Accident and injury type | Observed BEFORE | Expected AFTER | Observed AFTER | Safety effect (percent) | |
|---|---|---|---|---|---|
| | | | | Best estimate | 95% CI[a] |
| Accidents | | | | | |
| All | 778 | 823 | 817 | +2 | −8; +13 |
| Injury | 274 | 223 | 217 | +2 | −16; +23 |
| Property damage only | 504 | 601 | 600 | +3 | −9; +17 |
| Injuries | | | | | |
| All | 319 | 250 | 248 | +8[b] | −15; +36[b] |
| Fatal | 6 | 6 | 3 | −2 | −22; +24 |
| Severe | 165 | 157 | 147 | | |
| Minor | 148 | 87 | 98 | +4 | −23; +41 |

[a] 95% confidence interval.
[b] Inhomogeneous i.e. results of random effects model.

junctions, which is statistical significant for injuries, and also substantial for accidents but not statistical significant.

If corrections for traffic volumes were not done, the expected number of accidents in the 65 junctions would be 770 instead of 823, and safety effects would generally be worse. The reason why inclusion of corrections for traffic volumes generates a higher number of expected accidents is that the analysed signalised junctions experience a larger increase in traffic volumes compared to traffic in the general comparison group in Copenhagen. If the beta figures were lower than 0.5 then the expected number of accidents would also have been lower, e.g. beta figures of 0.4 would result in 812 expected accidents. Beta figures of 0.6 would result in 834 expected accidents. This shows that the results are not particular sensitive to the beta figures.

A reason to the substantial variation in effects is that the safety effects seem to depend heavily on the number of blue cycle crossings marked within the junction. Table 4 shows that the weighted mean effect for one, two and four blue cycle crossings is a change in the number of accidents of −10, +23 and +60%, respectively. Corresponding figures for injuries are −19, +48 and +139%. These figures are or are very close at being statistical significant at the 5% level.

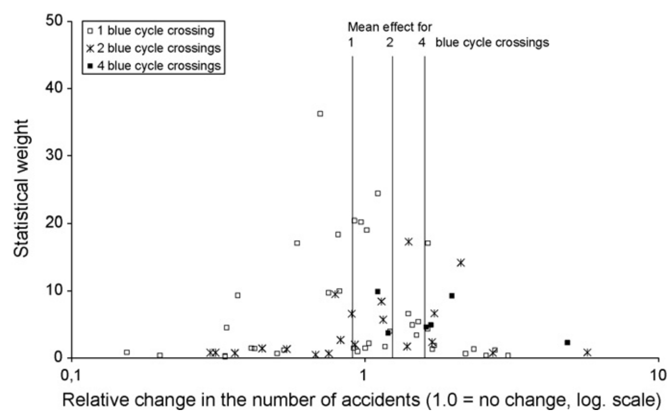


Fig. 2. Funnel graph for effects on accidents of one, two and four blue cycle crossings.

Fig. 2 presents a funnel graph for effects on accidents of one, two and four blue bicycle crossings. A funnel graph is a scatter plot of results for the individual junctions. The abscissa measures the value of each result, in terms of the size of the change in the number of accidents. Values greater than 1 indicate an increase in accident numbers, whereas values smaller than 1 indicate a reduction. The ordinate measures the statistical weight, which is

Table 4
Safety effects of blue cycle crossings by number of blue cycle crossings in each junction

| Number of blue cycle crossings within junction | Observed BEFORE | Expected AFTER | Observed AFTER | Safety effect (percent) | |
|---|---|---|---|---|---|
| | | | | Best estimate | 95% CI[a] |
| All accidents | | | | | |
| 1 blue cycle crossing | 545 | 610 | 534 | −10 | −20; +2 |
| 2 blue cycle crossings | 172 | 159 | 196 | +23 | −1; +52 |
| . . . 2 perpendicular | 77 | 69 | 67 | −4 | −31; +35 |
| . . . 2 parallel | 95 | 90 | 129 | +44 | +9; +89 |
| 4 blue cycle crossings | 61 | 54 | 87 | +60 | +15; +123 |
| All injuries | | | | | |
| 1 blue cycle crossing | 234 | 181 | 141 | −19 | −35; +2 |
| 2 blue cycle crossings | 68 | 56 | 77 | +48 | +3; +112 |
| . . . 2 perpendicular | 34 | 28 | 38 | +47 | −14; +149 |
| . . . 2 parallel | 34 | 28 | 39 | +49 | −9; +144 |
| 4 blue cycle crossings | 17 | 13 | 30 | +139 | +30; +338 |

[a] 95% confidence interval.

Table 5
Safety effects on accidents of blue cycle crossings by number of blue cycle crossings and junction arms in each junction

| Number of blue cycle crossings within junction and junction arms | Observed BEFORE | Expected AFTER | Observed AFTER | Safety effect (percent) | |
|---|---|---|---|---|---|
| | | | | Best estimate | 95% CI[a] |
| 1 Blue cycle crossing | | | | | |
| 3-armed junctions | 68 | 75 | 63 | −13 | −39; +23 |
| 4-armed junctions | 432 | 495 | 433 | −8[b] | −24; +12[b] |
| 5-armed junctions | 45 | 41 | 38 | −8 | −40; +42 |
| 2 Blue cycle crossings | | | | | |
| 3-armed junctions | 18 | 17 | 13 | −24 | −63; +59 |
| 4-armed junctions | 150 | 138 | 177 | +27 | +1; +59 |
| 5-armed junctions | 4 | 4 | 6 | +69 | −53; +503 |

[a] 95% confidence interval.
[b] Inhomogeneous i.e. results of random effects model.

based on the number of observed accidents in the junction and the general comparison group. The statistical weights in Fig. 2 were calculated according to a fixed effects model. Fig. 2 includes a considerable spread in estimates of safety effects both negative and positive. There is no indication of outlying data points.

The difference in safety effects of blue cycle crossings in relation to the number of blue markings in each junction calls for an explanation. Table 5 presents safety effects on accidents by number of blue cycle crossings and junction arms. Table 5 indicates that in addition to the relation to the number of blue cycle crossings in each junction, the safety effect depends on the number of junction arms. More junction arms seem to result in a poorer safety effect both in junctions with one and two blue cycle crossings. Junctions with one blue cycle crossings have on average fewer arms compared to junctions with two or four blue cycle crossings. This may to a little extent explain differences in safety effects of one, two and four blue cycle crossings, respectively. Junctions with two blue cycle crossings have been split into two groups; perpendicular and parallel blue cycle crossings. These two groups exhibit the same tendency, namely a better effect the fewer junction arms. The two groups are merged in Table 5. All junctions with four blue cycle crossings are 4-armed.

For junctions with one blue cycle crossings and 3-armed junctions with two blue cycle crossings there seem to be a relation

Table 6
Safety effects on accidents of blue cycle crossings by number of blue cycle crossings within junction, junction arms and width of junction

| Number of bcc[a], junction arms and width of junction | Observed BEFORE | Expected AFTER | Observed AFTER | Safety effect (percent) | |
|---|---|---|---|---|---|
| | | | | Best estimate | 95% CI[b] |
| 1 bcc, 3-arms | | | | | |
| 14–24 m wide | 17 | 15 | 9 | −35 | −71; +48 |
| 25–36 m wide | 51 | 59 | 54 | −8 | −37; +35 |
| 1 bcc, 4-arms | | | | | |
| 14–24 m wide | 25 | 22 | 15 | −21 | −60; +55 |
| 25–36 m wide | 249 | 265 | 232 | −10[c] | −34; +22[c] |
| 37–50 m wide | 158 | 207 | 186 | −8 | −25; +14 |
| 1 bcc, 5-arms | | | | | |
| 25–36 m wide | 45 | 41 | 38 | −8 | −40; +42 |
| 2 bcc, 3-arms | | | | | |
| 14–24 m wide | 5 | 4 | 2 | −55 | −91; +130 |
| 25–36 m wide | 13 | 13 | 11 | −13 | −61; +98 |
| 2 bcc, 4-arms | | | | | |
| 14–24 m wide | 11 | 13 | 23 | +80 | −12; +270 |
| 25–36 m wide | 87 | 77 | 92 | +19 | −13; +62 |
| 37–50 m wide | 52 | 48 | 62 | +28 | −12; +86 |
| 2 bcc, 5-arms | | | | | |
| 25–36 m wide | 4 | 4 | 6 | +69 | −53; +503 |
| 4 bcc, 4-arms | | | | | |
| 14–24 m wide | 7 | 7 | 8 | +20 | −57; +231 |
| 25–36 m wide | 46 | 40 | 66 | +65 | +13; +143 |
| 37–50 m wide | 8 | 8 | 13 | +68 | −31; +305 |

[a] Blue cycle crossing.
[b] 95% confidence interval.
[c] Inhomogeneous i.e. results of random effects model.

Table 7
Safety effects on accidents of blue cycle crossings by number of blue cycle crossings in each junction and type of accident

| Number of blue cycle crossings within junction and junction arms | Observed BEFORE | Expected AFTER | Observed AFTER | Safety effect (percent) | |
|---|---|---|---|---|---|
| | | | | Best estimate | 95% CI[a] |
| 1 Blue cycle crossing | | | | | |
| Direct influence | 117 | 141 | 89 | −32 | −48; −10 |
| . . . pedestrian | 12 | 10 | 5 | −32 | −73; +71 |
| . . . bicycle/moped | 105 | 131 | 84 | −31 | −48; −8 |
| No direct influence | 428 | 469 | 445 | −1[b] | −18; +19[b] |
| 2–4 Blue cycle crossing | | | | | |
| Direct influence | 79 | 73 | 95 | +28 | −6; +76 |
| . . . pedestrian | 11 | 9 | 15 | +56 | −31; +251 |
| . . . bicycle/moped | 68 | 64 | 80 | +23 | −13; +73 |
| No direct influence | 154 | 140 | 188 | +33 | +7; +66 |

[a] 95% confidence interval.
[b] Inhomogeneous i.e. results of random effects model.

between junction size and safety effects, see Table 6. Small junctions exhibit better safety effects compared to larger junctions. However, traffic volume and junction size correlates considerably and therefore the relation to safety effects may be triggered by traffic volumes, junction size or both. There seems not to be a relation between junction size and safety effects for 4- and 5-armed junctions with two or four blue cycle crossings.

The blue cycle crossing is hypothesised to have a "direct influence" on accidents with cyclists or moped riders that would have used/did use a crossing, which were painted blue, and accidents with pedestrians using the pedestrian crossing just next to the cycle crossing, which were painted blue. The idea with the blue cycle crossing is to warn motorists about cyclists that use the crossing. It is hypothesised that motorists look out for these cyclists more carefully and in this search for cyclists also more often see the moped riders and pedestrians at the crossings mentioned above. Crashes at these cycle and pedestrian crossings are predominantly with right and left turning motor vehicles that hit cyclists and pedestrians using the crossings. All other accidents at the junctions are thought be under "no direct influence" of the blue cycle crossing. Table 7 presents safety effects of the two groups of accidents with direct and no direct influence respectively. Accidents with direct influence has been split into sub-groups of pedestrian accidents and bicycle/moped accidents respectively.

Accidents that are directly influenced by the marking of one blue cycle crossing in a junction are statistical significantly reduced by 32%, whereas accidents with no direct influence remain fairly unchanged in numbers. At junctions, where two or four blue cycle crossings have been marked, there is an increase in accidents of about 30% both for accidents under direct and no direct influence.

The reduction in accidents that are directly influenced by one blue cycle crossing is especially large for rear-end collisions involving bicycles/mopeds and collisions with right-turning cars. Accidents with no direct influence from one blue cycle crossing remain fairly unchanged for any accident situation. The increase in accidents at junctions with 2–4 blue cycle crossings is especially large for rear-end collisions only with motor vehicles involved and right-angle collisions with passenger cars driving on red traffic lights. Accidents with right-turning or left-turning cars and rear-end collisions with bicycles/mopeds involved remain unchanged or increase only very slightly at junctions with 2–4 blue cycle crossings.

The relationships between safety effects of blue cycle crossings on one hand and junction size, number of junction arms and traffic volumes on the other hand may stem from varying proportions of accidents that are under direct influence in the different types of junctions, because accidents under direct influence has better safety effects compared to accidents under no direct influence. Table 8 shows that this is actually the case for junctions with one blue cycle crossing. Expected accidents under direct influence constitutes a higher proportion of the total number of expected accidents as the junction becomes smaller,

Table 8
Proportion of accidents that are directly influenced and safety effects on accidents of one blue cycle crossing depending on junction size of the junction

| Number of blue cycle crossings within junction and junction size | Percent of accidents, which are under direct influence | Safety effect (percent) on accidents under direct influence | | Safety effect (percent) on accidents under no direct influence | |
|---|---|---|---|---|---|
| | | Best estimate | 95% CI[a] | Best estimate | 95% CI[a] |
| 1 Blue cycle crossing | | | | | |
| Total | 23 | −32 | −48; −10 | −1 | −18; +19 |
| 14–24 m wide | 38 | −54 | −81; +11 | −10 | −52; +69 |
| 25–36 m wide | 25 | −35 | −55; −7 | 0[b] | −24; +31[b] |
| 37–50 m wide | 17 | −14 | −49; +45 | −7 | −26; +18 |

[a] 95% Confidence interval.
[b] Inhomogeneous i.e. results of random effects model.

and the safety effect on accidents under direct influence also becomes better as the junction becomes smaller, whereas the safety effect on accidents under no direct influence does not change in magnitude as the size of the junction changes. This indicates that the individual road user is more influenced in an interaction that are influenced by the blue cycle crossing in minor junctions compared to larger junctions, and a higher proportion of the interactions between road users are influenced by the blue cycle crossing at minor junctions compared to larger junctions. Similar trends as Table 8 shows may not be found at junctions, where two or four blue cycle crossings have been marked.

## 4. Discussion

The "warning message" that one blue cycle crossing at a signalised junction signals to road users is beneficial in terms of safety. This also seems to be true at 3-armed junctions with two blue cycle crossings. The safety benefit arises due to fewer accidents with pedestrians, cyclists and moped riders that are "directly influenced" by the blue cycle crossing. The fewer arms or smaller size or lower traffic volume the junction has the better is the safety effect of one blue cycle crossing. This is because the directly influenced accidents constitute a higher share of junction accidents in small junctions compared to large junctions, and that the safety effect on directly influenced accidents is best at small junctions.

With two or four blue cycle crossing in the junction, the warning message seems to be disregarded and results in less safe behaviour. It seems that too many blue cycle crossings results in motorists having too much focus on the pavement or cyclists and too little focus on traffic signals, because rear-end collisions among motor vehicles and accidents with red-light driving motorists increases in numbers. Another element is that the accidents that are reduced to a major degree when marking one blue cycle crossing remain more or less unchanged when marking two or four blue cycle crossings. Perhaps motorists disregard the "warning messages" if there are too many of them (cannot see the wood for the trees) or are confused and spread their focus too much.

Based on the results of this study, a sound policy would be to: 'Mark one and only one blue cycle crossing at signalised junctions, where vulnerable road users are involved in accidents. The blue marking should be located at the crossing where most accidents have occurred. Junctions currently with two or more blue cycle crossing should have some blue marking removed, so only one blue cycle crossing is present'.

The results are also relevant to discuss in relation to other types of road information such as signs, markings, billboards, signals, etc. One may read the results as: 'Some information is better than no information and much better than too much information. Keep information simple and at a low level, and let the road be as self-explaining as possible'. If this also is true for signs, it might be that 2–5 signs on a road section are better than none, but six or more signs are even worse, however, this may off course depend on the information on the signs. Perhaps more studies should focus on the amount of information on topics like junction markings in general, direction signs, density of traffic signals, etc.

Behavioural studies are needed in order to find more explicit reasons for the differences in safety effects of respectively one, two and four blue cycle crossings. Such studies of attention, information processing, etc. that include warning messages, guiding elements or distracters being it signs, markings, billboards, etc. often lacks evidence for safety effects. Here the behavioural change is not described except for some changes at conflict areas in Portland, USA (Hunter et al., 2000).

The blue cycle crossing seems to have the best safety effect in "smaller" signalised junctions. This may indicate that such marking could result in safety gains in non-signalised junctions. A Danish study of another kind of cycle crossing in give-way junctions surely points towards this, because a white harlequin pattern cycle crossing was found to reduce accidents and injuries with cyclists/moped riders by 40–45%, which was not statistically significant due to a low number of accidents (Jensen, 2002).

The study is based on a "second-best" methodology. Corrections for changes in traffic volumes and road safety trends have been made. Despite methodological shortcomings, study results show systematic patterns. Some safety effects are statistical significant. There exist dose–response relationships between safety effect and the number of blue cycle crossings, junction arms and junction size. Safety gains arise in junctions with one blue cycle crossing for types of accidents for which the marking is targeted, whereas safety flaws arise in junctions with 2–4 blue cycle crossings for non-targeted types of accidents. Overall, there is high internal consistency in the changes of safety, which indicate causality, and the causal direction seems clear.

## 5. Conclusions

The main conclusions of the research reported in this paper can be summarised in the following points:

1. A before-after accident and injury study of marking of blue cycle crossings at signalised junctions has been completed taking into account changes in accident trends, traffic volumes and regression-to-the-mean effects in the before period. Blue cycle crossings are marked in order to warn road users about conflicts between cyclists and motorists and to provide cyclists with a lane through the junction area.
2. The weighted means or best estimates for safety effects of one blue cycle crossing in a junction are a reduction of 10% in accidents and 19% in injuries. Corresponding figures for two blue cycle crossings in a junction are increases of 23% in accidents and 48% in injuries, and for four blue cycle crossings increases are 60% and 139%, respectively. The last three safety effects are statistically significant on a 5% level. Results vary considerably from junction to junction, but the use of the meta-analysis method accounts for this.
3. The safety gains at junctions, where one blue cycle crossing was marked, arise because the number of accidents with riders in the flow of bicycles and mopeds that may have used the blue cycle crossing in the after period and pedestrians in the

pedestrian crossing parallel and just next to the blue marking was statistically significant reduced.

4. Further results show that the safety effect of blue cycle crossings seems to depend on number of junction arms, and junction size or traffic volumes. This may be explained by two facts. The directly influenced accidents constitute a higher share of junction accidents in small junctions compared to large junctions. The safety effect on directly influenced accidents is also best at small junctions.
5. The safety flaws at junctions, where two or four blue cycle crossings were marked, primarily arise because rear-end collisions among motor vehicles and accidents with red-light driving motorists increases in numbers.
6. In principle, it is impossible to rule out the possibility that uncontrolled confounding factors account for the results in the study. This is a general problem for non-experimental observational studies like the one in this paper. However, it is unlikely that confounding factors not controlled in the study could produce the dose–response relationships (see point 2) and particular safety gains and flaws (see point 3 and 4) that have been found. It seems more likely that the results reflect the safety effects of marking blue cycle crossings.

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