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Title: Effects of Roundabouts on Traffic Safety for Bicyclists: an Observational Study.

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ABSTRACT

A before-and-after study of injury accidents with bicyclists on 91 roundabouts in Flanders-Belgium was carried out. The study design accounted for effects of general safety trends and regression-to-the-mean, but couldn't take into account possible specific changes in traffic volume at roundabouts. Conversions of intersections into roundabouts turn out to have caused a significant increase of 27% in the number of injury accidents with bicyclists on or nearby the roundabouts. The increase is even higher for accidents involving fatal or serious injuries (41-46%). Compared to the formerly proven favourable effects of roundabouts on safety in general, this result is unexpectedly poor. However, the effects of roundabouts on bicycle accidents differ depending on when these roundabouts are built inside or outside built-up areas. Inside built-up areas the construction of a roundabout did increase the number of injury accidents involving bicyclists by 48% . For accidents inside built-up areas with fatal or serious injuries, an average increase of 77% is noticed. However, outside built-up areas the zero-hypothesis of 'no safety effect for bicyclists' cannot be rejected (best estimate: + 1% accidents, not significant). Roundabouts that are replacing traffic signals perform worse compared to roundabouts on other types of intersections.

KEY WORDS

Roundabout, bicyclist, safety, accident, intersection.

1. INTRODUCTION

Roundabouts in general have a favourable effect on traffic safety, at least for accidents causing injuries. During the last decades several studies were carried out into the effects of roundabouts on traffic safety. A meta-analysis on 28 studies in 8 different countries revealed a best estimate of a reduction of injury accidents of 30-50% (Elvik, 2003). Other studies, not included in the former one and using a proper design, delivered similar results (Persaud et al., 2001; De Brabander et al., 2005). All those studies reported a considerably stronger decrease in the number of severest accidents (fatalities and accidents involving serious injuries) compared to the decrease of the total number of injury accidents. The effects on property-damage only accidents are however highly uncertain (Elvik, 2003).

Less is known about the safety effects of roundabouts for particular types of road users, such as bicyclists (Daniels and Wets, 2005). Roundabouts seem to induce a higher number of bicyclist-involved accidents than might be expected from the presence of bicycles in overall traffic. In Great-Britain the involvement of bicyclists in accidents on roundabouts was found to be 10 to 15 times higher than the involvement of car occupants, taking into account the exposure rates (Brown, 1995). In the Netherlands safety records of 185 roundabouts were studied and a reduction of 30% was reported in the number of victims among bicyclists to the period before construction of the roundabout, while the overall number of traffic victims decreased by 95% (car occupants), 63% (motorcyclists), 63% (pedestrians) and 64% (other road users) (Schoon and van Minnen, 1993). Unfortunately, the study design could not take into account the possible effects of general trends in traffic safety and the regression-to-the-mean-effect.

In Flanders-Belgium bicyclists appear to be involved in almost one third of reported injury accidents at roundabouts (1118 reported accidents with bicyclists; 3558 in total, period 1991-2001), while in general only 14.6% of all trips (5.7% of distances) are made by bicycle (Zwerts and Nuyts, 2004). The apparent overrepresentation of bicyclists in accidents on roundabouts was the main cause to conduct an evaluation study on the effects of roundabouts, specifically on accidents involving bicyclists. The main research question was whether the resulting effect would be the same as for accidents in general, both for the totality of injury accidents as for the severest accidents (accidents resulting in fatal or serious injuries). It is important to know whether roundabouts have a different impact on the safety of different types of road users in order to develop adequate decision criteria for situations when a roundabout should be constructed or not. Supplementary questions were whether the effect would be different if the roundabout was constructed inside or outside built-up areas (as traffic conditions inside built-up areas may be considerably different from conditions outside built-up areas, e.g. number of bicyclists, average speed of cars, road width, presence of trucks, etc.). A final aim was to find out whether the effects on the number of accidents involving bicyclists would be different on intersections that were signal-controlled before the conversion to a roundabout compared to locations with no traffic signals in the before-situation.

2. DATA COLLECTION

A sample of 91 roundabouts in the Flanders region of Belgium was studied. The roundabout data were obtained from the Flemish Infrastructure Agency (part of the Ministry of Mobility and Public Works). The sample was selected according to the following successive selection criteria applied on the initial dataset:

- Roundabouts constructed between 1994 and 2000.

- 3 or 4 roundabouts selected randomly in each of the 28 administrative road districts in the Flanders region.

All the investigated roundabouts are located on regional roads (so called numbered roads) owned by either the Flemish Infrastructure Agency either the provinces. This type of roads is characterized by significant traffic, where other, smaller and less busy roads are usually owned by municipalities. The Annual Average Daily Traffic on the type of roads in question is 11 611 vehicles per day (AWV, 2004). No information was available about the AADT on the selected roundabouts. Both single-lane as well as double-lane roundabouts may occur on the roads that were selected in the sample, although the former type is more common. The dataset provides no information on the number of lanes on the roundabout. Also, no information was available about the type of bicyclist facility present at the roundabouts.

For the purpose of this study only those roundabouts that were constructed between 1994 and 2000 were taken into account. Accident data were available from 1991 until the end of 2001. Consequently a time period of accident data of at least 3 years before and 1 year after the construction of each roundabout was available for the analysis. For each roundabout the full set of available accident data in the period 1991-2001 was included in the analysis. Table 1 shows the distribution of the construction years for the roundabouts in the sample.

<insert table 1 here>

Exact location data for each roundabout were available so that accident data could be matched with the roundabout data. 40 roundabouts from the sample are located inside built-up areas (areas inside built-up area boundary signs, general speed limit of 50km/h), 51 outside built-up areas (general speed limit of 90 or 70 km/h) (see table 2). 22 roundabouts were constructed on intersections that were signal-controlled in the before-situation, 69 roundabouts were constructed on intersections with no traffic signals before.

Apart from the different speed limits other arguments exist to make a distinction between roundabouts inside versus outside built-up areas. Important differences in land use, share of different transportation modes (e.g. bicyclists), age and gender of road users might exist. Moreover some constraints for roundabout construction such as available public space are likely to be more restrictive inside built-up areas.

<insert table 2 here>

Two comparison groups were composed, consisting of 76/96 intersections inside/outside built-up areas serving as a comparison group for roundabouts inside/outside built-up areas (see table 3) . For the comparison groups, intersections on regional roads were selected in the neighbourhood of the roundabout locations. Preference for comparison group locations was given to intersections on the same main road as the nearby roundabout location with the same type of crossing road. The road categories were found on a street map. In order to avoid possible interaction effects of the comparison group locations with the observed roundabout locations, comparison group locations had to be at least 500 meter away from the observed roundabout locations. Apart from the confirmation they aren’t roundabouts, no information is available about the type of traffic regulation on the intersections in the comparison group. On these types of roads either signal-controlled, or priority-ruled intersections (one direction has priority) may occur.

<insert table 3 here>

Detailed accident data were available from the National Statistical Institution for the period 1991-2001. This database consists of all registered traffic accidents causing injuries. Only accidents where at least one bicyclist was involved were included. Accidents were divided into 3 classes based on the severest injury that was reported in the accident: accidents involving at least one fatally injured person (killed immediately or within 30 days after the accident), accidents involving at least one seriously injured (person hospitalized for at least 24 hours) and accidents involving at least one slightly injured. No distinction was made about which road user was injured, the bicyclist or any other road user such as a car occupant, a motorcyclist, another bicyclist or whoever.

Locations of accidents on numbered roads are identified by the police by references to the nearest hectometre pole on the road. All the accidents that were exactly located on the hectometre pole of the location were included in this study. Subsequently accidents that were located on the following or the former hectometre pole were added, except when the observed accident could clearly be attributed to another intersection. This approach was chosen in order to include possible safety effects of roundabouts in the neighbourhood of the roundabout as they might occur (Hydén and Várhelyi, 2000). Consequently the results should be considered as "effects on accidents on or near to roundabouts". At least one road on each location, both for the treatment group as for the comparison group, was a numbered road.

The same selection criteria were applied for accidents on locations in the comparison group as for accidents on locations in the treatment group.

The total number of accidents included in the treatment group was 411, of which 314 with only slight injuries, 90 with at least one serious injury and 7 with a fatal injury (see table 4). The total number of accidents in the comparison group is 649, of which 486 with only slight injuries, 142 with serious injuries and 21 with fatal injuries.

<insert table 4 here>

Tables 5 and 6 give the number of accidents for the treatment group, split up by the location inside and outside built-up areas and by the before-situation at the location (traffic signals or not). In table 5 this was done for all injury accidents, in table 6 only for the most severe accidents, i.e. accidents involving serious or fatal injuries.

<insert table 5 here>

<insert table 6 here>

Table 7a shows the number of accidents for the comparison group, split up by the location inside or outside built-up areas. Table 7b shows the distribution of the accidents in the comparison group per year, both for all injury accidents and for severe accidents.

<insert table 7a here>

<insert table 7b here>

The average yearly number of accidents with bicyclists on the roundabout locations in the before-situation was 0.51 (inside built-up areas) / 0.3 (outside built-up areas) (table 8a). In the period after construction of the roundabout the yearly averages were 0.6 (inside built-up areas) / 0.3 (outside built-up areas). During the full considered period the average yearly number of accidents in the comparison group was 0.41 (inside built-up areas) and 0.29 (outside built-up areas) (table 8b). Figure 1 gives an impression of the distribution of locations with respect to the number of count accidents both in the before and after period.

<insert table 8a here>

<insert table 8b here>

<insert figure 1 here>

3. METHODOLOGY

The objective was to ascertain the effect of a measure (construction of roundabouts) on a particular type of accidents (accidents involving bicyclists). The study was designed as a before and after study with a comparison group, controlling for general trends in traffic safety and possible effects of regression-to-the-mean (Hauer, 1997; Elvik, 2002; Nuyts and Cuyvers, 2003).

The first stage was to calculate the effectiveness for each location in the treatment group separately. Consequently the results were combined in a meta-analysis. This allowed to combine the results for roundabouts that were constructed in different years.

The effectiveness is expressed as an odds-ratio of the evolution in the treatment group after the measure has been taken compared to the evolution in the comparison group in the same time period (Eq. 1).

$$EFF_l = \frac{TREAT_{l,\,after} / TREAT_{l,\,before,\,regr}}{COMP_{after} / COMP_{before}} \qquad \text{(Eq. 1)}$$

The values of $TREAT_{l,after}$, $COMP_{after}$ and $COMP_{before}$ are count values and can simply be derived from the data. The value for $TREAT_{l,after}$ is the count number of accidents that happened on the location l during the years after the year when the roundabout was constructed. The values for $COMP_{after}$ and $COMP_{before}$ are the total count numbers of accidents for all locations in the comparison group respectively after and before the year during which the roundabout has been constructed. The values for the year during which the roundabout was constructed are always excluded, both in the treatment group and in the comparison group. For each roundabout those before-period (after-period) in the comparison group was selected that matches with the before-period (after-period) of the roundabout. Therefore no normalisation to years averages or similar rates in Equation 1 is necessary and total counts can be used.

The use of the comparison group allows for a correction of general trend effects that could be present in the accident evolution on the studied locations.

The value of $TREAT_{l,before,regr}$ reflects the estimated number of accidents on the treatment location l before construction of the roundabout, taking into account the effect of regression-to-the-mean. The regression-to-the-mean effect is likely to occur at locations where a decision has been taken to construct a roundabout as the Infrastructure Agency considers an increased number of accidents among others as an important criterion for constructing a roundabout at a certain location. The value is calculated as a result of the formula (Eq. 2):

$$TREAT_{l,\,before,\,regr,} = w * (\mu_{(TREAT_l\,+\,COMP)} * T) + (1-w) * (\sum_{t=1}^{T} TREAT_{l,\,t}) \qquad \text{(Eq. 2)}$$

with $w = \dfrac{1}{1 + k * \mu_{(TREAT_l\,+\,COMP)} * T}$ (Eq. 3)

and k = $\dfrac{\sigma^2_{(TREAT_l\,+\,COMP)} - \mu_{(TREAT_l\,+\,COMP)}}{\mu^2_{(TREAT_l\,+\,COMP)}}$ (Eq. 4)

T equals the number of years in the before period. The value k (Eq. 4) expresses the overdispersion factor. This value is specific for the negative binomial distribution and reflects the amount in which the data are more spread than it would be the case in a Poisson-distribution. The value k must be positive and is calculated from the data itself. k-values were derived for each location separately, using all available accident data. However, in some cases, the k-value that was derived that way appeared to be close to zero or even turned sometimes out to be negative. In the former case, this could reveal a problem of erroneous pure Poisson characteristics due to the small size of the sample and the low sample mean (Lord, 2006). In the latter case this is even contradictory to the basic assumption of the negative-binomial distribution of accidents (variance larger than the mean). As the use of a different value for k might lead to different results and an unreliably estimated overdispersion parameter could significantly undermine estimates (Lord, 2006), we used three scenarios in all cases where no k-value could be derived from the data themselves. In the first scenario an extremely small, but positive fixed value for k was used ($k=10^{-10}$). In the second scenario the same value for k was used for accidents involving fatalities or serious injuries as for all accidents (as all cases were no k-value could be derived from the data applied to accidents with fatalities and serious injuries). In the third scenario an extreme high value for k was used ($k= 10^{10}$). Using this approach, a sensitivity analysis was performed on the impact of k on the results.

The value w (Eq. 3) reflects the weighting of the group in comparison to the weighting of the location itself when estimating the number of accidents on the observed location before construction of the roundabout.

Equation 2 expresses the estimated number of accidents at the observed location in a time period T. Equation 2 equals the weighted sum of the number of accidents on the individual location and the average of a comparable location (i.e. the average of location and the comparison group). The higher the value k in Equation 3 or the number of years T in the before-period, the lower the weight (value w) for the comparison group and accordingly the higher the weight (1-w) for the number of accidents on the roundabout location itself. Note that an extreme high value for k means that the value w in Equation 3 almost equals to zero which corresponds a hypothesis of "no regression-to-the-mean-effect" as in such a case in Equation 2 only count data from the treatment location itself are used.

Consequently the value of EFF_l can be calculated. This value reflects the best estimate for the impact of the construction of a roundabout at location l. $Ln(EFF_l)$ denotes the natural logarithm of EFF_l. As EFF_l has a lognormal distribution (Fleiss, 1981) the variance s^2 of $Ln(EFF_l)$ can be calculated as

$$s_l^2 = \frac{1}{TREAT_{l,\,after}} + \frac{1}{TREAT_{l,\,before,\,regr}} + \frac{1}{COMP_{after}} + \frac{1}{COMP_{before}} \qquad \text{(Eq. 5)}$$

The 95% confidence interval can be derived as

$$CI_{EFF_l} = EXP\left[Ln(EFF_l) \pm 1.96 * s\right] \quad \text{(Eq. 6)}$$

This method was applied to calculate best estimates and confidence intervals for each roundabout location separately. After doing this, a meta-analysis was carried out in order to retrieve generalized impacts on groups of locations. The generalized effect is expressed as

$$EFF_{ALL} = EXP\left[\frac{\sum_{l=1}^{n} w_l * Ln(EFF_l)}{\sum_{l=1}^{n} w_l}\right] \quad \text{(Eq. 7)}$$

with $w_l = \frac{1}{s_l^2}$ (Eq. 8)

The confidence interval for EFF_{ALL} is derived in a similar way as in equation 6.

$$CI_{EFF_{ALL}} = EXP\left[\frac{\sum_{l=1}^{n} w_l * Ln(EFF_l)}{\sum_{l=1}^{n} w_l} \pm 1.96 * \frac{1}{\sqrt{\sum_{l=1}^{n} w_l}}\right] \quad \text{(Eq. 9)}$$

4. RESULTS

Both treatment group and comparison group were divided into locations inside and outside built-up areas. Consequently analyses were made for roundabouts inside built-up areas using all locations in the comparison group inside built-up areas as a comparison group for this estimation. The treatment locations were divided into two groups, depending whether the investigated intersection was equipped with traffic signals or not in the before-situation. The effectiveness-index was calculated for each treatment location using the described methodology. After calculating the effectiveness-index for all the locations in the same group a meta-analysis was made for the whole group.

Table 9 shows the results of the analyses. The best estimate for the overall effect of roundabouts on injury accidents involving bicyclists on or nearby the roundabout is an increase of 27%. The best estimate for the effect on accidents involving fatal and serious injuries is an increase of 41 to 46%, depending on the used k-value.

<insert table 9 here>

Performing the meta-analysis for all locations inside built-up areas reveals an increase of accidents of probably 48% (effectiveness-index 1.48) after the roundabout construction. The result is significant at the 5% level.

On intersections inside built-up areas and not equipped with traffic signals before, a significant increase of accidents involving bicyclists of 55% is noted. On intersections with traffic signals before, the best estimate is an increase of 23% of accidents. However, this result is clearly not significant. Estimations were also made for the group of the most serious accidents, i.e. accidents involving fatal and serious injuries. The results show a significant 77% increase in accidents involving bicyclists inside built-up areas.

Subsequently the same procedure was followed for locations outside built-up areas. When it comes to all injury accidents the overall best estimate of the impact is close to one, which means that the zero-hypothesis of "no effect" cannot be rejected at all. Nor do we see a significant effect for accidents involving fatal and serious injuries. The overall best estimate shows an increase of 15 to 24% of severe accidents. Nevertheless, the confidence interval is broad and even a decrease in accidents cannot statistically be excluded.

In order to reveal whether there are any significant differences in the results for different before-situations (traffic signals or not) or different locations (inside or outside built-up area), a series of two-tailed t-tests with two samples assuming unequal population variances was performed. Table 10 shows the results. Significant differences are found for "all accidents causing injuries" outside built-up areas (a best estimate of index 1.27 on intersections with traffic signals before versus an index of 0.89 on intersections without traffic signals before).

<insert table 10 here>

Furthermore significant differences are found for locations inside versus outside built-up areas at intersections that were not equipped with traffic signals before (both for "all injury accidents" and "accidents with fatally or seriously injured").

5. DISCUSSION

We are aware of only one previous before-and-after study investigating the effects of roundabouts on different types of road users. This study (Schoon and van Minnen, 1993) provided indications of a less favourable effect of roundabouts on injuries among bicyclists compared to other road users. However, according to the results presented above, the effect does not look favourable at all. This finding could provide an explanation for the higher-than-expected prevalence of injury accidents involving bicyclists on roundabouts as we found it in the accident data in Flanders and as it was also been noted in some other countries (Brown, 1995; CETUR, 1992). However, it is recommendable to perform similar studies in other countries in order to confirm whether results are comparable.

Our best estimate for the overall effect of roundabouts on the number of injury accidents involving bicyclists is an increase of 27% (95% C.I. [0%; 61%]. The effect on severe accidents is even worse: an increase of 41-46% . It is interesting to compare these results with a former study (De Brabander et al., 2005) that studied the effects of roundabouts on safety among all types of accidents in the same region and used a strongly comparable dataset. This study revealed an overall decrease of 34% of accidents causing injuries (95% C.I. [-43%; -28%]) and a decrease of 38% [-54%; -15%] for accidents involving fatal and serious injuries.

These contradictory results for accidents involving bicyclists and all accidents raise the question whether it is recommendable or not – at least from a safety point of view – to construct roundabouts. Although roundabouts turn out to be a safe solution in general, the results for bicyclist's safety are clearly poor.

The effects on bicyclist's safety differ depending on the location of the roundabouts. It is unquestionable that the effect of roundabouts inside built-up areas is bad. Outside built-up areas the effect on safety for bicyclists is about zero: not better nor worse compared to the before-situation. However, also there seems to be a tendency towards a deterioration (best estimates +1% for all injury accidents, +15-24% for accidents with fatally and seriously injured, although clearly not significant).

Another issue is to judge the effect depending on the type of intersection (with or without traffic signals) in the before-situation. Inside built-up areas there is no clear effect. Outside built-up areas the differences are more distinct. Intersections with traffic signals in the before-situation perform significantly worse in comparison to non-signalised intersections.

One must take into account that an estimated effect is always a “most likely” effect that may conceal many differences between individual locations. Figure 2 illustrates this. The figure shows the estimations for the effectiveness-index for the individual roundabout locations (all accidents, 91 data points) and their weight (value w_l in Equation 8) in the meta-analysis. It is obvious that results at individual intersections differ considerably. The lowest estimated effect is a 80% decrease (index 0.2), the highest an increase of 787% (index 8.87). Generally, it could be expected that the data points with the highest weights (lowest variance of the effectiveness-index) are closer to the general best estimate, which should show a more or less normal distribution. To a large extent this seems to be the case.

<insert figure 2 here>

The variations between the individual results can be explained mainly by the stochastic nature of accidents as rare events, but there might also be something more. Looking at figure 2, there are some indications of a double peak in the curve. This could reveal the presence of distinct subgroups in the sample of roundabouts with different safety effects. Looking at the second peak, in the neighbourhood of coordinates (5.27; 1.89), all intersections are located inside built-up areas. However, as one of the major conclusions in this study is that roundabouts inside built-up areas perform weaker compared to roundabouts outside built-up areas when it comes to the safety of bicyclists, a higher representation of locations inside built-up areas in the group of the worst performing locations shouldn't be really surprising. The available data don't enable to give an accurate explanation for the second peak in the curve. Unknown influencing factors may exist. For example, no information was available about the type of bicyclist facility (motorised traffic and bicyclists mixed together – the so called mixed traffic solution, adjoining – close to the roadway - cycle tracks or physically separated cycle paths) present at the roundabouts studied, while specific design characteristics may have an important effect on accidents for specific groups of road users (Daniels and Wets, 2005). Also the number of lanes on the roundabout, which was not known in this case, might influence the results as double-lane roundabouts tend to reduce accidents less in comparison to single lane roundabouts (Persaud et al, 2001). More research on this topic should be carried out.

One of the restrictions of this study is the lack of data about the evolution of traffic volume on the locations studied, particularly the evolution of motorised traffic and bicyclist traffic. By using a large comparison group it was possible to account for both general trends in traffic volume as well as possible evolutions in modal choice. But, at a local scale level, one cannot exclude the effect of roundabouts on exposure, for motorised traffic as well as for bicyclists. It is possible that some bicyclists or car drivers will change their route choice after the construction of a roundabout, either resulting in an increased use of the roundabout or a decrease in the use, depending on personal preferences. Either changes in the route choice could make the results in this study weaker (if roundabouts for instance would attract bicyclists this would create a higher exposure for bicyclists at the site, but a corresponding lower risk elsewhere, in which case we are too pessimistic in our estimates) but the results might also be stronger (if bicyclists would use roundabouts less than the previous types of intersections, in which case our estimations are even too modest). As no data on exposure were available, we couldn't account for possible changes in the choice of route. Further research in this area is nevertheless recommended.

6. CONCLUSIONS

As roundabouts are in general improving safety on intersections, there are few reasons for doubting the added-value of roundabouts as far as safety is concerned. But, looking at the poor results for bicyclist accidents and keeping in mind the attention that many governments pay to vulnerable road users, roundabouts don't seem to be an appropriate solution in all circumstances in which they were built in the past. At least in built-up areas where speeds are lower and bicyclists are more numerous, road authorities should look at pros and cons carefully before constructing a roundabout. Further research should reveal whether it is possible to define more specific circumstances in which roundabouts should be constructed or not and whether some geometric features of roundabouts correlate with less or more accidents involving bicyclists.

7. ACKNOWLEDGEMENTS

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TABLE 1 Number of roundabouts per construction year – study sample

CONSTRUCTION YEAR	N° of Roundabouts
1994	17
1995	21
1996	16
1997	8
1998	7
1999	14
2000	8
FULL SAMPLE	91

TABLE 2 Treatment Group Locations (Roundabouts)

	No traffic signals before	Traffic signals before	TOTAL
Inside built-up areas	33	7	40
Outside built-up areas	36	15	51
TOTAL	69	22	91

TABLE 3 Comparison Group Locations

	Number of locations in comparison group
Inside built-up areas	76
Outside built-up areas	96
TOTAL	172

TABLE 4 Number of Accidents considered

	Treatment group	Comparison group
Number of accidents involving at least 1 slight injury	314	486
Number of accidents involving at least 1 serious injury	90	142
Number of accidents involving at least 1 fatal injury	7	21
TOTAL	411	649

TABLE 5 Number of Accidents – Treatment group

	Traffic signals before				No traffic signals before				TOTAL
	TOTAL	Period before constr.	Year of constr.	Period after constr.	TOTAL	Period before constr.	Year of constr.	Period after constr.	
Inside built-up areas	50	26	6	18	186	82	10	94	236
Outside built-up areas	67	34	4	29	108	59	10	39	175
TOTAL	117	60	10	47	294	141	20	133	411

TABLE 6 Number of Severe Accidents (with fatal or serious injuries) – Treatment Group

	Traffic signals before				No traffic signals before				TOTAL
	TOTAL	Period before constr.	Year of constr.	Period after constr.	TOTAL	Period before constr.	Year of constr.	Period after constr.	
Inside built-up areas	10	7	0	3	41	18	1	22	51
Outside built-up areas	18	13	1	4	28	18	4	6	46
TOTAL	28	20	1	7	69	36	5	28	97

TABLE 7a Number of Accidents – Comparison Group

	Number of accidents involving injuries	Number of accidents involving fatal or serious injuries
Inside built-up areas	340	74
Outside built-up areas	309	89
TOTAL	649	163

TABLE 7b Number of Accidents per year – Comparison Group

year	Number of accidents involving injuries	Number of accidents involving fatal or serious injuries
1991	65	19
1992	68	13
1993	65	19
1994	58	16
1995	54	18
1996	54	13
1997	70	18
1998	62	15
1999	49	13
2000	48	13
2001	56	6
TOTAL	649	163

TABLE 8a Average yearly number of accidents – Roundabout locations

	Before construction	After construction
Inside built-up areas	0.51	0.60
Outside built-up areas	0.33	0.30

TABLE 8b Average yearly number of accidents – Comparison group locations

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	FULL PERIOD
Inside built-up areas	0.49	0.64	0.49	0.33	0.39	0.33	0.45	0.38	0.29	0.29	0.39	0.41
Outside built-up areas	0.29	0.20	0.29	0.34	0.25	0.30	0.38	0.34	0.28	0.27	0.27	0.29

FIGURE 1. Annual number of accidents involving bicyclists per location before and after roundabout construction

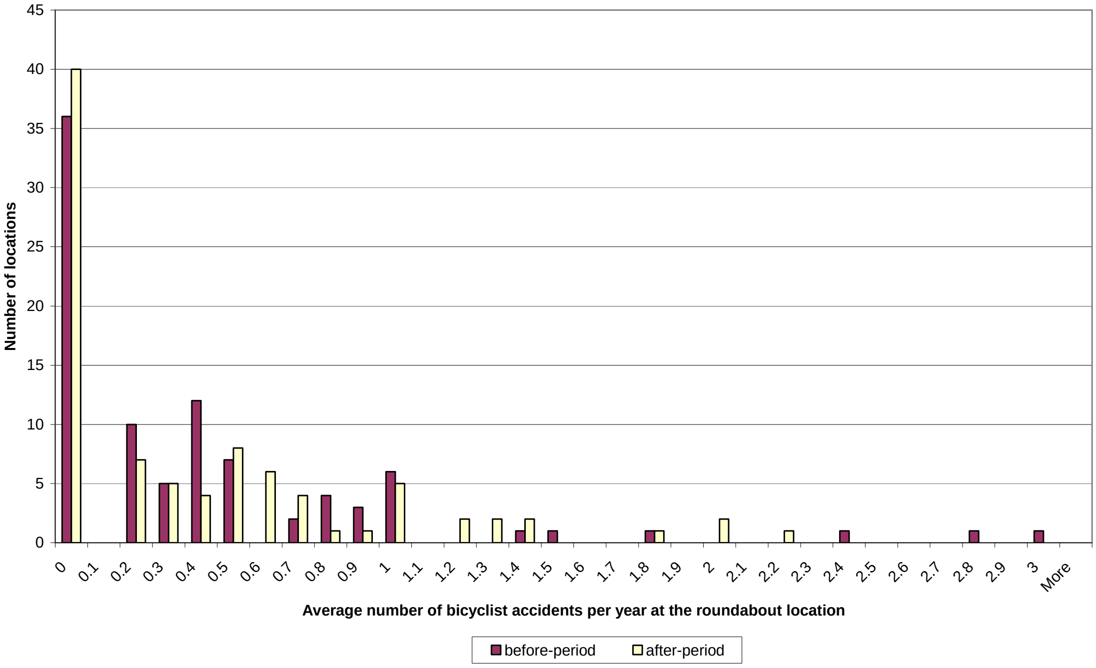

TABLE 9 Results

		Traffic signals before	No traffic signals before	All locations
Inside built-up areas	All injury accidents	1.23 [0.62-2.45] (ns)	1.55 [1.10-2.17] (*)	1.48 [1.09-2.01] (*)
	Accidents with fatally and seriously injured	1.63 [0.45-5.90] (ns)	1.81 [0.99-3.29] (ns)	1.77 [1.03-3.05] (*)
Outside built-up areas	All injury accidents	1.27 [0.68-2.38] (ns)	0.89 [0.56-1.42] (ns)	1.01 [0.69-1.47] (ns)
	Accidents with fatally and seriously injured	1.78 [0.72-4.38] (ns) ° 1.62 [0.68-3.88] (ns) °° 1.36 [0.55-3.33] (ns) °°°	1.06 [0.59-1.91] (ns) ° 1.06 [0.59-1.91] (ns) °° 1.05 [0.57-1.99] (ns) °°°	1.24 [0.76-2.03] (ns) ° 1.21 [0.74-1.97] (ns) °° 1.15 [0.69-1.92] (ns) °°°
All locations	All injury accidents	1.25 [0.79-1.99] (ns)	1.28 [0.97-1.68] (ns)	1.27 [1.00-1.61] (*)
	Accidents with fatally and seriously injured	1.73 [0.83-3.61] (ns) ° 1.62 [0.79-3.34] (ns) °° 1.44 [0.69-3.01] (ns) °°°	1.38 [0.91-2.10] (ns) ° 1.38 [0.91-2.10] (ns) °° 1.40 [0.91-2.16] (ns) °°°	1.46 [1.01-2.10] (*) ° 1.44 [1.00-2.07] (*) °° 1.41 [0.97-2.05] (ns) °°°

ns = non significant, * = p≤0.05, ** = p≤0.01

° Use of fixed $k = 10^{-10}$

°° Use of k-value = k for all injury accidents

°°° Use of fixed $k = 10^{10}$

FIGURE 2 Funnel Graph – Best Estimates of the Effectiveness-Index – All Roundabouts – All Accidents.

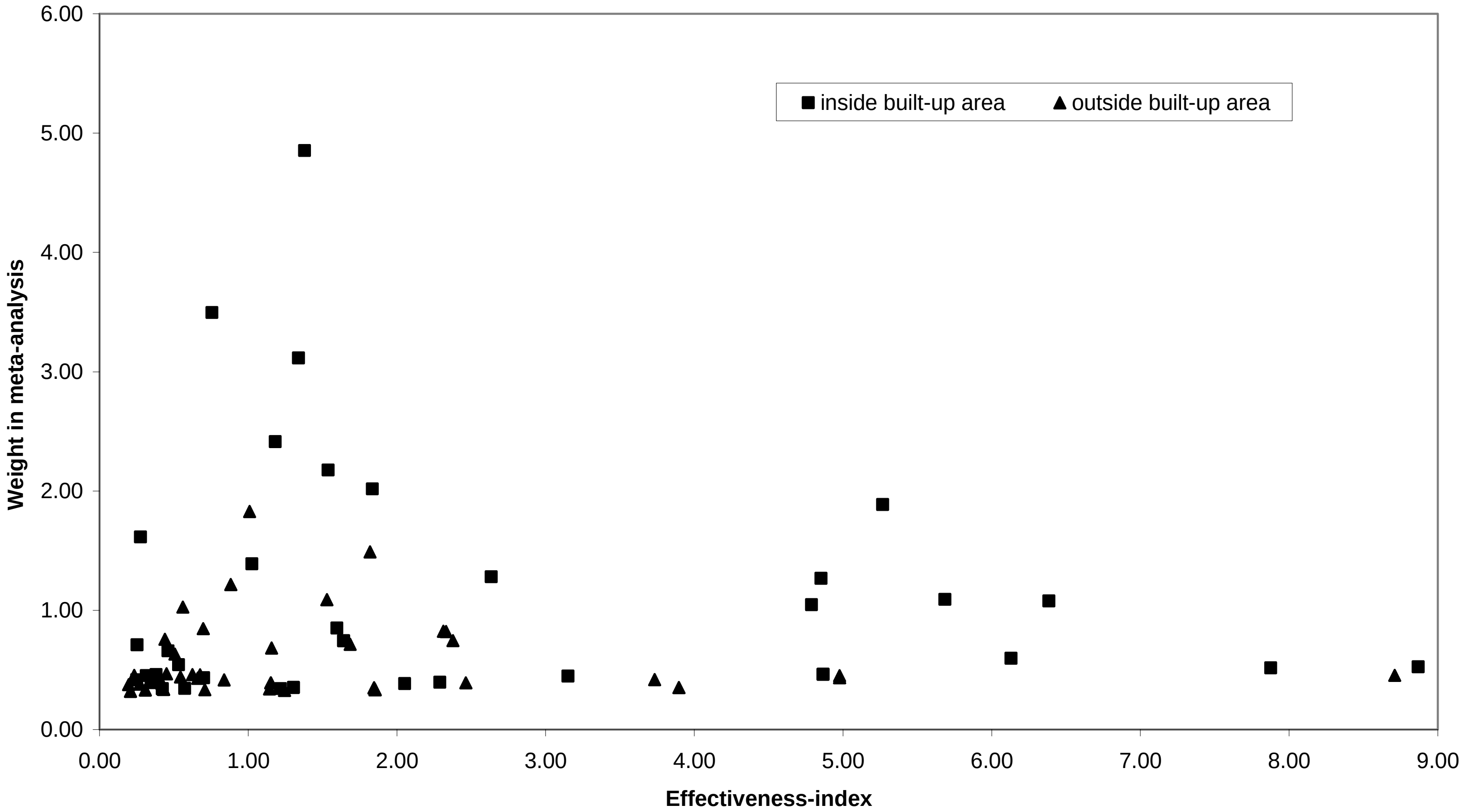

TABLE 10 t-tests

			t-statistic	p-value	
Inside built-up areas	All injury accidents	signals vs no signals before	0.23	0.83	ns
	Accidents with fatally and seriously injured	signals vs no signals before	-0.14	0.89	ns
Outside built-up areas	All injury accidents	signals vs no signals before	2.19	0.04	*
	Accidents with fatally and seriously injured °	signals vs no signals before	1.23	0.23	ns
All locations	All injury accidents	signals vs no signals before	1.59	0.12	ns
	Accidents with fatally and seriously injured °	signals vs no signals before	0.66	0.51	ns
All locations	All injury accidents	inside vs outside built-up areas	1.78	0.08	ns
	Accidents with fatally and seriously injured °	inside vs outside built-up areas	1.79	0.08	ns
Signals before	All injury accidents	inside vs outside built-up areas	-0.02	0.99	ns
	Accidents with fatally and seriously injured°	inside vs outside built-up areas	0.17	0.87	ns
No signals before	All injury accidents	inside vs outside built-up areas	2.37	0.02	*
	Accidents with fatally and seriously injured°	inside vs outside built-up areas	2.04	0.05	*

ns = non significant, * = $p \leq 0.05$, ** = $p \leq 0.01$

° used results with k = k_all accidents for locations outside built-up areas