REDESIGNING BLACK SPOTS IN TRAFFIC: AN EFFECT EVALUATION

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First submitted: July 30, 2012
Revised paper submitted: November 15, 2012

Number of words: 5741
Number of tables: 4
Number of figures: 1
→ Total number of words: 6991

ABSTRACT

In order to work to a better traffic safety, many countries handle a black spot program, through which the most dangerous traffic spots are selected and subsequently the infrastructure is adapted. To handle these black spots, a lot of means are invested, but often the outcome for traffic safety remains unclear. Therefore we evaluated the effect of the adaptation of dangerous traffic spots on traffic safety. Through analysis of the crash rates, this study evaluates the safety effects of an extensive black spot program that has been implemented in Flanders-Belgium. This program included around 800 black spots, from which 134 locations, redesigned between 2004 and 2007, were included in this study. The adopted approach is an Empirical Bayes before-and-after study that accounts for effects of general trends and for the stochastic nature of crashes, including regression to the mean. Two different comparison groups were established. Furthermore ANOVA-analyses were made to check whether differences in effects occurred depending on the characteristics of the location and the implemented intersection design. Dependent on the applied comparison group, the analyses showed a decrease in the number of injury crashes of 24 to 27%, significant at the 1%-level. A separate analysis for crashes with serious or fatal injuries showed a decrease of 40 to 52%, also significant at the 1% level. The results suggest a more favourable evolution for intersections that were priority controlled in the before situation compared with signal-controlled intersections. Crash reductions were also higher at locations with a lower traffic volume compared to locations with a higher volume. This study shows the investment of the means in a black spot program does have a favourable outcome on traffic safety. A critical selection of the black spots can help to reach stronger traffic safety effects with less means.

BACKGROUND

In an attempt to work to a better traffic safety, different countries introduced a black spot program. The term black spot refers to locations that have a higher expected number of accidents than other similar locations, as a result of local risk factors *(1)*. The objective of a black spot program is to reduce the number and severity of crashes, mainly through infrastructural adaptations of the black spots. This however requires a lot of means. Therefore it is important that the effect of these investments are analyzed, in order to decide whether means are invested well, and to learn from for future measures.

To reach the traffic safety goals, also the Flemish Government in Belgium decided to select the most dangerous spots and adapt their infrastructure. Based on the number and the severity of crashes, 809 black spots were selected. The size of these spots varied and was dependent on the extent of occurrence of the crashes. However 99% were intersections, all located on regional roads. Every location that counted at least three injury crashes during the period 1997-1999 was selected, and subsequently a priority score was calculated. For this calculation the number of injured were taken into account: every slightly injured got a weight of 1, every severely injured 3 and every deadly injured 5. A total priority score of minimum 15 was necessary to be selected as a dangerous spot.

Priority score = 1* X + 3* Y + 5* Z

With

X= number of slightly injured (person that got injured, but cannot be defined as severely or deadly injured)

Y= number of severely injured (person that needed more than 24 hours of hospitalization)

Z= number of injured that died at the location of the crash or within 30 days after the crash

At the moment of current research was performed, 406 of the 809 locations have been redesigned and were in use again. For 160 locations it was decided not to reconstruct, or to implement only minor modifications such as an alteration of the signal phasing or slightly changed markings. The remaining 243 locations were redesigned or in a design stage.

Different previous studies examined the effectiveness of black spot programs. Elvik *(2)* executed a meta-analysis of 36 before-and-after studies, that all examined the effectiveness of black spots programs. He found that the more confounding factors were accounted for, the smaller the accident reduction attributable to the black spot treatment became. High decreases (in the order of 50-90%) were found in studies that did not controlled for any confounding factor. However studies that controlled for trend effects, regression to the mean and crash migration found no statistical significant result *(2)*. A recent Australian study examined 1599 black spot projects, which is 62% of the 2578 funded black spot projects approved and completed during the seven-year period 1996–97 to 2002–03. This study showed a reduction of 30% in fatal and casualty crashes and 26% in property damage only crashes. Trend effects were controlled through inclusion of the total crash rates in each state or territory. To control for regression to the mean, pre-treatment crash data were selected during the interval of time between the date on which the funding application was submitted to the Australian Government and the date on which work on the project commenced *(3)*. They found the conversion to roundabouts to be the most effective method, with a reduction of 70% in the number of casualty crashes. Next to this altering the flow direction and new signals during the day was also highly effective, which respectively showed a reduction in casualty crashes of 58 and 51%.

STUDY DESIGN

To examine the traffic safety effectiveness, a before and after design was adopted. More specifically the Empirical Bayes method was used, which is widely accepted as the best standard in the evaluation of traffic safety measures *(4,5,6,7)*. Through this method the observed number of crashes after treatment are compared with the expected number had there been no treatment. This ‘expected’ number is based on the number of crashes before treatment with correction for extraneous factors. Such correction is necessary, as besides the effects of the treatment itself, a range of other factors will have had an effect on traffic safety. Those confounding factors are regression to the mean (RTM), general crash trend, coincidence of the occurrence of crashes and general changes in traffic volumes *(2)*. To account for chance effects, different years of before and after crash data were included. According to Elvik *(8)* it is not necessary to use statistical methods to control for traffic volumes, but it is sufficient to use a large comparison group, from which the total crash rates encompasses several hundreds. As the first comparison group consists of 211 locations, scattered around Flanders, and the second comparison group includes all crashes in Flanders, this is sufficient to control for volume changes. Furthermore can be expected that no large changes in traffic volumes will appear after the adaptation of a black spot. To control for RTM and trend statistical formulas were used, as explained below.

DATA

Research and Comparison Group

In order to make an analysis of the crash rates possible, a geographical localization of the crashes is necessary. These localized crash data are available for Flanders up to and including 2008. Having available at least one year of crash data after the adaptation of the black spot was considered to be necessary. Subsequently, black spots adapted and open for traffic up to 2007 inclusive could be evaluated, and a final research group of 134 black spots was selected. The flow chart of the selection for the research and comparison group is shown in figure 1. In total the Flemish government selected 809 black spots. On 160 of those 809 spots only small measures were planned, such as alteration of the signal phasing or slightly changed markings. These locations are not selected, as the date of those small adaptations, which is necessary to make an evaluation possible, was not known. From the remaining 649 spots 201 were treated before 2008, which were selected as research locations. After 2008 294 locations remained to be treated, which subsequently could be included in the comparison group. The other 154 locations could not be included in the research group, nor in the comparison group, as the works started before 2009 (and thus could not be selected in the comparison group), but were not ended yet before 2008 (and thus could neither be selected in the research group). From the 201 and 294 locations in the research and comparison group, not all necessary information was available. Therefore 69 locations from the research group and 91 locations from the comparison group were excluded, mainly due to missing information about volume data. These rates were supplemented with extra locations, as some black spot locations existed of two intersections. In these analyses each intersection was analyzed separately, therefore the research group had two locations extra, the comparison group eight locations. This eventually leaded to 134 research locations, which were all intersections. According to the location, different treatments were applied. Generally 6 treatments could be distinguished.

- Traffic lights → conflict-free traffic lights: The majority of the research locations (53) were traffic lights regulated intersections, that were converted to conflict free lights. This had the consequence the left turns were protected.
- Traffic lights → traffic lights: 15 intersections that were traffic light regulated during the before period, mainly got adaptations in the lay-out. Examples of adaptations are: better construction of cycle paths (broadening paths, raise paths, create crossings), separate turning lanes and installation of speed cameras.
- Traffic lights → roundabout: Five locations were converted from a traffic regulated intersection to a roundabout.
- Priority controlled → priority controlled: From the locations that were priority controlled during the before period, 26 remained priority controlled, but the lay-out of the intersections was adapted. Examples here were better construction of cycle paths, construction of traffic islands and installation of medians.
- Priority controlled → traffic lights: Nine locations that were previously priority controlled got traffic lights, from which six were conflict free traffic lights.
- Priority controlled → roundabout: Eight priority controlled locations were converted to a roundabout.

Other characteristics (priority factor, localization inside/outside urban area, number of legs, maximum speed limit, number of lanes, presence of median, traffic volume) of the research locations are, together with the results, shown in table 3.

The final comparison group consisted of 211 locations, which also were all intersections. These locations can be expected to be comparable with the research locations for certain characteristics (for example traffic volumes, maximum speed limit,…), whereas they differ in that there were no traffic safety measures executed during the research period. As it is unclear whether or not a certain order in the treatment of black spots is handled, and thus a certain distortion could be observed, a second comparison group was handled. This consisted out of all injury crashes in Flanders.

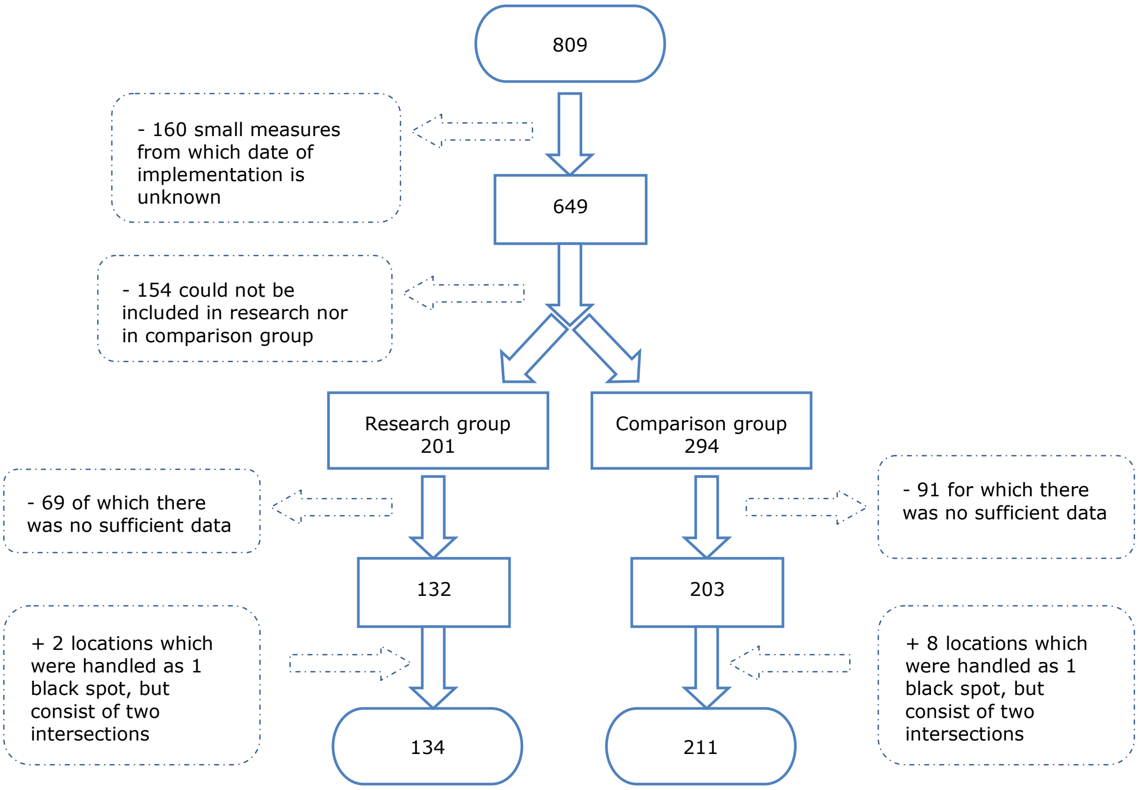

FIGURE 1 Flow chart of the selection of locations for the research and comparison group.

All crashes in a radius of 100 meter around the black spot were selected. From this can be expected that all crashes related to the black spot were included, also at the more larger intersections and roundabouts. As the selection of the black spots was based on crash data from 1997-1999, these data were excluded from the research, in order to make a first control for the regression to the mean effect. Subsequently the research period for this study encompassed 2000-2008. To make a more detailed analysis possible, a distinction according to the severity of the crash was made: at first the effect on injury crashes was examined, which were all crashes in which a person got injured, independently of the severity of the injury. Next to this, severe crashes were separately analyzed. This group of severe crashes included crashes with severely injured (every person that needed more than 24 hours of hospitalization as a consequence of a crash) and deadly wounded (every person that died within 30 days after the crash). Property damage only crashes were not included, as these are not gathered systematically.

To make sure the comparison group is comparable with the research group, the odds ratios of the crash rates from the years of the before period were calculated. The odds ratio is the ratio of change in the number of crashes in the research group, compared to the change in number of crashes in the comparison group. The odds ratio of two consecutive years is

$$\text{Odds ratio} = \frac{R_t/R_{t-1}}{C_t/C_{t-1}} \qquad [1]$$

With:
R_t= the number of crashes in the research group in year t
R_{t-1}= the number of crashes in the research group in year t-1
C_t= the number of crashes in the comparison group in year t
C_{t-1}= the number of crashes in the comparison group in year t-1

When groups are comparable, it can be expected that before the implementation of the measure, the relative crash evolution from year to year of the comparison locations will be similar to the evolution at the research locations. The comparison group can be interpreted as comparable when the odds ratio is near to 1 *(6)*. The results of these calculations are shown in table 1. As the first adaptations are executed in 2004, the odds ratio is calculated until this year. The calculations show that comparison group 1 (black spots treated after 2008) as comparison group 2 (all crashes in Flanders) are comparable with the research group, both for all injury crashes, as for the more severe crashes.

TABLE 1 Odds Ratios for Injury Crashes and Severe Crashes in the Research Group with each of the Comparison Groups

	Comparison group 1		**Comparison group 2**	
	All injury crashes	Severe crashes	All injury crashes	Severe crashes
00-01	1.02	0.92	0.95	0.86
01-02	1.04	1.14	1.11	0.93
02-03	1.14	1.13	0.94	0.90
Average	1.07	1.06	1.00	0.90

Next to this, also the qualitative characteristics from comparison group 1 were compared with the research group. To examine this, next equation is used:

$$\frac{number\ of\ locations\ in\ research\ group\ with\ a\ certain\ characteristic / total\ number\ of\ locations\ in\ research\ group}{number\ of\ locations\ in\ comparison\ group\ with\ a\ certain\ characteristic / total\ number\ of\ locations\ in\ comparison\ group} \quad [2]$$

Here the localization outside/inside urban area was compared and the type of intersection during before period (priority controlled or traffic lights). Also the legally imposed speed limit, presence of median and number of lanes on the main road and secondary road of the intersection was analyzed. No strong differences were found. Only intersections with a speed limit of 90km/h on the main road were significantly more present in the research group compared to the comparison group (p=0.041). Also the number of intersections with a median at the main road were slightly over represented in the research group (p=0.031).

METHOD

Analysis per Location

Control for Regression to the Mean

To control for RTM Hauer et al. *(9)* give next equation:

$$L_{RTM,before} = w * (\mu_{C,before} * km_L * T_{before}) + (1\text{-}w)(\textstyle\sum_{t=1}^{tbefore} L_t) \quad [3]$$

With:

$L_{RTM,before}$= estimated number of crashes during the before-period in location L after correction for regression to the mean

w= the importance of the comparison group

$\mu_{C,before}$= average number of crashes per year in the comparison group during the before period

km_L= length of location L in km (intersections get a length of 1km)

T_{before}= length of period before the measure

L_t= number of crashes at location L in year t

1-w= the importance of location L

To calculate the average number of crashes in the comparison group (μ_C), two possibilities can be chosen: a comparison group that consist of comparable locations or a model that estimates the crash rates, based on the characteristics of comparable locations. In this study a model is used, which is also based on the Flemish black spot dataset *(10)*. The dependent value of the model was the number of crashes, based on crash rates of 2000-2003. This period is located after the selection of the black spots, for which crash rates from 1997-1999 were taken into account, and through which the effect of RTM is excluded. Furthermore this period is located before measures were implemented, as the first locations were adapted in 2004. The model estimates the number of injury crashes and severe crashes through traffic volumes at major and minor roads of the intersection:

$$E_{injury}(\lambda) = e^{-1.7131}\, Q_{Maj}^{0.3231} Q_{Min}^{0.2463} \quad [4]$$

$$E_{severe}(\lambda) = e^{-3.2138} Q_{Maj}^{0.3327} Q_{Min}^{0.2009} \quad [5]$$

Where

$E(\lambda)$ = expected annual number of crashes (dependent variable), with E_{injury} are all crashes with injured, and E_{severe} are all crashes with severe injuries and fatalities

Q_{maj} = traffic volume of major road

Q_{min} = traffic volume of minor road

More information concerning the measurements on which this model is based, can be found in De Ceunynck et al. *(10).*

The weight (w) can be calculated through next equation:

$$w = \frac{1}{1 + (\mu_{C,before} * T)/k_{before}} \quad [6]$$

With k is an over dispersion parameter per unit of length *(11, 12)*, which is also calculated through the model.

Control for Crash Trend

To control for trend effects, the crash rates from the before and after period in the comparison group are taken into account. For this research two comparison groups were used. At first, black spots adapted after the study period, secondly all injury crashes in Flanders are included.

The control for crash trend can be expressed through an odds ratio:

$$Eff = \frac{L_{after}/L_{before,RTM}}{C_{after}/C_{before}} \quad [7]$$

L_{after}= number of crashes on location L during the after period

$L_{before,\ RTM}$= number of crashes on location L during the before period, after correction for regression to the mean

C_{after}= number of crashes in the comparison group during the after period

C_{before}= number of crashes in the comparison group during the before period

With a 99% confidence interval (CI):

EFF, below limit = exp[ln(EFF) – 2.58 * s]

EFF, above limit = exp [ln(EFF) + 2.58 * s] [8]

And a standard deviation (s) as the root of the variance (s^2):

$$s_L^2 = \frac{1}{L_{after}} + \frac{1}{L_{before,RTM}} + \frac{1}{C_{after}} + \frac{1}{C_{before}} \quad [9]$$

Control for Zero Counts in the After Period

When one of the factors in formula [7] becomes zero, the calculation of the variance (formula [9]) becomes impossible. Also the calculation of the index of effectiveness (formula [7]) is impossible when the denominator equals zero. Elvik *(13)* described these zero counts as a problem for three reasons. He stated it is highly implausible that the true long-term mean number of accidents at any location is zero. Secondly zero counts suggest that a safety treatment could be either a hundred percent crash reduction (if there was a positive count before and a zero count after) or an infinite increase in the number of crashes (if there was a zero count before and a positive count after), both of which are highly implausible. Thirdly, zero counts have to be adjusted when in a meta-analysis a statistical weight is to be assigned to each result. To solve this problem, a model for the after period was calculated, also based on the volume data on the major and minor road. The analyses for injury crashes leaded to next equation:

$$E_{injury}(\lambda) = e^{-6,1395} Q_{Maj}^{0.55} Q_{Min}^{0.345} \quad [10]$$

However for the severe crashes the model was not significant. Therefore an EB-estimate is applied like proposed by Elvik *(13)*. To control the RTM of the severe crashes in the after period, the mean number of crashes from the comparison group (μ_c) from formula [3] is replaced by the mean number of crashes from the after period in the research group:

$$L_{RTM,t,after} = w * \lambda_{after} + (1-w)(\textstyle\sum_{t=1}^{Tafter} L_t) \quad [11]$$

With:
λ_{after}= mean number of crashes at the research location during the after period
T_{after}= length of period after the measure
L_t= number of crashes at location L in year t
w= $\frac{1}{1+\ \lambda_{after}/\ k_{after}}$

And k_{after}=k_{before}*($k_{L,after}$/$k_{L,\ before}$) [12]

With
k_{after}= adjusted value of the over-dispersion parameter for the after period
k_{before}= k-factor for the before period, calculated from the accident prediction model
$k_{L,after}$= k-factor for the after period for the sample of treated intersections, calculated through inverse value of equation [13]
$k_{L,\ before}$= k-factor for the before period for the sample of treated intersections, calculated through inverse value of equation [13]

over dispersion parameter= $\frac{\frac{Var\,(x)}{\lambda}-1}{\lambda}$ [13]
With
var (x)= variance of crash rates (from the after period when $k_{L,after}$ is calculated; from the before period when $k_{L,\ before}$ is calculate) of the research locations
λ = mean number of crashes (from the after period when $k_{L,after}$ is calculated; from the before period when $k_{L,\ before}$ is calculate) of the research locations

Through this calculation not only the zero accidents from the after period are removed, but also the chance effect of the occurrence of crashes is controlled.

Meta-Analysis
Next to the individual evaluation per location, the total effect across different locations can be calculated, which results in more statistical reliable results *(14)*. Every location within the meta-analysis gets a weight, which is the inverted value of the variance. Subsequently locations at which many crashes occurred, are given a higher weight.
w_l= $\frac{1}{s_l^2}$ [14]
Supposing that the measure is executed at n different places, the weighted mean index of effectiveness of the measure over all places is:
Overall index of effectiveness = $\exp\left[\frac{\sum_{l=1}^{n} w_l * \ln\,(EFFl)}{\sum_{l=1}^{n} w_l}\right]$ [15]

The estimation of a 99% confidence interval is
99% CI =$\exp\left[\frac{\sum_{l=1}^{n} wl * \ln\,(EFFl)}{\sum_{l=1}^{n} wl} \pm 2.58 * \frac{1}{\sqrt{\sum_{l=1}^{n} wl}}\right]$ [16]

Comparative Analysis According to Characteristics
Through formula [15] different locations with similar characteristics can be taken together to count the overall effect. However, it cannot be said whether some structural variation in the effectiveness exists according to some characteristics of the locations. Therefore an ANOVA(Analysis of variance)-analysis in SPSS is used, in order to determine whether significant differences between the means of two or more groups of intersections exist, for example the comparison of the index of effectiveness of locations inside and outside the built-up area. Three conditions must be fulfilled before the ANOVA-test can be applied. At first all groups need to have a normal distribution. As this is not always the case, the logarithms functions of the obtained odds ratios are used. Secondly, all groups need to include at least five observations. A third condition is that the dispersion of groups is sufficiently equal. To control for this, the 'Levene's Test for equality of variance' is used. When this test is significant, the dispersion is not sufficiently equal and a non-parametric test can be applied. When this test also shows no sufficient equal dispersion, the results cannot be interpreted.

RESULTS

A meta-analysis of the 134 black spots, using comparison group 1 (black spots adapted after 2008) to control for trend, found a decrease in the number of crashes of 24%, which was significant at the 1% level. When comparison group 2 (the total number of crashes in Flanders) is used to control for the trend, a decrease of 27% was found, also significant at the 1% level. Concerning the most serious crashes, consisting of crashes with fatal or serious injuries, also significant decreases at the 1% level were found. This decrease amounted 40%, using comparison group 1 and 52%, using comparison group 2.

Table 2: Results (Index of Effectiveness, [99% BI]) for the Analyses of the 134 Black Spots

	Injury crashes	Severe crashes
Comparison group 1 (black spots adapted after 2008)	0.76 [0.66; 0.87]	0.60 [0.40; 0.91]
Comparison group 2 (all injury crashes in Flanders)	0.73 [0.64; 0.84]	0.48 [0.32; 0.72]

Additional to the overall effect, it was also examined whether the effectiveness on injury crashes differed according to the type of treatment, characteristics of the location (localization inside/ outside urban area, priority score (which indicates number and severity of injured during 1997-1999), number of legs) and characteristics of the main and secondary roads of the intersection (number of lanes, presence of median, maximum speed limit, traffic volume). The road with the highest road category was selected as main road. When plural roads had the same road category, the roads were ordered according to the traffic volume. The results of those analyses are shown in table 3. An almost significant difference was found between locations according to the situation before the treatment (F=2.997; df=1; p=0.086). Priority controlled intersections showed a higher decrease in the number of crashes (33%), compared to spots with traffic lights (21%). Next to this a significant difference was found according to the traffic volume at the main road of the intersections (F=6.650; df=3; p<0.001). Locations with a lower volume showed a higher decrease compared to locations with a higher volume. Locations with a traffic volume up to 1900 vehicles per hour showed a decrease of 37% in the number of injury crashes, which was significantly (p=0.024) higher compared to locations with a volume of 1900-2700 vehicles per hour, which showed a decrease of 24%. Locations with a volume up to 1900 vehicles were also significantly (p=0.001) more effective compared to locations with the highest volume (4000 or more vehicles per hour), that showed a non-significant decrease of 14% in the number of crashes. Furthermore a significant difference was found according to the type of treatment. However, the variances between the different groups were not sufficiently equal, and also the non-parametric test showed a nearly significant result, which has the consequence the results could not be interpreted. As can be seen from table 3, no other significant results could be found.

Independently of the fact that variances were not sufficiently equal, it is interesting to take a further look at the results of the different treatment types. As a comparison of the effects according to the situation before the adaptation already showed, the highest effects are found for locations that were priority controlled during the before period. The highest decrease (42%) in crash rates is found for locations that were priority controlled, and got a better lay-out of the intersection. Secondly the installation of traffic lights at locations that were priority controlled showed a significant decrease of 35%. Thirdly conversions from traffic lights to roundabouts showed a decrease of 28%. This result was however not significant, which is attributable to the low number of locations. Next to this the conversion of traffic lights into conflict free lay-out showed a significant decrease of 22%. Finally conversions of priority controlled locations to roundabouts showed a decrease of 13% and adaptation of the lay-out of traffic lights regulated intersections showed a decrease of 11%, both results were however not significant.

TABLE 3 Results (F-value, Df, p-value) of the Comparison of Characteristics of the Intersection, Through an ANOVA-Analysis, and the Results of the Meta-Analysis (Index of Effectiveness [95%CI])

Characteristic	F-value	Df	p	Categories	Nr. of locations	Index of effectiveness [95% CI]
Inside /outside urban area	0.298	1	0.586	Inside	37	0.81 [0.66; 0.98]*
				Outside	86	0.71 [0.63; 0.81]*
Priority factor	1.904	3	0.132	15-20	29	0.80 [0.63; 1.02]
				21-23	28	0.89 [0.69; 1.15]
				24-32	42	0.69 [0.57; 0.84]*
				≥33	35	0.73 [0.62; 0.88]*
Number of legs	0.475	2	0.623	4 legs	96	0.76 [0.68; 0.85]*
				4 legs diagonal	14	0.72 [0.49; 1.06]
				3 legs	15	0.81 [0.52; 1.28]
Type of intersection before period	2.997	1	0.086	Priority controlled	55	0.67 [0.55; 0.82]*
				Traffic lights	74	0.79 [0.70; 0.90]*
Type of conversion	2.418	5	0.04°	Traffic lights → roundabout	5	0.72 [0.38;1.36]
				→ conflict free lights	53	0.78 [0.67; 0.89]*
				→ traffic lights	15	0.89 [0.66; 1.19]
				Priority controlled		
				→ roundabout	8	0.87 [0.49; 1.57]
				→priority controlled	26	0.58 [0.42; 0.80]*
				→ traffic lights	9	0.65 [0.43; 0.99]*
Number of lanes						
Main road	1.469	1	0.228	2	68	0. 71 [0.60; 0.85]*
				4	64	0.79 [0.69; 0.90]*
Secondary road	0.993	2	0.373	1	12	0.78 [0.52; 1.18]
				2	109	0.75 [0.67; 0.84]*
				4	11	0.80 [0.59; 1.09]
Presence of median						
Primary road	0.102	1	0.75	No	67	0.78 [0.65; 0.92]*
				Present	67	0.75 [0.66; 0.85]*
Secondary road	0.282	1	0.596	No	112	0.75 [0.67; 0.84]*
				Present	21	0.79 [0.63; 1.00]
Maximum speed limit						
Primary road	0.905	2	0.407	50	29	0.79 [0.63; 0.98]*
				70	39	0.73 [0.60; 0.89]*
				90	62	0.77 [0.66; 0.89]*

Secondary road	1.38	2	0.256	50	51	0.74 [0.62; 0.87]*
				70	36	0.74 [0.62; 0.89]*
				90	36	0.83 [0.67; 1.04]
Traffic volume						
Primary roads	6.65	3	<0.001	0-1899	32	0.63 [0.47; 0.82]*
				1900 - 2699	34	0.76 [0.60; 0.95]*
				2700 -3999	34	0.71 [0.58; 0.86]*
				≥4000	34	0.86 [0.73; 1.03]
Secondary roads	0.977	3	0.406	0-339	33	0.64 [0.47; 0.86]*
				340-899	34	0.73 [0.58; 0.92]*
				900-1599	35	0.75 [0.62; 0.90]*
				≥1600	32	0.83 [0.70; 0.99]*

* significant at the 95% confidence interval
° Almost significant, but variance not sufficiently equal. Non parametric test (Kruskall-Wallis) also showed an almost significant result: chi²:13,911; df:8; p=0,084

Next to the crash rates, also analyses on the level of casualties were executed, to make a differential effect according to type of road user possible. The following road user categories were included: car occupants, moped rider, cyclist, motorcyclist, pedestrian and truck driver. Also here a before-and-after comparison was executed, with control for trend effects through application of the black spot comparison group. As the relative differences from the before to after period in columns 3 and 6 of table 4 show, a higher decrease in the research group compared to the comparison group was found for every road user. This is confirmed by the relative change, which is the odds ratio of the change in crashes from the before to after period in the research group with the change in crashes from the before to after period in the comparison group. As column 7 shows, all of these results are smaller than one, which indicate the decrease in the research group is higher compared to the comparison group. From this can be concluded that the adaptation of the black spots generated a favorable effect on each of the road user categories.

TABLE 4 Mean number of Injured per Year per Location, Before and After the Adaptation of the Infrastructure, Subdivided to Type of Road User

	Column 1	*Column 2*	*Column 3*	*Column 4*	*Column 5*	*Column 6*	*Column 7*
	Mean number of injured road users per year per black spot						**Relative change**
Type of road user	**Research group**			**Comparison group (black spots treated after 2008)**			
	before	*after*	*% difference*	*before*	*after*	*% difference*	
Car occupants	2.19	1.07	-50.90	1.95	1.59	-18.55	**0.60**
Moped riders	0.30	0.19	-36.43	0.40	0.29	-26.71	**0.87**
Cyclists	0.41	0.29	-29.59	0.45	0.45	+2.16	**0.69**
Motorcyclists	0.16	0.10	-39.55	0.15	0.13	-10.64	**0.68**
Pedestrians	0.07	0.05	-27.20	0.09	0.08	-18.44	**0.89**
Truck drivers	0.05	0.01	-77.63	0.05	0.04	-21.33	**0.28**

DISCUSSION

The overall analyses showed a significant decrease both for the injury crashes, as for the severe crashes. For the injury crashes a decrease of 24 to 27% was found, for the severe crashes 40 to 52%. These are significant and meaningful results, that can fully be ascribed to the adaptation of the black spots. Furthermore it can be concluded that the decrease in the number of severe crashes is significantly stronger compared to the decrease in the number of all injury crashes. A paired sample t-test (SPSS18) showed that both for the analyses that used the black spot comparison group (t=-2.581; df=133; p=0.007), as for the analyses that used the crash rates in Flanders, (t=-5.605; df=133; p<0.001) a statistical significant difference was found. Next to the crash level, also a favorable effect was found on casualty level for each of the road users (car occupants, moped rider, cyclist, motorcyclist, pedestrian and truck driver).

A comparison of the effectiveness based on the characteristics of the locations indicated an almost significant difference between locations according to the situation before the treatment of the spot. Priority controlled locations showed a higher decrease compared to locations with traffic signals. A possible explanation is that priority controlled intersections can undergo different adaptations in order to control traffic flows: for example the installation of traffic lights or the conversion to a roundabout. Such measures can be expected to have a strong effect on traffic safety. As intersections with traffic lights are already highly controlled, possible changes are limited, and will subsequently be less effective. Though no significant differences were found according the type of conversion and no specific type of measure could be indicated as more effective.

Furthermore a significant difference was found according to the traffic volume at the main road of the intersection. Locations with the lowest traffic volume showed a stronger decrease compared to locations with a higher volume. This result can be explained by the selection procedure of the black spots, which is based on the number and severity of crashes. Existing literature showed traffic volume is the most influencing structural variable for the number of crashes at a certain location *(15)*. As traffic volumes were not taken into account during this selection, an actual chance exist that locations with a high volume were selected because of the high crash rates as a result of this high intensity. For the intersections with a high crash count but with a lower volume, probably other structural factors could have had an effect, which could be handled more easily through infrastructural measures.

A possible disadvantage from the comparison group that consisted of all crashes in Flanders in order to control for the trend, is that also the crashes that occurred at the research locations were included. This could lead to an underestimation of the effect, as the effect of the adaptation of the black spots is included in the general trend. However the research locations included on average only 1.1% of all crashes in Flanders. Furthermore the results of the analyses of comparison group 2 were in line with the results of the analyses with comparison group 1 (non-adapted black spots), and were even higher.

The results of the analyses showed the adaptation of the 134 black spots had a positive effect on traffic safety. However the research group only encompassed 134 of the 809 black spots, from which can be questioned whether these results can be generalized to all black spots in Flanders. Those 134 black spots are not comparable with the 160 spots, where only small adaptations were executed. Concerning the other 649 black spots, the research group was not randomly selected. The selection was more or less based on the year the black spot was treated, from which the spots adapted before 2008 were selected. When a certain pattern was handled in the order of treatment, the 134 black spots could be different from the other 515 locations. However, an analysis of the comparability of the research group and the comparison group that consist of black spots adapted after 2008, showed no structural differences between both groups. From this can be concluded that the results of the present paper is a good estimation of the total black spot program in Flanders. Nevertheless, a new evaluation when the entire program will be finished could give extra information, as a lot more locations would be included. More extensive analyses, for example according to the nature of the implemented design, could be possible.

CONCLUSIONS

(1) As a result of the adaptation of the black spots, a significant decrease in the number of crashes, both for all injury crashes, as for the severe crashes was found. This decrease was higher for the severe crashes (40-52%) compared to all injury crashes (24-27%). From the present paper it can be concluded that the adaptation of black spots not only has a significant, but also a substantial effect on traffic safety.

(2) Priority-controlled spots were more effective compared to intersections with traffic signals. Furthermore the effect was stronger on locations with a lower traffic volume compared to a higher volume.

(3) On the level of casualties, a significant decrease was found for every road user category.

ACKNOWLEDGEMENTS

This research was carried out within the framework of the Policy Research Centre on Mobility and Public Works - track traffic safety and was partly supported by a grant from the Research Foundation Flanders. The content of this paper is the sole responsibility of the authors.

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