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Safety effects of restricting the speed limit from 90 to 70 km/h

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ABSTRACT
Speed is a main risk factor in traffic safety, which increases both the chance and the severity of the crash. In order to work to a better traffic safety through influencing the travel speeds, road authorities may decide to lower the legally imposed speed limits. In 2001 the Flemish government decided to lower speed limits from 90 to 70 km/h at a considerable number of highways. Current study examines the effectiveness of this measure, through the application of a comparison group before-after study to account for general trend effects in road safety. Sixty-one road sections with a total length of 116 km were included. Those locations knew a restriction of the speed limit in 2001/2002. The comparison group consisted of 19 road sections with a total length of 53 km and an unchanged speed limit of 90 km/h during the total research period. Taking trend into account, the analyses showed a 5% decrease [0.88; 1.03] in the crash rates after the speed limit restriction. A stronger effect was found for the crashes with serious injuries and fatalities, which showed a decrease of 33% [0.57; 0.79]. Separate analyses between crashes at intersections and at road sections showed a higher effectiveness at road sections. From this study can be concluded speed limit restrictions do have a favorable effect on traffic safety, especially on the severe crashes. Future research should examine the cause for the difference that was found in the effect between road sections and intersections, taking vehicle speeds into account.

Keywords: before-after evaluation; crashes; speed limit reduction; traffic safety

1. Introduction

Speed is defined as an important risk factor in traffic safety (Elvik, et al., 2009). Although crashes are caused by different factors and the contribution of speed is difficult to examine (Nilsson, 2004), higher speeds proved to increase the likelihood to get involved in a crash. Different causes can contribute to this relationship. One of them is that drivers have less time to pick up information and react, which consequently leads to a lower chance to avoid a crash. At the same time the distance that is covered until the car stops extensively prolongs. Not only the chance to get involved in a crash increases, but also the severity of the crash raises with speed, since the degree of kinetic energy at the moment of the collision is higher (OECD, 2006). In order to favorably influence the traffic safety, the Flemish government decided in 2001 to lower the speed limits from 90 to 70 km/h at a large number of highways, based on four main criteria, from which at least one had to be fulfilled. Those criteria were: road sections without cycle paths or with cycle lanes close to the roadway; road sections with obstacles close to the roadways with a high risk of collision; road sections outside urban areas but with a high building density, and a high number of vulnerable road users; and road sections on which several severe crashes occurred in the past (Juvyns, pers. comm.). The speed limit was often only restricted at specific sections of roads, for example sections between two intersections or sections between two parts of urban environment. For the majority of the locations, the speed limit restriction was introduced in 2001-2002. No enforcement and educational efforts were combined with this change, only traffic signs were adapted.

2. Background

Analysis of previous studies that examined the traffic safety effects of speed limit restriction, generally showed a favorable effect on traffic safety. However, also no effects, or even increases in crash rates were found. A review of eight studies (Stuster, Coffman, & Warren, 1998) that examined the effect of lowering speed limits in six different countries, found a significant decrease in crash rates in six studies, that ranged from 9 to 19% for the injury crashes and 12 to 24% for the more severe crashes. The two other studies found no significant change. A meta-analysis of Elvik and Vaa (2004), who examined the effect of speed limit restrictions from 80-90 to 60-70 km/h found a decrease of 23% for all injury crashes and 43% for the fatal crashes. They also analyzed studies that examined the effect of the restriction from 60-70 to 50-60 km/h. In this meta-analysis they found a decrease in crash rates of 9 and 23% for respectively all injury crashes and fatal crashes. Overall, taking different studies with a variable before- and after legally imposed speed limit into account, they found a decrease in the number of injury crashes of 14%, and a decrease of 15% in the number of fatal crashes. A Norwegian study, applying the empirical Bayes method (Ragnøy, 2005), examined 631270 km of roads that knew a speed limit restriction from 80 to 70 km/h and 271049 km roads that had a restriction from 90 to 80 km/h. The study found a significant decrease of 15.5% in the number of crashes at road sections where speed was restricted from 80 to 70 km/h. However, lowering the speed limit from 90 to 80 km/h appeared to have an increasing effect on crashes, which was estimated at 49.8%. A study in Australia examined the effects of changing speed limits from 100 to 80 km/h at arterial roads. This resulted in a significant decrease of 46% in the number of injury crashes. On the contrary, restricting the speed limit from 75 to 60 km/h brought about a nearly statistically significant casualty crash frequency increase of 43% (Newstead & Narayan, 1998). According to the authors this was due to an increasing variance in travel speeds, as some drivers did not adapted their speed behavior to the new speed limit, whereas others did. It is however difficult to compare the results of these different studies, as the circumstances of for example road and environmental type, and range of speed limit decrease largely differ along the studies. Furthermore, the application of different methods to analyze the traffic safety effect, can also lead to different results.

McCarthy (1998) profoundly examined the relationship between speed limits and traffic safety. He showed a lot of factors can mediate the effect of speed limits on traffic safety, of which especially the speed choice of the driver is important. This choice on its turn is influenced by different elements, such as socio-economic factors, personal risk perception and the extent of enforcement. Next to this, also road conditions and the vehicle have an effect. When a speed limit is not in accordance to the road conditions, this limit will not or hardly being kept. Furthermore, the relation between changes in speed and the occurrence of crashes is often given as a power function. The exponent differs according to the crash severity. For example Nilsson (2004) noted an exponent of 2 for all injury crashes, 3 for crashes with serious injuries and fatalities and 4 for fatal crashes. Elvik (2004) only uses mutually exclusive categories, and found for injury crashes an exponent of 2, for serious injury crashes a power of 2.4 and for fatal crashes 3.6.

3. Data

All road sections that knew a speed limit restriction from 90 to 70 km/h during 2001-2002 located in the province of Limburg, one of the five provinces in Flanders, Belgium, were included in the research group. Only road sections on which other measures were performed during the research period that could have had an effect on travel speeds or traffic safety, were excluded. Therefore local authorities were asked to report whether next to the speed limit decrease, other measures were implemented during the research period. This were for example changes in traffic regulations such as the right-of-way rules and changes in infrastructure, such as narrowing or broadening roads. Locations that only had some small changes in infrastructure, such as repair and maintenance works, were not excluded. Eventually 61 road sections were included with a total length of 116 km, located in 16 different municipalities in the province of Limburg. The length of the sections ranged from 0.1 to 6.04 km. For most of the road sections a speed limit restriction was applied in 2002, 13 had an adaptation in 2001. The comparison group consisted of 19 sections, with a total length of 53 km. Also the comparison locations were all located in the province of Limburg. As can be seen from table 1, most of the road sections (80%) are situated at local roads, 15% are secondary roads, that connect, collect and distribute at local and intercity level, 5% are primary roads whose function is connection, collection and distribution at the Flemish level. The majority of the road sections are situated outside the urban area (72%), and have 2x1 lanes (92%). Examples of roads that were adapted are shown in figure 1.

Table 1
Main characteristics of the research and comparison locations (Agency of Roads and Traffic, Ministry of Mobility and Public Works)

	Research group	**Comparison group**
	Number of locations (%)	
Road category:		
- Primary	3 (5%)	1 (5%)
- Secondary	9 (15%)	5 (26%)
- Local	49 (80%)	13 (68%)
Urban area		
- Inside	17 (28%)	2 (10%)
- Outside	44 (72%)	17 (90%)
Number of lanes		
- 2x1	56 (92%)	16 (84%)
- 2x2	4 (7%)	0 (0%)
- 3x1	1 (2%)	3 (16%)

Fig.1 Examples of roads at which the speed limit was restricted from 90 to 70km/h (Source: Google Street View)

At the moment of the study, crash data for Belgium were available until 2009 (Federal Public Service Economy, department Statistics). However, in order to select the crashes at the research locations, geo-coded crash data were necessary. These were available from 1996 until 2007 (Ministry of Mobility and Public Works, Agency of Roads and Traffic). Subsequently the before-period starts from 1996 to 2000/2001, the after period from 2002/2003 to 2007. The year during which the speed limit was adapted, 2001 or 2002, was excluded from the research period. According to the severity of crashes, two groups of crashes were handled. First injury crashes, which include all crashes with at least a slightly injured person. Secondly the more severe crashes, which include crashes with seriously injured (defined as every person that got involved in a traffic crash and needed a hospitalization of more than 24 hours) and deadly injured (every person that as a consequence of a traffic crash died on the spot, or within 30 days after the crash). Crashes with property-damage only were not included since these are not systematically gathered. To select the crashes, the spatial analysis program ArcGIS, version 9.3 was used. A buffer of 10 meter was applied to make sure all crashes at the selected locations were included. Furthermore a distinction was made according to the location of the crash, with a distinction between road section and intersection. At the research locations on average 322 injury crashes per year occurred. Fifty-five percent took place at intersections, 45% at road sections. The comparison group consisted of 64 injury crashes per year, with an occurrence of 44% at intersections. For more severe crashes, on average 74 crashes per year for the research group were selected, with a proportion of 48% at intersections. The comparison group consisted of on averagely 21 severe crashes, with 37% that occurred at intersections. A first view is given by figure 1, which shows the mean crash rates per km, both for all injury crashes and the more severe crashes in the research and comparison group. For all groups a decrease can be observed, which especially for the severe crashes is stronger in the research group compared to the comparison group.

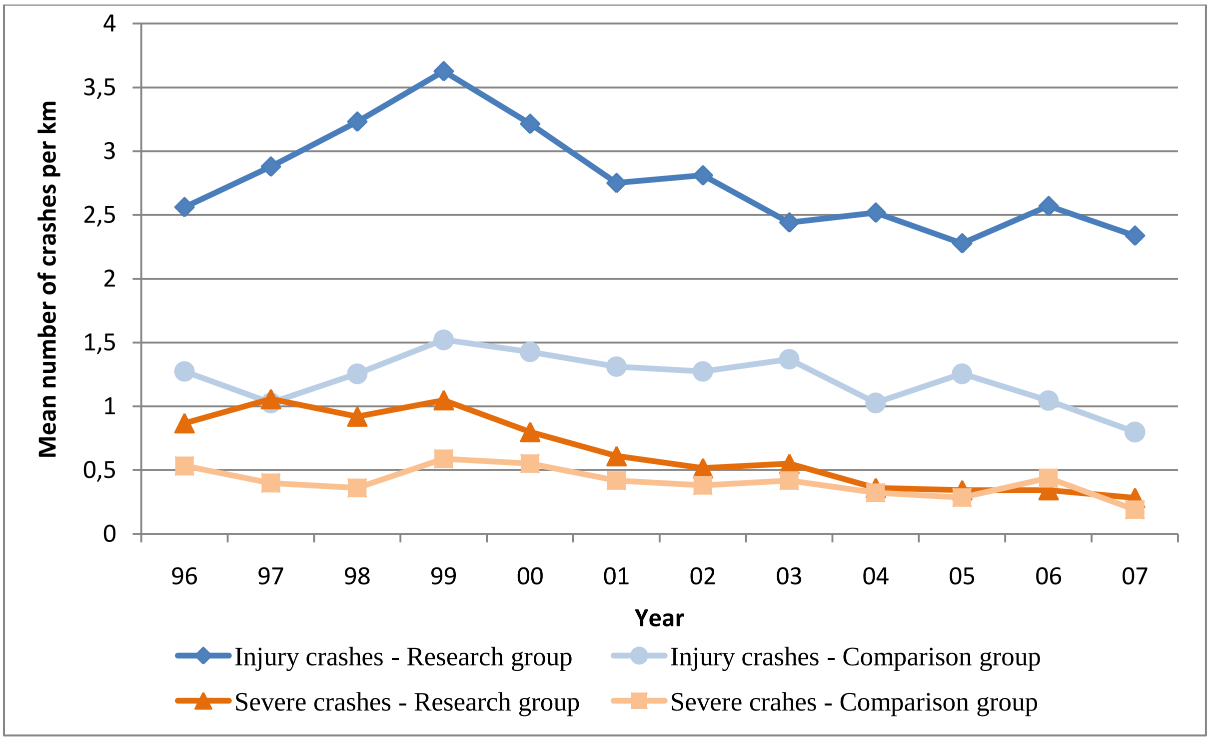

Fig. 1. Mean crash rates per km in research and comparison group from 1996 to 2007, both for injury crashes and more severe crashes

4. Study design

4.1 Before-After Study

To evaluate the effectiveness of a traffic safety measure, the most commonly used study design is a before-after (B&A) study (Elvik, 2002; Shinar, 2007), which compares the number of crashes after the implementation of a measure with the number of crashes at the same location before the implementation. Within those B&A studies, different methods can be used, which mainly differ in the extent they control for confounding variables. A confounding variable is defined as any exogenous variable affecting the number of crashes or injuries whose effects, if not estimated, can be mixed up with the measure under evaluation (Elvik, 2002). A first group of B&A

studies are the simple B&A methods, which compare the crash rates after the measure with before, without control for any confounding variable. A second group are the B&A methods that control for trend effects. As before to after the measure different elements are changed that could have had an autonomous effect on the occurrence of crashes, it is important to take those effects into account. These elements are for example traffic safety campaigns, stronger enforcement, adaptations of infrastructure, changes in traffic volume, etc. The trend effect can be controlled through the application of a comparison group. A third group are the Bayesian methods, of which one is the empirical Bayes (EB) method. Preference is given to this EB method as it controls for the most important confounding factors (Elvik, 2002; Hauer, 1997), such as common trend, effects of chance and the regression to the mean (RTM) phenomenon.

4.2 Comparability of the comparison group

The comparison group has an important role in B&A studies, as it is applied to count for trend and often also for RTM. The locations in the comparison group have to be similar to the research group on a couple of characteristics, that is for example geometric design, traffic volumes and vehicle fleet (Persaud & Lyon, 2007). The comparability of the comparison group can be examined through the calculation of the odds-ratio (OR) for the crash rates during the years before the measure.

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

R_t= number of crashes in the research group in year t
R_{t-1}= number of crashes in the research group in year t-1
C_t= number of crashes in the comparison group in year t
C_{t-1}= number of crashes in the comparison group in year t-1
When the OR is near to 1, the comparison group is comparable to the research locations. Maximum standard deviation should not be higher than 0.20. The ORs are calculated for the total comparison group for the years before the speed limit restriction. The results of these calculations are shown in table 2. The odds ratios for the injury crashes show that the comparison group is comparable to the research group. A subdivision between crashes that occurred at intersections and at road sections, shows a slightly better comparability for crashes that occurred at intersections compared to road sections. The ORs for fatal and serious injury crashes are less comparable, with an OR more different from 1, and standard deviations that exceed 0.20. This can be explained by the low number of crashes, where small fluctuations result in higher relative changes.

Table 2
Odds ratios (OR) and standard deviations (s) for injury and more severe crashes for all years before the implementation of the measure

	Injury crashes		
	Total OR (s)	**Intersections OR (s)**	**Road sections OR (s)**
96-97	1.39 (0.20)	0.95 (0.28)	2.05 (0.29)
97-98	0.92 (0.20)	1.00 (0.27)	0.84 (0.29)
98-99	0.93 (0.18)	0.94 (0.25)	0.90 (0.26)
99-00	0.95 (0.18)	1.25 (0.26)	0.76 (0.24)
Average	1.05 (0.19)	1.03 (0.27)	1.14 (0.27)
	Fatal and serious injury crashes		
	Total OR (s)	**Intersections OR (s)**	**Road sections OR (s)**
96-97	1.62 (0.32)	1.07 (0.51)	2.23 (0.42)
97-98	0.96 (0.34)	0.75 (0.49)	1.23 (0.49)
98-99	0.70 (0.32)	0.85 (0.44)	0.56 (0.47)
99-00	0.81 (0.29)	1.15 (0.45)	0.64 (0.39)
Average	1.02 (0.32)	0.96 (0.47)	1.16 (0.45)

Also the qualitative characteristics, as shown in table 1 can be compared. Therefore a comparison is made for the classification and urbanization of roads. To examine this, next equation is used:

$$\frac{\text{length of roads in research group with a certain characteristic} \Big/ \text{total length of roads in research group}}{\text{length of roads in comparison group with a certain characteristic} \Big/ \text{total length of roads in comparison group}} \quad [2]$$

Five equations were calculated: three for the functional classification of roads (local, secondary and primary), and two for the level of urbanization (inside or outside built-up areas). In order to analyze whether differences are significant, the Fisher's Exact Test is calculated. The comparison group is more or less comparable with the research group for local roads (1.12; p=0.6707); secondary roads (0.83; p=0.2619) are slightly underrepresented in the research group, in common with primary roads (0.74; p=0.4262). Roads outside urban areas are comparable (0,92; p=0.1708), roads inside urban areas are overrepresented in the research group (1.50; p=0.3579). However none of these differences were significant. Regarding the results of those analyses and the calculated odds ratios, we consider the comparison group to be acceptable.

However, next to these analyses, the absolute crash rates from the research and comparison group need some specific attention. As from figure 1 can be seen, the crash rates at the research locations are systematically higher than those at the comparison locations, both for the period before and after the measure. This is an important remark, which has consequences for the evaluation method. Preference goes to the EB method, as this controls for RTM and trend effects. However, because of this discrepancy in crash rates between the research and comparison group, it was not possible to use the EB method. This method controls for RTM through the estimation of the number of crashes that would have occurred before, instead of using the recorded number before. This estimation is based on statistical analyses, using a comparison group or on some available crash prediction model. In this study the comparison group encompasses much lower crash rates compared to the research group. Figure 1 shows considerable differences between the mean numbers of crashes in the research group and the comparison group throughout the full period 1996-2000. These differences seem to be rather structural as the speed limit reduction was only introduced starting from 2001. Consequently, an EB estimation of crash rates in the period before implementation of the measure, based on this comparison group, would result in a biased (in the present case: an unreasonably low) estimated number of crashes compared to the recorded crash rates. Selecting another comparison group was not possible, as no other locations within the province of Limburg with an unchanged speed limit of 90km/h were present and no information from locations elsewhere could be obtained. Consequently no attempt to correct for possible RTM-bias could be done and the evaluation was continued as a B&A study with comparison group to account for trend effects.

5. Method

5.1 Evaluation per location

The effectiveness of lowering the speed limit is first calculated per location, and can be expressed in an index of effectiveness (Eff) (Hauer, 1997), which shows the relative change in the crash rates from before to after. When the index is lower than 1, this shows that the crashes decreased and the measure had a favorable effect on traffic safety. An index higher than 1 indicates a higher crash rate after the implementation of the measure compared to before. The equation has to be adapted for trend effects. Therefore it is being assumed that the research locations followed the same trend than the comparison group. This trend is reflected by the evolution of the crash rates from before to after in the comparison group. Consequently, the effect estimate can be expressed as:

$$\text{Eff} = \frac{L_{after}}{L_{before} * \frac{C_{after}}{C_{before}}} = \frac{L_{after} / L_{before}}{C_{after} / C_{before}} \quad [3]$$

L_{after}= number of crashes on location L after the measure
L_{before}= number of crashes on location L before the measure
C_{after}= number of crashes in the comparison group after the measure
C_{before}= number of crashes in the comparison group before the measure

The reliability of this estimate is assessed by the 95% confidence interval (CI):
95% CI, lower limit = exp[ln(eff) – 1.96 * s]
95% CI, upper limit = exp [ln(eff) + 1.96 * s] [4]

With the variance (s) is the root of the standard deviation (s²)

$$s^2 = \frac{1}{L_{after}} + \frac{1}{L_{before}} + \frac{1}{C_{after}} + \frac{1}{C_{before}} \qquad [5]$$

5.2 Effectiveness across different locations

Next to an individual analysis per location, a meta-analysis can be executed (Fleiss, 1981), which calculates the overall effect of all locations with an adapted speed limit. To count the overall effect, every location gets an importance, which is inversely proportional to the variance:

$$w_l = \frac{1}{Sl^2} \qquad [6]$$

Suppose that the measure was implemented at m different locations, the weighted mean index of effectiveness of the measure over all locations (EFF) is:

$$\text{EFF} = \exp\left[\frac{\sum_{l=1}^{m} w_l * \ln(effl)}{\sum_{l=1}^{m} w_l}\right] \qquad [7]$$

The estimation of a 95% confidence interval is

$$95\%\ \text{CI EFF} = \exp\left[\frac{\sum_{l=1}^{m} wl * \ln(effl)}{\sum_{l=1}^{m} wl} \pm 1.96 * \frac{1}{\sqrt{\sum_{l=1}^{m} wl}}\right] \qquad [8]$$

6. Results

The results of the analyses are shown in table 3. When each location is analyzed separately, a decrease in injury crashes is found at 62% of the locations after lowering the speed limit from 90 to 70 km/h. Furthermore a separate analysis is made for crashes that occurred at intersections and at road sections. In 43% of the locations the crashes rates at intersections decreased. At road sections a decrease is found at 70% of the locations. For the fatal and serious injury crashes, a decrease is found at 67% of the locations. A distinction between road sections and intersections showed a decrease in severe crashes at respectively 49 and 67% of the locations. At the road sections also 7 locations (12%) had an index equal to 1.

The meta-analysis for the total number of injury crashes showed a decrease in crash rates of 5% after lowering the speed limit. This decrease was only significant at the 25% level. For crashes that occurred at intersections, an increase of 11% is found, significant at the 10% level. On the contrary, analysis of crashes at road sections resulted in a significant decrease of 11%. A meta-analysis for the more severe crashes showed a significant decrease of 33% at all researched locations. This strong decrease was mainly found for crashes that occurred at road sections, for which a significant decrease of 36% was found. The severe crashes at intersections showed a decrease of 6%, which was non-significant. These results clearly show the speed limit restriction had a stronger effect on severe crashes, compared to the total number of injury crashes. Also a higher effectiveness is found for the occurrence of crashes at road sections compared to intersections.

Table 3
Results of a B&A study with correction for trend effects

Analysis per location						
	Total		**Intersections**		**Road sections**	
	# eff < 1	**# eff >1**	**# eff < 1**	**# eff >1**	**# eff < 1**	**# eff >1**
Injury crashes	38 (62%)	23 (38%)	26 (43%)	35 (57%)	43 (70%)	18 (30%)
Severe crashes	41 (67%)	20 (33%)	30 (49%)	31 (51%)	41 (67%)	13 (21%)
Meta-analysis						
	Total		**Intersections**		**Road sections**	
	Eff [95% CI]		**Eff [95% CI]**		**Eff [95% CI]**	
Injury crashes	0.95 [0.88; 1.03]		1.11 [1.00; 1.23]		0.89 [0.80; 0.99]	
Severe crashes	0.67 [0.57; 0.79]		0.94 [0.73; 1.20]		0.64 [0.52; 0.73]	

7. Discussion

The evaluation of a traffic safety measure should ideally be executed through the application of the EB method (Elvik, 2002; Hauer, 1997). Because the crash rates are much lower in the comparison group compared to the research group, this method was not applicable here, as this would lead to biased estimations. A possible explanation for this discrepancy between the research and comparison group arises from a criteria that was used to select the road sections for restriction of the speed limits. One criterion was roads that are localized outside urban areas, but still have a high building density. Locations in the comparison group on the other hand, are mainly situated at rural roads, where traffic volumes are possibly lower compared to the selected research locations. Selecting another comparison group was not possible, and consequently it was not feasible to use the EB method and to control for RTM. However, it is rather unlikely that RTM occurred as the locations were not solely selected on the basis of a high crash count. Furthermore the before period counted 5 to 6 years, which probably already tempered the RTM effect.

Traffic volume data were not taken into account, since these data were not available. These volume data could have given an explanation of the low crash rates in the comparison group compared to the research group. Next to this it would have been interesting to compare the traffic volumes after the implementation of the speed limit restriction with before, in order to analyze whether the speed limit restriction had an effect on route choice of the drivers.

The analyses clearly showed a higher effectiveness for more severe crashes with serious injuries and fatalities compared to all injury crashes. This can be ascribed to the fact that speed is directly related to injury severity in a crash. This is different than the probability of being involved in a crash, which is more complex, as the occurrence of crashes can seldom be attributed to a single factor (Transportation research board, 1998).

The analyses also showed a stronger effectiveness at road sections compared to intersections, both for injury crashes, for which even a contradictory was found, and the more severe crashes. This is more difficult to explain. Crashes that occur at intersections may be less influenced by speed compared to road stretches, and causation might rather be related to maneuvers, for example turning left. This explains why no decrease was found, but this does not explain why an increase is found. A possible cause for this increase in the number of crashes, is the increase in the variance of travel speeds.

Lowering the speed limit will not automatically lead to an adaptation in travel speeds of all drivers. Factors such as habits, non-acceptance of the new measure or inattentiveness might explain why the actual speed adaptation is lower than the required speed adaptation (McCarthy, 1998). Furthermore, the speed limit change was only signalized through the adaptation of traffic signs. Parker (1997) stated that changing posted speed limits alone, without additional enforcement, educational programs or other engineering measures, only has a minor effect on driver behavior. Furthermore the infrastructure of the road was not adapted, which makes it less appealing for drivers to adapt their behavior, whereas others will strictly follow the rules. This can lead to an increase in the variance in travel speeds, which is an important risk factor for the occurrence of crashes (Aarts & Van Schagen, 2006).

Changes in speed behavior on their turn not necessarily result in an equal effect on traffic safety. As formulated by Nilsson (2004), this relationship can be expressed by power estimations of the difference in speeds. In a back-of-the-envelope calculation this theory can be compared with the results from current study, and the power estimations can be applied to observed travel speeds at Flemish roads. In 2007 the average speed at 70km/h roads was 75 km/h, at roads with a limit of 90 km/h this was 82.5 km/h. The V_{85} was respectively 95.1 and 85.6 km/h (Riguelle, 2009). An application of the power estimations on these speeds, resulted in an estimated decrease in crash rates between 17 and 34%, as shown in table 4.

Table 4

Estimation of % decrease in number of crashes using power estimations by Nilsson (2004) for mean and V_{85} speeds at 90 and 70 km/h roads in Flanders in 2007

	Mean speeds 82.5 → 75 km/h	V85 speeds 95.1→85.6 km/h
Fatal crashes	-32%	-34%
Serious crashes	-25%	-27%
Injury crashes	-17%	-19%

Results from our analyses are less favorable concerning all injury crashes. For the severe crashes the results are more in line with these theoretically expected results. However, this reasoning lacks validity due to its non-experimental setting. At least, we would recommend a more detailed analysis of the speed behavior at the concerned roads.

8. Conclusions

The restriction of the speed limit from 90 to 70 km/h at highways in Flanders, showed a favorable effect on severe crashes, for which a significant decrease of 33% was found. The effect at the injury crashes was more limited, which showed a decrease of 5%. Furthermore a more favorable effect was found for the crashes that occurred at road sections compared to intersections. Whereas for the intersections an increase of 11% was found in the total number of injury crashes, the opposite was found for crashes at road sections, that is a decrease of 11%. For the severe crashes only decreases were found, which was clearly stronger at road sections (36%), compared to intersections (6%). However, more research is needed in order to examine the relationship between the speed limit and the travel speeds of the driver. Furthermore, it would be interesting to examine the possible causes of the difference in effect that was found between road sections and intersections.

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