TRAFFIC SAFETY EFFECTS OF NARROW 2+1 ROADS WITH MEDIAN BARRIER IN SWEDEN

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ABSTRACT

Deaths on rural roads are a serious road safety problem. Due to the risks imposed by high speeds, multi-functionality, lower infrastructure safety and mix of different road users, rural roads are often dangerous roads with relatively high risk levels compared to motorways. In Sweden, a special road safety concern during the 1990's was the large amount of fatal and serious crashes on rural 13 m wide 2-lane roads. The solution proved to be a redesign to a 2+1 road usually with a median barrier. Starting 2009, this solution was also applied on rural roads with road width of about 9 – 10 meters. A 2+1 road with median barrier has a continuous three-lane cross section with alternating passing lanes to allow defined sections of overtaking, the two directions of travel separated by a flush divider with a median barrier. Comparing 13 meter wide 2+1 roads with narrow 2+1 roads (9 m), the main difference is the length and frequency of passing lanes. For narrow 2+1 roads, the share of passing lanes varies between 15 – 30% compared to about 40% for the 13-meter roads.

The main objective of this study is to evaluate the traffic safety effects of these narrow 2+1 roads. A before and after study with control group is performed based on crash statistics from the Swedish crash data base STRADA. Using a control group, the results have been adjusted for the general road safety trend and changes of traffic volumes. In addition, a limited Empirical Bayes study was done to adjust for regression to the mean.

Results from the before and after study show a number of significant effects; the total number of fatalities and seriously injured decreased by 50 % and the total number of personal injury crashes decreased by 21%. The severity consequence (the rate of the number of killed and seriously injured divided by the number of personal injury crashes) decreased by 38%. Looking only at links (excluding intersections), the number of fatalities and seriously injured decreased by 63% and the personal injury crashes by 28%. Correcting for regression to the mean gave very similar results. It should be noted that the after period is still short and a continued follow up will be done during 2015. For almost all of the included road sections, the speed limit was also raised from 90 km/h to 100 km/h when the road was rebuilt to 2+1. No difference in efficiency compared to earlier evaluations of traditional 2 +1 roads with 100 km/h and 40% passing lanes can be observed.

1. INTRODUCTION

Deaths on rural roads are a serious road safety problem. According to ETSC (2010) at least 21 500 people in the EU lost their lives on rural roads other than motorways during 2009. Road deaths on rural roads account for 55% of all road deaths[1] across the EU. Due to the risks imposed by high speeds, multi-functionality, lower infrastructure safety and mix of different road users, rural roads are often dangerous roads with relatively high risk levels compared to motorways. On rural two-lane roads, head-on collisions account for a large proportion of traffic crashes where people are killed or seriously injured.

A special road safety concern during the 1990's in Sweden was the large amount of fatal and serious crashes on rural 13 m 2-lane roads and on semi-motorways[2]. These roads (with a total length of about 3700 km) covered 25% of the total vehicle mileage but only 14% of the total road length. Annually in the 1990's, about 25% of the total number of road deaths in Sweden occurred on these roads. The main problem on all two-lane roads was run off and head on crashes causing more than 70% of all fatalities (Carlsson, 2009, Bergh et al., 2005). The scenario in the crashes tended to be rather similar: a driver loses control for some reason and crashes against an opposing driver or against some obstacle in the road side area. This serious road safety problem put a pressure to create new cost effective measures to decrease the number of road deaths on these wide roads. The solution proved to be a redesign of the roads from a wide 2-lane road alignment to a 2+1 road usually with a cable barrier (keeping the same road width).

The purpose of any median barrier safety system is to contain and redirect errant vehicles, preventing the vehicle from crossing the safety barrier to the opposing lane. A 2+1 road with median barrier has a continuous three-lane cross section with alternating passing lanes and the two directions of travel separated by a flush divider with a median barrier. The direction of traffic with two lanes alternates along the road to allow defined sections of overtaking. The main advantage of a 2+1 road is enhanced safety due to the separation of opposing traffic streams which prevents cross-over crashes including head on crashes (Bergh et al. 2005, Gazzini, 2008, Potts and Harwood, 2003). A 2+1 design provides a smart and cost effective solution for upgrading major roads of appropriate width where traffic is too light to qualify for building a dual carriageway or motorway. The cost for rebuilding a rural road to a 2+1 road is about one fifth of the costs of building a motorway. Sweden has about 5000 kilometers of roads with separated traffic flow, covering about 45% of the traffic flow on national rural roads, 2700 km of which are 2+1 roads.

In Sweden (Bergh et al., 2005), as well as in Ireland (NRA, 2007, Gazzini, 2008), cable barriers were chosen, but other solutions such as concrete barriers have been tried for example in Norway (Saukshaug and Giæver, 2004) and in recent years also in Sweden. Advantages with cable barriers are that they are cheap compared to concrete barriers, are easily repaired when hit and can be dropped/opened rather easily for access in emergency situations. The most obvious disadvantages are cable crashes leading to the need of repair of the cable barrier. Independent of barrier type, the more narrow design leads to

[1] Fatal crashes involving at least one road vehicle in motion on a public road or private road to which the public has right of access.

[2] 2-lane motorway, normally 13 m wide with interchanges. Slow moving vehicles, bicyclists, pedestrians etc. are not allowed.

higher rut wear. These factors give increased maintenance costs for the road authority and increased crash costs for insurance companies.

An alternative 2+1 solution, used in for example Finland (Kaistinen et al., 2004), Denmark (Herrstedt, 2001) and Germany (Weber and Löhe, 2003, Irzik, 2010) is to separate the two directions of travel only by pavement markings. In Sweden, the markings are sometimes combined with milled rumble strips, Vadeby et al. (2013).

1.1. Objective

In Sweden, the 2+1 solution started on 13 meter wide rural roads. As of 2009, this solution is also applied on rural roads with road width of about 9 – 10 meters. For almost all of the studied roads, the speed limit was raised from 90 km/h to 100 km/h when the road was rebuilt. The objective of this study is to evaluate the traffic safety effects of these narrow 2+1 roads.

2. METHODS

A narrow 2+1 road is a rebuilt rural two-lane road with road width of 9 – 10 meters compared to the ordinary 2+1 road which is 13 m wide (Figure 1). The narrow 2+1 road is widened at some sections to allow a passing lane in one direction and the main difference between the narrow 2+1 road and the ordinary 2+1 road is the frequency and length of the passing lanes. For a sparse 2+1 road the share of passing lanes are between 15 – 30% compared to 40% for the 13-meter wide 2+1 roads. The design standards for 2+1 roads are described in STA (2015).

Figure 1: A narrow 2+1 road, width 9-10 m (left photo) and ordinary 2+1 road, width 13 m (right photo).

The traffic safety evaluation is based on crashes reported by the police in the Swedish national STRADA crash database (Swedish Traffic Accident Data Acquisition) for the 2003–2013 period. Crashes with pedestrians, bicycles, mopeds, track-based vehicles, and game are excluded from the analyses. In total, 15 rural road sections with a total length 105 km and an annual traffic volume of 240 million vehicle kilometer are included in the analysis. The crash outcome in the after period is compared with the outcome in the before period. Only road sections with both a before- and after period are included in the analysis.

Table 1 shows traffic volumes, number of injury crashes, and number of fatalities and seriously injured (FSI) people in the before and after periods. The traffic volumes are approximately 2.5 times higher in the before period compared with the after period, reflecting a longer duration of the before-period. For all crashes on the evaluated roads, there are 85 FSI in the before period and 13 in the after period, while there were 209 injury crashes before and 63 after 2+1.

Table 1: Traffic volumes, number of injury crashes, and number of fatalities and seriously injured (FSI) people in the before and after periods.

	Traffic volume (million vehicle km)		Number of injury crashes		Number of FSI	
	Before	**After**	**Before**	**After**	**Before**	**After**
Link	1670	690	175	48	70	8
Intersection*	1670	690	34	15	15	5
Total*	1670	690	209	63	85	13

*One crash is excluded in the analysis due to an extreme situation

To evaluate the traffic safety effects of narrow 2+1 roads, the numbers of injury crashes and of people killed or seriously injured (FSI) before and after rebuilding to 2+1 are compared in an Empirical Bayes (EB) study as well as a before–after study with a control group.

In the before and after study with control, the change between the before and after periods is estimated as:

$$\hat{\theta} = ck\frac{\sum Y}{\sum X}$$

where X is the number of observed crashes in the before period, and Y the number in the after period (summarized over all road sections), c corrects for differences in traffic volumes between the before and after period and k corrects for the changes in the control group. To estimate the trend (k) in the control group, the number of injury crashes as well as the number of fatal and seriously injured (FSI) per year for an average before and after period were calculated. The index is calculated as the ratio between the after and before outcomes in the control group and is 0,912 for personal injury crashes and 0.742 for FSI. The traffic safety effect is estimated by θ*-1*. Following a first-order Taylor expansion (Lehmann, 2001), the variance is estimated by

$$\mathrm{Var}(\hat{\theta}) = [ck\frac{\sum Y}{\sum X}]^2(\frac{1}{\sum X} + \frac{1}{\sum Y})$$

and a 95% confidence interval is:

$$KI = \hat{\theta} \pm 1{,}96 * \sqrt{Var(\hat{\theta}}.$$

To control for regression to the mean (RTM), an empirical Bayes (EB) approach were used. EB is the most common method of controlling for regression to the mean in before–after studies (Hauer, 1997). There are several versions of the EB approach (Elvik, 2008; Persaud et al., 2004), which in the present case, briefly stated, relies on estimating the expected number of crashes by combining two sources of information: the recorded number of crashes and the normal expected number of crashes estimated by an crash prediction model. In principle, the normal expected number of crashes can be obtained from the empirical distribution of a control dataset. The data available for this evaluation do not contain a proper control dataset for estimating the normal expected number of crashes, but instead rely on an EB approach developed for and often used in Swedish traffic safety evaluations (Brüde, Larsson, 1988). The expected number of crashes, E(α|r), is calculated as

$$E(\alpha|r) = w\alpha + (1 - w)r$$

where α is the expected normal number of crashes (for a specific road type), r is the recorded number of crashes, and w is a weight, which is calculated as

$$w = \frac{1}{1 + k\alpha}$$

The expected normal number of crashes, α, is calculated from standard model values (i.e., estimated crash and FSI rates) based on the national average outcome over a fixed period for a certain road type and speed limit, and the weight, *w*, is estimated to be 0.1 for Swedish conditions (Swedish Road Administration, 2014). The standard model values are based on the 2003–2008 period, which is the average before period (Table 2). The standard model values for the control group are similar to the observed crash rates for the case group, for injury crashes the standard model rate is 0.104 injury crashes per million vehicle kilometer and the observed injury crash rate is 0.105 per million vehicle kilometer.

Due to a limited availability of updated standard model values for intersections, the results based on the EB-method will only be valid for links.

Table 2: Standard model values (estimated crash/FSI rates per million vehicle kilometer) and observed crash and injury rates (per million vehicle kilometer) for the before period on links.

Standard model values for the control group (only links)		**Observed crash/injury rates in the case group (only links)**	
Injury crashes/ million vehicle km	**FSI/million vehicle km**	**Injury crashes/ million vehicle km**	**FSI/million vehicle km**
0.104	0.0421	0.105	0.0419

3. RESULTS

3.1. Estimated traffic safety effects

The results of the before and after analysis, the limited Empirical Bayes analysis as well as 95% confidence intervals are shown in Table 3. Regarding severe crashes, the results indicate that the redesign to 2+1 roads reduce FSI on links by 63% (significant) and in total single-vehicle crashes by 50% (significant). For injury crashes, the reduction is 28% on links (significant) while no significant change is seen for the total number of injury crashes. Comparing the results from the EB and before and after study, they show very similar results both for injury crashes and fatalities and seriously injured (FSI). This is due to the only minor differences between the standard model values and the observed crash rates in the before period.

Table 3: Estimated traffic safety effects of 2+1 roads including corrections for RTM (Empirical Bayes) as well as no correction for RTM (before and after study with control), 95 % confidence intervals.

	Empirical Bayes		**Before and after study with control**	
	Injury crashes	**Fatalities and seriously injured (FSI)**	**Injury crashes**	**Fatalities and seriously injured (FSI)**
Links	-27.0 ± *23.3*	-62.9 ± *27.2*	-27.6 ± *23.1*	-63.0 ± *27.1*
Total	-	-	-20.5 ± *22.4*	-50.4 ± *28.9*

The severity consequence (the rate of the number of killed and seriously injured divided by the number of personal injury crashes) decreased by 49% on links and with 38% in total (both links and intersections).

Earlier results from the Swedish evaluation of 13 meter wide 2+1 roads (Carlsson 2009) showed that the number of fatalities decreased by 76% and the total number of fatalities and seriously injured decreased by more than 50%. Comparing these results with the results in Table 3 it should be noted that the narrow 2+1 roads got an increased speed limit from 90 km/h to 100 km/h when rebuilt, while for the 2+1 roads in Carlsson´s evaluation, the speed limits remained the same.

As seen in Table 1, the crash and injury data in the after period are still very limited. To illustrate the variations after three years of evaluations (2011, 2013 and 2013), Figure 2 illustrates the estimated traffic safety effects as a function of accumulated traffic mileage (million vehicle kilometers) based on a before and after analysis with control group. All results shown in the figure are significant. For injury crashes, the effects decreased after the first year and has been rather stable during 2012 and 2013. For the number of fatalities and seriously injured the total effect (both intersections and links) has been stable around -50%, while the effect on links has been alternating between -60% - -75%.

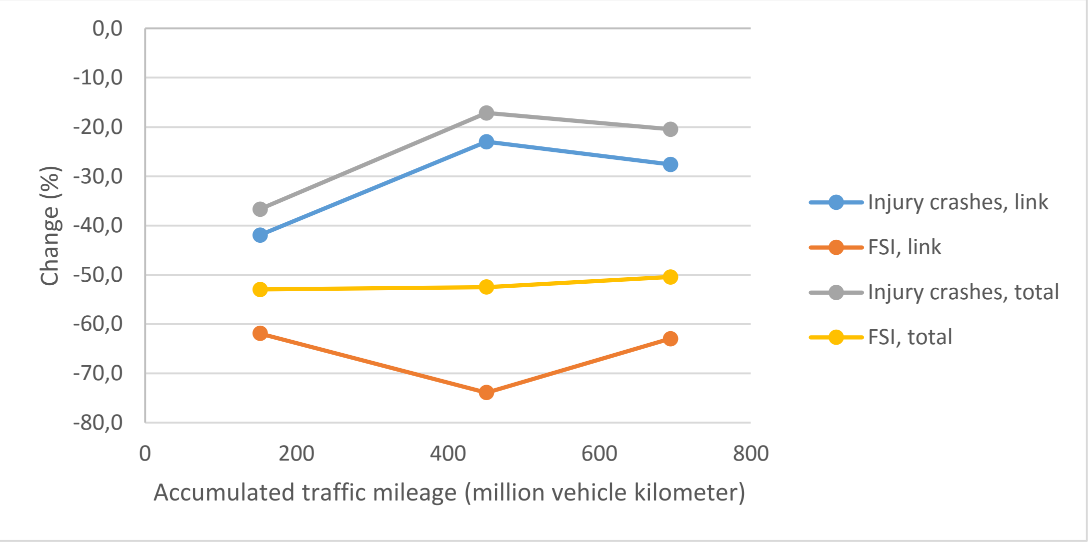

Figure 2: Change of injury crashes (links and total), Fatalities and seriously injured, FSI (links and total) as a function of accumulated traffic mileage (million vehicle kilometer).

3.2. A comparison between safety levels of rural roads

The injury crash rate (number of injury crashes per billion vehicle kilometers) and the rate for fatalities and seriously injured (number of fatalities and seriously injured per billion vehicle kilometer) in the after period (links only, when rebuild to narrow 2+1 with speed limit 100 km/h) are presented in Table 4. The FSI rate is 9.2 fatalities and seriously injured per billion vehicle kilometers and the injury crash rate is 55.4 injury crashes per billion vehicle kilometers.

Table 4: Injury crash rate and the rate for fatalities and seriously injured, FSI-rate (per billion vehicle kilometer) in the after period when rebuild to narrow 2+1 with speed limit 100 km/h.

Injury crash rate	FSI-rate
55.4	9.2

Figure 3 illustrates the different safety levels for different types of rural roads in Sweden, fatalities or seriously injured (FSI) per billion vehicle kilometer over the period 2009-2012 (links only). The results show that motorways and different types of 2+1 roads have about the same safety level of 10 FSI per billion vehicle kilometers, while ordinary rural two-lane roads with speed limit 80 and 90 km/h have about 35 FSI per billion vehicle kilometer and rural roads with speed limit 70 km/h have more than 45 FSI per billion vehicle kilometer. The FSI-rates for 2+1 roads shown in Table 4 and Figure 2 are very similar indicating that the safety level is about the same for all types of 2+1 roads.

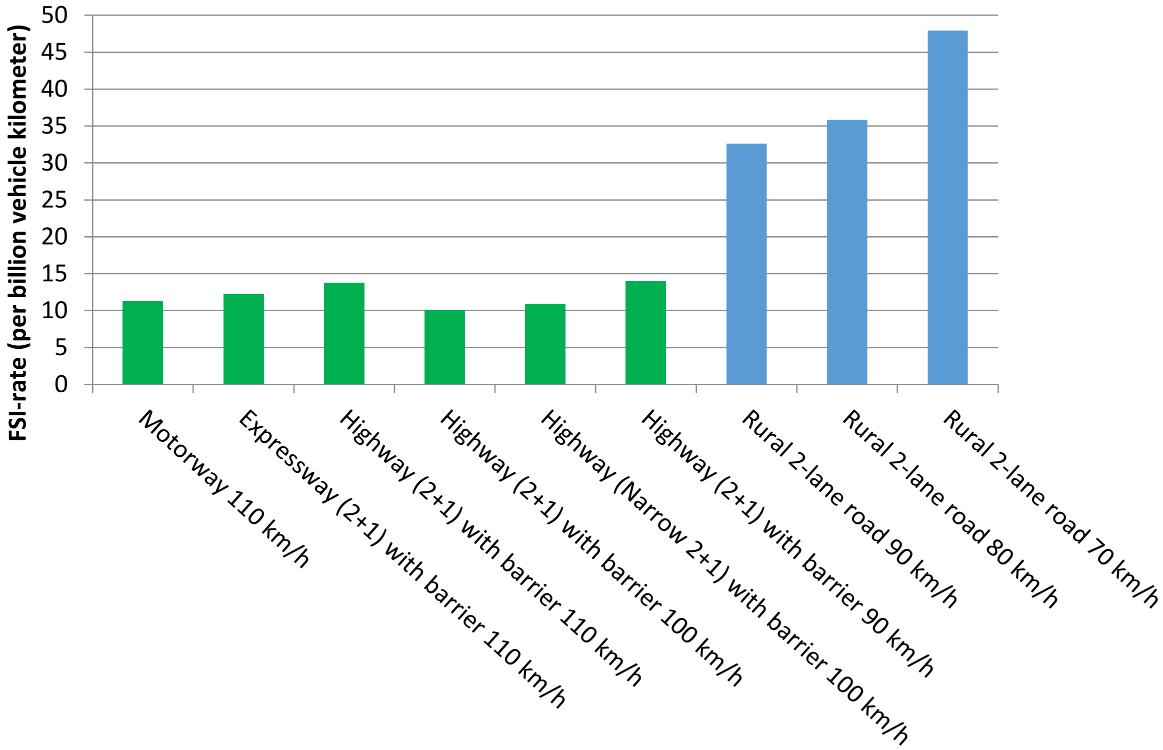

Figure 3: People killed or serious injured (KSI) per billion vehicle-km in Sweden for some road types over the period 2009-2012 (links only).

4. DISCUSSION

When introducing 2+1 roads the total number of fatalities and seriously injured decreased by 50 % and the total number of personal injury crashes decreased by 21 %. The severity consequence (the rate of the number of killed and seriously injured divided by the number of personal injury crashes) decreased by 38 %. Looking only at links (road sections excluding intersections), the number of fatalities and seriously injured decreased by 63% and the personal injury crashes by 28%. Correcting for regression to the mean gave very similar results. This is due to the minor differences between the standard model values used in the EB-approach and the observed crash rates in the before period.

For almost all of the included roads, the speed limit was raised from 90 km/h to 100 km/h when the road was rebuilt to a 2+1 road. The results from the evaluation therefore shows the combined effect of rebuilding a rural road to a narrow 2+1 road and increasing the speed limit from 90 to 100 km/h.

Comparing the results from this study (15-30% passing lanes) with the national evaluation of the original 2+1 roads (13 m) with 40% passing lanes, there are only minor differences. Carlsson, 2009 showed a substantial decrease in the number of fatalities (76%). The total number of fatalities and seriously injured decreased by more than 50% and the reduction in injury crashes for links, was somewhat higher than the total reduction. The safety level of 2+1 roads with cable barrier on links was almost as good as for motorways with speed limit 110 km/h. Carlsson (2009) also showed that the predominant crash types on 2+1 roads are run-off and rear-end crashes, which together correspond to 60 – 80% of all fatal and serious injury crashes. Carlsson also concluded that collisions with cable barriers are as expected very frequent, but normally without severe consequences. The observed crash rate is about 0.50 per million axle pair km. This means on average almost two median barrier crashes per km and year.

Evaluations from pilots in Norway (Saukshaug and Giæver, 2004) and Ireland (Bulpitt, 2006, Gazzini 2008) confirms the results from Sweden. Four 2+1 roads of total 15 km length were evaluated in Saukshaug and Giæver (2004) and the results showed that all injury crashes have been reduced by about 60 %. In Ireland, the evaluation of the pilots showed reductions of the rates of fatalities and serious injured by 50 – 60%. In Finland (Liikennevirasto, 2010), the safety level of 2+1 roads with cable barrier is about the same as for motorways.

An alternative 2+1 solution is when the two directions of travel are separated only by pavement markings. Earlier studies have shown that the reductions are far from that of median barrier 2+1 roads. In Sweden, the reduction for fatalities and serious injuries is estimated to 32% (Carlsson, 2009), while in Germany, painted 2+1 road are considered to have about 36% lower risk for fatal and injury crashes than conventional 2-lane roads. In Finland, the injury crash rate is about the same as for ordinary two-lane roads (Potts and Harwood, 2003). These results support the solution of 2+1 with barriers.

Some quality considerations regarding the scope and methodology used to estimate the traffic safety effects merit discussion. The analyses presented here are based on police records and it is well known that the under-reporting of crashes is a problem. At the same time it is well known that the under-reporting is greater for less severe injuries and crashes. However, there is no reason to believe that the underreporting differs between the case and control group or for different types of road sections included.

The methods used is both a before and after study with control group and an Empirical Bayes study. The Empirical Bayes method corrects for trend, traffic volume and regression to the mean, while the before and after study only controls for trend and traffic volumes. Due to a limited availability of updated standard model values for intersections, the results based on the EB-method was only used for links. However, the total results presented by both methods are very similar, indicating that this might be a minor problem. The EB-method used is an approach developed for Swedish conditions. This method may need updating, and further analysis and comparison of different methods to correct for RTM is a future recommendation.

Due to a limited number of crashes in the after-period, the results are not divided by road user category in this study. A special concern when rebuilding a road to a 2+1 road with median barrier is the safety for motorcyclists and whether a cable or other type of barrier is positive or negative for their safety. In Carlsson (2009) it was estimated that fatal and serious injury risk as well as fatality risks for motorcyclists have been reduced by 40 – 50 % when the road was rebuilt. In Forsman and Vadeby (2014), analyses of injury severity in multiple-vehicle crashes involving motorcycles indicate that the odds of being killed or seriously injured are lower on roads with median barriers (i.e., motorways and 2+1 roads) than on two-lane roads.

Another important issue, that not has been studied here, is the reduced capacity when building a 2+1 road. Carlsson (2009) estimated that the capacity is about 1600 – 1700 vehicle/h in one direction during a 15 minutes period which is 300 vehicle/h less than for an ordinary 13 m 2-lane road giving a capacity loss of some 15%. The bottleneck consists of the transition segment from two to one lane.

In conclusion, rebuilding a 9-10 meter wide road to a 2+1 road with median barrier, reduced the number of fatalities and seriously injured by 50 % and that the total personal injury crashes by 21%. Looking only at links (excluding intersections), the number of fatalities and seriously injured decreased significantly by 63% and the injury crashes by 28%. The results are in line with earlier Swedish evaluations, but it should be noted that the data set is very limited and the after period is still short and a continued follow up will be done.

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