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Safety and accessibility effects of code modifications and traffic calming of an arterial road

Lars Leden [a,b,*], Per-Erik Wikström [c,1], Per Gårder [d,2], Peter Rosander [e,3]

[a] *VTT Building and Transport, P.O. Box 1800, FIN-02044 VTT, Finland*
[b] *Luleå University of Technology, Division of Architecture and Infrastructure, SE-97187 Luleå, Sweden*
[c] *Swedish Road Administration, Stockholm Region, SE-171 90 Solna, Sweden*
[d] *University of Maine, Orono, ME 04469-5711, USA*
[e] *Luleå University of Technology, Division of Traffic Engineering, SE-971 87 Luleå, Sweden*

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Abstract

The European Road E12 through the community center of Storuman, Sweden was reconstructed in 1999 and 2000. Pedestrian walkways, traffic islands, chicanes of a type referred to as "Danish buns", a roundabout and a two-directional cycle track along the E12 were installed. The purpose of the reconstruction was to improve safety for pedestrians and bicyclists, primarily for children, the elderly and the disabled, and to reduce the barrier effect of the E12 thoroughfare. In May 2000, the code governing the conduct of drivers at marked crosswalks in Sweden became stricter to improve safety and mobility for pedestrians. The combined effect of reconstructions and change of code was analyzed. Traffic behavior was studied at the intersection where the roundabout was constructed. Yield behavior towards pedestrians changed significantly. The difference was even greater with respect to yielding to child bicyclists – from 6% before to 84% after – even though the code change only related to pedestrians. Crash data analysis suggests a minor increase in fall injuries after reconstructions and change of code. Measures of speed, behavioral studies, questionnaires, face-to-face interviews and crash data analysis suggest that safety has increased not only along the E12 but also along adjacent roads. The final conclusion is that a bypass is not needed in a case like Storuman. Traffic calming of the main arterial through the town seems sufficient.

Keywords: Traffic safety; Mobility; Child; Disabled; System effects; Migration effects; Behavior; Traffic calming; Yield behavior

1. Background and aim

In Sweden, it has become increasingly common that citizens and/or interest groups do not to want bypasses around their communities. Reasons for this include a fear that the community will suffer economically with the loss of through traffic, and an extension of this fear that the community will lose its attractiveness. The positive effects of traffic are desired, but a drastic reduction of the negative effects is also desired. This point of view breaks the trend of the previously common desire to build bypasses, with their documented safety benefits. Elvik and Vaa (2004) in a meta analysis of five Norwegian, two Swedish, one Danish, one British and one German study on effects of bypasses conclude that construction of bypasses, on average, decreases the number of injury accidents by around 25%. But even if the alternative of a bypass is chosen, road safety measures often need to be introduced along the old roadway through the community. This is because a large proportion of traffic has destinations there.

Storuman was chosen as the study site because its site is typical of communities that traditionally had bypasses constructed. It is a small town, with a total population of approximately 6500 people out of which around 3800 live in its compact area. Also, Storuman is located in a part of northern Sweden, Norrland, which is characterized by closeness to lakes and wild nature, which would have made construction of a bypass difficult for environmental reasons. The European Road E12 with an average daily traffic volume of 3000 motor vehicles per day goes right through the community, where it shares a right-of-way with National Highway 45, see Fig. 1. The share

* Corresponding author. Tel.: +358 20 722 4298; fax: +358 20 722 7056.
E-mail addresses: Lars.Leden@vtt.fi (L. Leden), Garder@Maine.edu (P. Gårder), Peter.Rosander@ltu.se (P. Rosander).
[1] Tel.: +46 8 757 6895; fax: +46 8 986 711.
[2] Tel.: +1 2075812177; fax: +1 2075813888.
[3] Tel.: +46 920 492 409; fax: +46 920 491 697.

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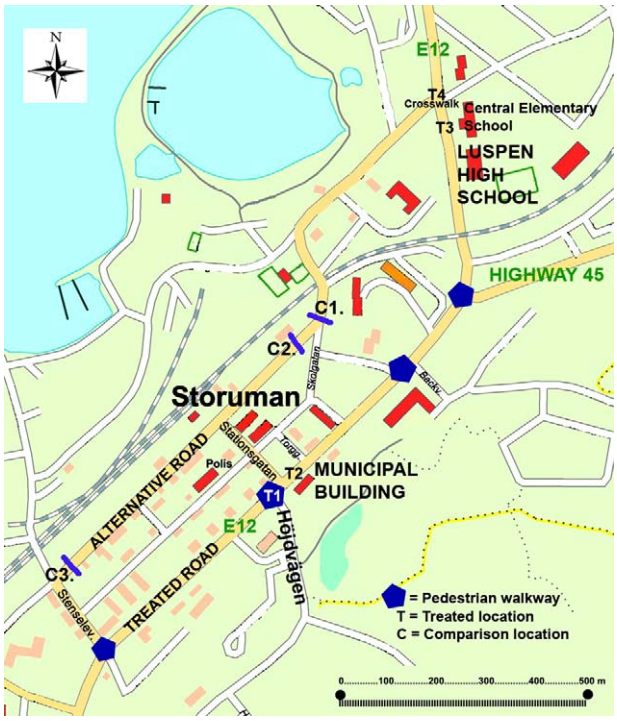

Fig. 1. Survey points analyzed on the alternative road (Järnvägsgatan).

of heavy-vehicle traffic is 20%. There are a large number of small towns in Sweden – as well as Finland and other countries with low population densities – that have similar conditions as Storuman.

When rejecting the alternative of building a bypass, it was necessary to consider a number of measures to attain the required level of safety on the through road. The purpose of the reconstruction in Storuman was to increase traffic safety especially for pedestrians and bicyclists, primarily children, the elderly and the disabled and to reduce the barrier effect of the E12 and thus increase accessibility and the safe flow of pedestrians and cyclists in the center of the community which is bisected by the E12. Whether that objective was attained is analyzed and discussed below. A standard research practice is to only deal with effects in the immediate vicinity of the reconstruction. S*ystem effects* across the road network are often neglected. This was an important factor behind the decision that the main scope of this study was to evaluate system effects of the reconstruction of the E12 and the change of code.

The Swedish Road Administration (1998) states that a pedestrian's risk increases by 20–40% when he/she is crossing in a marked crosswalk compared to at similar sites with no zebra markings (referring to results of a meta analysis by Elvik and Vaa (2004). Ekman (1997) has argued that marked crosswalks deteriorate safety due to a false sense of safety for pedestrians. In May 2000, the code governing the conduct of drivers at marked crosswalks in Sweden became stricter with the intent to improve safety and mobility for pedestrians. According to the 'new' Swedish code, drivers must yield to pedestrians entering or crossing in marked crosswalks. Previously, drivers had to yield only when they could reasonably do so. However, as before the change of code, pedestrians are required to consider the speed and proximity of approaching vehicles before crossing. This means that today, both parties have culpability if a pedestrian walks out right in front of a car. Previously, drivers were considered 'innocent' if they reasonably could not stop. About 10% of all marked crosswalks on 50 km/h streets in Sweden were eliminated in 2000 and 4% more in 2001 (unpublished data in draft by Thulin, 2003). Especially marked crosswalks at locations with low pedestrian flows were removed since risks are higher if pedestrian flows are low, see, e.g. Leden (2002) and Ekman (1996).

Also, a new concept, *pedestrian walkways*, was introduced. These are recommended locations for pedestrians to cross, with no zebra markings, no warning signs telling drivers that pedestrians are expected, and without any legal obligations for the driver to give way to pedestrians. Such walkways were established at four locations in Storuman. The four locations are marked with pentagons in Fig. 1.

2. Reconstructions in Storuman

The Swedish Road Administration's Northern Region (1997) made an analysis of the problems in Storuman, and decided to reconstruct the E12. This was later followed by a school questionnaire and a traffic network analysis. With these included as a basis, countermeasures were suggested for traffic calming of the E12 through Storuman. Initial minor reconstruction in Storuman was carried out during the autumn of 1999, and was intensified during April/May 2000. Work continued during the entire summer up to final inspections during September/October 2000. In the analysis below, crashes which occurred during 2000 are counted as having occurred during the period of reconstruction.

A two-directional cycle track was built along E12. Trees were planted and aesthetically interesting simple wooden posts, so called meeting posts, were erected to symbolize that Storuman is a meeting place in the wilderness. Traditionally, blue and white meeting posts were used in Sweden on narrow roads to mark a place where it was possible to meet another vehicle. Nowadays, these posts have been replaced by official signs with an M symbol.

Below follows a short compilation of traffic safety measures that were implemented in Storuman. Numbers below refer to treated locations marked in Fig. 1.

1. Across the E12 at Höjdvägen a rumble area was constructed, together with central refuge islands, at a pedestrian walkway across the E12. There were, however, so many complaints about the noise that the rumble area had to be removed in the autumn of 2001. Across Höjdvägen at E12 a zebra crossing was removed and replaced by an informal pedestrian walkway with a central refuge island, see Fig. 2.
2. Measures carried out in the central business district, in front of the municipal building, included resurfacing with broad flagstones, new street lights and railings along the parking area.
3. At the Luspen high school, a wide central refuge with a so-called "Danish bun" was constructed. Previously, there had

Fig. 2. Intersection Höjdvägen—E12 after reconstruction with a pedestrian walkway. View southwards along the E12.

been an unmarked crossing for unprotected road users at this location, see Fig. 3.

4. The intersection between the E12 and Materialvägen was rebuilt as a roundabout.

For a more extensive description of the traffic environment before and after reconstruction, see Wikström (2002).

3. System effects due to reconstruction and change of code

Extensive measurements including video recordings were carried out before and after reconstructions at locations where traffic calming measures were to be implemented and also along an alternative route, see Fig. 1. The reconstruction, in combination with the change of code, had significant system effects. For example, it influenced the choice of mode and thereby the flow of pedestrians and bicyclists in the community, as well as the choice of route and speed of motor vehicles. Streets parallel to E12, not reconstructed to be safer than before, may have seen increased traffic. The effects of such changes will be discussed in detail below.

3.1. The flow of pedestrians and cyclists increased

Five treated locations in Storuman along the E12 and one of the comparison locations were video filmed, and the flows of pedestrians and bicyclists were counted. Two different data-collection structures were used (see Wikström, 2002). This means that some locations have data for both pedestrians and bicyclists while other locations lack comparable data for one of these groups At most locations, the flow of pedestrians and bicyclists across the E12 increased. At treated location 1 (see Fig. 1), this increase was to almost five times the flow seen before the pedestrian walkway across the E12 had been established here. However, at the E12—Luspen school crossing, the flow of pedestrians across the E12 was halved, see Table 1. This was due to a fence having been erected at this location to prevent crossings. The crossing patterns for pedestrians and cyclists changed significantly and the flow of pedestrians and cyclists across the E12 increased somewhat (on average by 20% according to Table 1). The flow of pedestrians and cyclists also increased at the *comparison location* 1 which was video filmed, by 55% for pedestrians and 19% for cyclists. The increase of pedestrians at the comparison site is statistically ensured ($p < 0.001$) whereas the change in the number of bicyclists is uncertain, with a 14% chance that the variation in the number was just a random fluke. But the increases indicate that here has been a general increase in walking and cycling in the community of Storuman. And that increase should not be seen as an estimate of what would have happened at the E12 if no measures had been implemented there. Rather, the increase at the 'comparison' location is a system effect of the overall improved perception of safety for bicyclists and pedestrians in downtown Storuman.

3.2. More school children cycled to school

The purpose of the school questionnaires was to study whether the choice of mode to and from school had changed

Fig. 3. At the Luspen High School before (left) and after reconstruction with a wide refuge island, so called "Danish bun" (right).

Table 1
Number of pedestrians and cyclists across the E12

Location	Before reconstruction				After reconstruction			
	Number passing	Number of 15-min periods	Number passing per 15 min	S.D. (average)	Number passing	Number of 15-min periods	Number passing per 15 min	Percentage change (%)
E12-Höjdvägen	30	98	0.3	0.08	176	98	1.8	487
E12-Luspen School	415	88	4.7	0.26	188	88	2.1	−55
E12-Stenselevägen	99	73	1.4	0.15	172	73	2.3	74
E12- Materialvägen	862	88	9.6	0.89	1148	88	12.9	33
Total	1406	347	4.1		1684	347	4.9	20

after reconstruction and change of code, and to explore how the schoolchildren experienced the change in safety when crossing the E12. About 100 children (grades 4–6 at the Central Elementary School) participated in questionnaire surveys in 1998 before and in 2001 after reconstruction. The surveys were completed during October both years, which means that weather conditions should not affect the result to a great extent. However, results might be biased as different children were answering the questions in 1998 and 2001.

The proportion of children who were driven to school by motor vehicles declined by some 16% points from 37% before to 21% after the reconstruction, see Table 2. Binomial testing shows that this is a statistically significant reduction, $p = 0.026$. The greatest reduction, of 12% points, was among those children who traveled to school by bus. The biggest change of mode was that more children chose to cycle alone to school after reconstruction. Before reconstruction, 29% cycled to school – alone or with a friend – compared to 51% after reconstruction (statistically significant increase, $p = 0.008$) and somewhat fewer children walked, 34% before compared to 27% after (not significant change). This may indicate that the traffic system is perceived to be safer than earlier, resulting in many more children being allowed to cycle to and from school. The large reduction among children traveling by bus indicates that children were living further from the schools during the before survey.

3.3. Automatic recording of flows and speeds

In order to investigate whether the flow and speed of motor vehicles changed along an alternative road after reconstruction of the E12 and change of code, the flow and speeds were measured at three comparison locations (see Fig. 1) using traffic counters of the METOR 2000 type which use two pneumatic tubes across the roadway and automatic recording devices. Each time a wheel axle of a vehicle goes over one of the tubes, a change of pressure occurs in the tube, which is registered as a pulse in the equipment and the direction, speed and class of vehicle is registered. Pneumatic tubes are frequently used throughout Sweden for counting vehicle flows, so motorists would typically assume that this is just another count. These types of devices have not been used for enforcement purposes in Sweden since the 1950s. Motorists therefore do not adjust their speeds when seeing the tubes. And, even if they did, the same equipment was used in the before and after studies, so the equipment should not influence the data even if a few motorists feared that the tubes could be connected to police enforcement.

No reconstruction had been carried out along the alternative road. The entire route had a speed limit of 50 km/h.

Table 2
Choice of mode of travel to the Central Elementary School in Storuman before and after reconstruction

Travel mode	Before reconstruction (%)	After reconstruction (%)
Walked alone	12	13
Walked with a parent	1	3
Walked with a friend	21	11
Cycled alone	18	35
Cycled with a parent	0	0
Cycled with a friend	11	16
By bus	27	15
By car	10	6
Other mode	0	1

3.4. Heavy-vehicle traffic increased on an alternative road

A compilation of the average flow of passenger cars and of heavy-vehicle traffic was produced for each day of the week from survey periods extending over several weeks. The "average weeks" have then been compared with one another using paired comparison analysis, which means that the flow of, for example, passenger cars is compared between average weekdays before reconstruction and after reconstruction. The analyses have been carried out using the software program StatGraphics 4.0 and 95% confidence intervals have been calculated.

The flow analysis of cars along the alternative road did not show any clear change after reconstruction. However, at all three survey points, an increase in the flow of heavy vehicles was noted. At two of the three survey points, the increase per 24-h period was statistically significant at the 95% level. The increase of heavy-vehicle traffic can be due to drivers of heavy vehicles considering E12 to have become too complicated, and they therefore choose to drive on the alternative road.

3.5. Speed of motor vehicles decreased on an alternative road

Speeds were reduced at all three survey locations along the alternative road after the implementation of traffic safety mea-

Table 3
The 85-percentile speed of passenger cars (km/h) on an alternative road

	Location 1	Location 2	Location 3
Before reconstruction	53.0	45.0	53.7
After reconstruction 1	49.9	43.0	–
After reconstruction 2	49.5	42.5	51.3

Table 4
The 85-percentile speed of heavy vehicles (km/h) on an alternative road

	Location 1	Location 2	Location 3
Before reconstruction	51.3	42.9	52.0
After reconstruction 1	49.2	40.1	–
After reconstruction 2	48.0	42.7	49.7

sures along the E12, see Table 3 and Table 4. This applies both to cars and to heavy vehicles. In the case of passenger cars, the speed for the 85-percentile declined by 2.0–3.5 km/h and for heavy vehicles by 0.2–3.3 km/h. In addition, speeds were somewhat lower in a second after study, 6 months after the reconstruction, compared with the initial after study directly after the completion of the reconstruction.

4. Slight increase in the number of accidents involving pedestrian falls

Police reported crash data and crashes registered in the database established by the medical health center in Storuman were analyzed separately for the before period. For the after period a new national database for reporting injuries called STRADA was used since it contains both types of crash records. The share of injuries with specified crash location increased after 1997, see Rosander (2005). The main reason for this seems to be that the positional exactness of the reporting system is progressively being improved since STRADA was introduced in Storuman in 1999.

The number of traffic injuries per year in the community of Storuman seems to have been more or less the same before and after the reconstruction and change of code, as seen in Table 5. Crashes involving a pedestrian falling (single-pedestrian crash) have increased somewhat after reconstruction and change of code, but this might at least partly be an effect of an improved reporting procedure. And the change is not statistically significant ($p = 0.15$). Almost all accidents involving falls applied to pedestrians who had slipped, usually on slippery, paved surfaces. In the majority of the traffic injuries, it was pedestrians, bicyclists or people riding mopeds who were injured. If there was, by chance, an unusually large number of reported crashes in Storuman before reconstruction and this affected the decision to reconstruct the E12 through Storuman, we may have regression-to-the-mean effects. However, whether this is the case is unknown. As the number of pedestrians and bicyclists increased in the community of Storuman, because people walked and cycled more after the reconstruction (see below), an increase in single-pedestrian and single-bicycle crashes would be expected.

Table 5
Number of traffic injuries, injuries caused by pedestrian falling (or slipping) and other injuries on streets and roads registered either at the hospital in Storuman or by the police before, during or after reconstruction of the E12

	Number		Number per year		
	Traffic injuries	Falling injuries	Traffic injuries	Falling injuries	Total
Before (1996–1999)	34	17	8.5	4.2	12.8
During reconstruction (2000)	4	9	4	9	13
After (2001–2003)	21	19	7	6.3	13.3

A large amount of data was missing from the police records. One reason is that the police do not define accidents involving falls as traffic accidents. If only traffic accidents are looked at, the police were aware of only some 30%. Therefore, it is crucial to also include hospital records in this type of crash data analysis. There seems to be an overall reduction in injuries after the reconstruction, if we look at non-falling pedestrian crashes.

5. Pedestrians and bicyclists experienced increased safety and accessibility

Traffic behavior was studied at the intersection where the roundabout was constructed. Video recordings from before and after the reconstructions and change of code were used to study if pedestrians and cyclists were given way by drivers. Behavior of the motor vehicle drivers changed significantly. Before, 32% of children crossing as pedestrians were given way to by car drivers compared to 72% after. For cycling children, the difference was even greater, though the code change only concerned pedestrians, 6% were given way to before compared to 84% after. Also, the behavior of children changed significantly. Fewer children ran across the road in the after situation, 10%, compared to 25% before.

Interviews were conducted with pedestrians and bicyclists who passed the survey location after reconstruction and change of code. Forms with given alternatives were used for estimating changes in safety and mobility. Pedestrian and bicycle flows were low and no special procedures were used to select interviewees. A large proportion of respondents were young road users as the survey location is situated near the Luspen high school. Almost all pedestrians (78%) considered it safer than before to cross the E12 at the new roundabout, 8% considered that there was no difference, and 9% answered that it felt more dangerous now than before reconstructions and change of code. Adults had a more conservative estimation of the change than children and elderly. None of the youngest respondents, 7–12 years of age, considered safety to have declined. Also, according to the school survey, safety had improved when crossing the E12 after reconstruction and change of code. The respondents experienced also improved accessibility (both according to face-to-face interviews and according to the school survey).

6. Many disabled people were negative to the use of paving stones

After reconstruction and change of code, a qualitative interview survey was carried out with eight disabled people (who live in or near Storuman) and two representatives for disabled people. They were interviewed by telephone. Three people had impaired sight and a fourth one was totally blind. Three people had problems walking. One of the three was in a wheelchair. The interviews focused on the effects for the disabled concerning the reconstruction in Storuman. The result of the survey was that many of the interviewees were positive about the reconstruction. However, they expressed conflicting opinions about the use of paving stones, acknowledging that the stones increase safety but reduce accessibility. Five respondents pointed out that the high curbstones reduce accessibility.

7. Final conclusions and discussion

In a classical study of the effect of changing two-way stops to four-way stops at 222 intersections in Philadelphia. Ebbecke (1976) concluded that even though the accidents were reduced significantly by number at the treated intersections there was no total reduction of accidents in the area. Hauer (1985) concluded, when reviewing the results of Ebbecke, that there is a justified suspicion that mixing two and four-way stops degrades the safety of the two-way stops. However, as Hauer points out, the process of learning what gives good safety does not seem to work as well as it could. Not much effort has been made to learn more about system effects of traffic safety countermeasures, though this type of effects was reported as early as 1976. There are exceptions: Hydén et al. (1997) concluded that the share of drivers running red-light decreased on adjacent streets as a result of the introduction of large-scale use of roundabouts in a Swedish town. Also, in the present study, significant system effects were detected of such an order that they obviously are not to be neglected. Of course there are several mechanisms behind system effects and changes in behavior, but an explanation could be that traffic safety awareness increased in connection with the reconstruction of the E12 and change of code and that this is reflected in reduced speed on the surrounding road network as well. It may also have lead to an increase in walking and cycling. One challenge for the future is to study system effects of traffic safety countermeasures much more thoroughly than usually has been done in the past.

Crash data analysis suggests a minor increase in fall injuries after reconstructions and change of code. But indirect safety measures suggest improved safety. Measures of speed, behavioral studies, questionnaires, face-to-face interviews and crash data analysis suggest that safety has increased not only along the E12 but also along adjacent roads. The final conclusion is that a bypass is not needed in a case like Storuman. Traffic calming the through road has been successful at least up to the present date. And even though alternative roads are not traffic calmed, the situation there seems to have improved. An important factor to explain this may be that Storuman is a not a large city. In Sweden in general, safety has deteriorated after the change of code at marked crosswalks where traffic calming countermeasures are missing. A crash analysis based on a macro study of all of Sweden suggests that the injury risk in marked, not reconstructed, crosswalks increased by 27% for pedestrians and 19% for bicyclists (Johansson et al., 2004).

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