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Agerholm, Niels; Caspersen, Sofie; Lahrmann, Harry Spaabæk

Publication date:
2008

Document Version
Publisher's PDF, also known as Version of record

Traffic safety on bicycle paths -

results from a new large scale Danish study

Authors

Niels Agerholm[1], agerholm@plan.aau.dk

Sofie Caspersen[2], sc@viatrafik.dk

Harry Lahrmann[1], lahrmann@plan.aau.dk

1 The Traffic Research Group, Department of Development and Planning, Aalborg University, Denmark

2 Via Trafik, a Traffic consultant company, Soevej 13B, 3460 Birkeroed, Denmark

Abstract

The article describes the results from a large scale study about the traffic safety effect from implementing one-way bicycle paths in build up areas in medium and large town in the western part of Denmark. The study was a before and after study with a comparison group and consisted of 40 km of road distributed on 46 road segments. On these roads, bicycle paths were implemented between 1st January 1989 and 31st December 2000. In general, implementing of bicycle paths resulted in an insignificant increase in the number of injury accidents by 14%. It was mainly caused by a statistical significant increase in the number of injury accidents with vulnerable road users i.e. moped riders, cyclists and pedestrians with 25%. The number of injury accidents that involved vulnerable road users did increase significantly at intersections (34%) while the effect on sections was small and uncertain. The effect in the intersections was the worst for moped riders with a tendency to statistical significant increase with 94%, while a similar but lower trend has been observed for cyclists and pedestrians.

1 Background

In most industrialised countries, traffic safety for vulnerable road users is a major problem (DSTI, 1998). Vulnerable road users are often children or elderly people who are forced to walk or use a bicycle or moped in the traffic. They are especially exposed to accident when interacting with other

road users in intersections. This was the case in Denmark in 2004, when 4,268, or more than 50% of all police reported accidents with injured persons happened in built-up areas. According to these traffic accident statistics, bicycle riders were 29%, moped riders were 18% of the injured road users and hence 47% of all the injured road users in built-up areas (The Danish Road Directorate, 2005).

Moreover, several studies in Denmark and abroad have shown that a large number of accidents involving vulnerable road users are not registered by the authorities. This problem seems to be particularly marked for moped riders and cyclists where as low as 2% of single accidents will be registered (Elvik & Vaa, 2004). Hence, despite the decrease in the number of accidents involving vulnerable road users that is reported in the official accident statistics, there is an urgent need for improving traffic safety for these groups.

One approach by the Danish road authorities to address these issues has been to implement bicycle paths. However, the safety effect from building bicycle paths has been researched in a number of studies and the results from these studies will be expanded further below.

1.1 Previous studies abroad

Several foreign studies in among others Sweden, Germany, U.S.A. and the Netherlands where traffic safety caused by bicycle paths has been studied found problems related to bicycle paths and traffic safety.

In 1975, an American study based on approximately 3,200 questionnaires, showed that the risk for cyclists of having an accident was 2.8 time higher when using a bicycle path compared to using the road (Kaplan, 1975). In the mid-eighties both Austrian and German studies concluded that the risk for cyclists was 3.4 to 4 times higher when using a bicycle path (Linderholm, 1984; Berlin Police, 1987). A large study from the Netherlands in 1988, showed that the number of cyclist accidents decreased by 25% on road sections while it increases with 32% in intersections when implement bicycle paths. For moped riders the results were even worse with an increase of 28% and 66% on sections and intersections, respectively (Dijkstra & Wegman, 1992).

In 1994, an American study showed that the accident frequency rate for cyclists increases by 1.8 while riding on a bicycle path. According to this study, riding on a bicycle paths resulted in an increased number of accidents in the intersections caused by inattention. In addition, another study showed that the traffic safety problem is related to intersections and that neither bicycle paths nor

bicycle lanes can solve this problem (Lewiston & Wachtel, 1994). Furthermore it has been recorded that most accidents seems to happen at the crossing between bicycle paths and roads (DSTI, 1998). Moreover, a quantitative meta study has shown that bicycle paths in intersections increase the accident risk by approximately 20% although the users find it 20% more secure (Gårder et al., 1994).

In general, a number of foreign studies showed an increased risk for cyclists when bicycle paths were implemented.

1.2 Danish studies

Previously in Denmark, the perception was that bicycle paths increased traffic safety. A comparative study (with or without paths) from 1969 based on only four main roads in the Danish capital, Copenhagen indicated that bicycle paths increased traffic safety (Jørgensen & Rabani, 1969). However, the first larger Danish study in 1979 raised questions about the positive traffic safety effect of bicycle paths. The '1979 study' was a comparative study based on a large number of roads in Copenhagen. It showed while bicycle paths improved traffic safety for cyclists, the paths has a serious negative effect on traffic safety for moped riders (Herrstedt & Jørgensen, 1979).

In 1985, the largest Danish study to date was conducted. It was a before and after study with a comparison group and included 105 road sections, with a total length of 64 km, distributed in the larger towns in the entire country. The results showed that the number of injury accidents and injured persons increased by 25% when a bicycle path was implemented. The increased number of accidents was mainly located in intersections where the number of cyclist accidents increased by approximately 50%, while the rise for moped accidents was even more serious with 65% increase in accidents. The problem seems greatest at intersections with traffic lights. The increase has been most clear in left turn accident into oncoming traffic, single accidents with mopeds or cyclists and accidents with pedestrians involved (Bach et al. 1985). Moreover, another Danish study showed that some 75% of the bicycle accidents involving cars happen in intersections (Larsen, 1994).

After these poor results regarding traffic safety on bicycle paths, particularly in intersections, some new small scale studies were carried out in the early nineties.

In one study, seven intersections were studied with conflict analysis technique, and the following variables were analysed: removal of the kerb on bicycle paths up to the intersections; narrowing of

the cyclist area on approach to the intersections; division of the cyclist and car area with a profiled stripe up to the intersection and bike area painted through the intersections. The result was: an increase in the number of turning drivers who gave way to cyclists, a change in behaviour among car drivers that is assumed to improve traffic safety for cyclists (Herrstedt & Nielsen, 1993).

Furthermore, in another study based on conflict analysis technique including four intersections, the changes mentioned in the study above were supplied with a 5 m secluded stop line for cars. The main result was a reduced proportion of cars that yield the right of way for cyclists by up to 75%. (Nielsen, 1994a)

Moreover, in a third study, 30 intersections were studied with conflict analysis technique and the number of accidents in the before and after period was analysed. These intersections were also equipped with a 5 m secluded stop line for cars. The results are based on a small amount of data, but they show a reduced number of accidents and serious conflicts involving right turning cars and straight riding cyclists. (Nielsen, 1994b)

Summarising, the three last-mentioned studies have shown improvements in traffic behaviour if different modes of transportation are forced to interact a little up to intersections even when they still are separated in intersections, but the results are uncertain and mostly based on short time behaviour studies. Moreover, the accident studies have not taken into account if any regression effect occurred.

A new large scale study on bicycle paths in Copenhagen showed some problems regarding traffic safety. It was a before and after study with comparison group and included 20.6 km roads where bicycle paths were implemented between 1977 and 2003. The before and after periods were between 1 and 5 years. A statistically significant increase in the total number of injury accidents by 10% was found. It is mainly caused by a significant increase of 18% in the number of injury accidents in intersections. On sections a small insignificant reduction by 10% and 4% for injury accidents and injuries, respectively was found. When looking at the number of injured vulnerable road users in intersections, the highest increase has been for moped drivers (37%). Statistically significant results have also been found for pedestrians (28%) and cyclists (22%). Additionally, data on Annual Daily Traffic (ADT) were collected for the studied segments. Data on ADT for both motorized vehicles and cyclists/moped riders were available for most sections. The ADT for cyclists increased by an average of 18 to 20%, while the motorized traffic decreased by 10%. The change in risk caused by these changes in traffic volume is modeled in the study and is included in

the results. The accident types that have increased the most were: rear end collisions between cyclists and moped riders; right turning cars involving cyclists or moped riders; and cyclists or moped drivers involving embarking/disembarking passenger from buses or coaches (Jensen, 2006).

Even though the problems regarding traffic safety and bicycle paths has been published over a number of years, the Danish municipalities have continued to use bicycle paths as a measure of traffic safety improvement for vulnerable road users.

Based on the above mentioned, the following hypotheses guided the analyses presented in the current paper:

- Bicycle paths built on Danish roads in built-up areas in the period from 1989 to 2000 have led to a decrease in traffic safety, despite the intention that the paths would improve traffic safety.
- Hence, there have been no improvements regarding safety for bicycle paths built in the nineties compared to those built in the seventies and early eighties.

2 Methods

In this study, a bicycle path is defined as a one-way path next to the traffic lane, in the same direction as the traffic lane. It is separated from the lane by a kerb and elevated by 7 to 12 cm. A blue print of the type of road segments included in the study is shown in Figure 1. In some of the sections there are two traffic lanes in each direction. On Danish bicycle paths, bicycles and unregistered mopeds with a built-in speed limit of 30 km/h are allowed. Pedestrians must use the pavement while registered mopeds with a built-in speed limit of 45 km/h must use the traffic lanes.

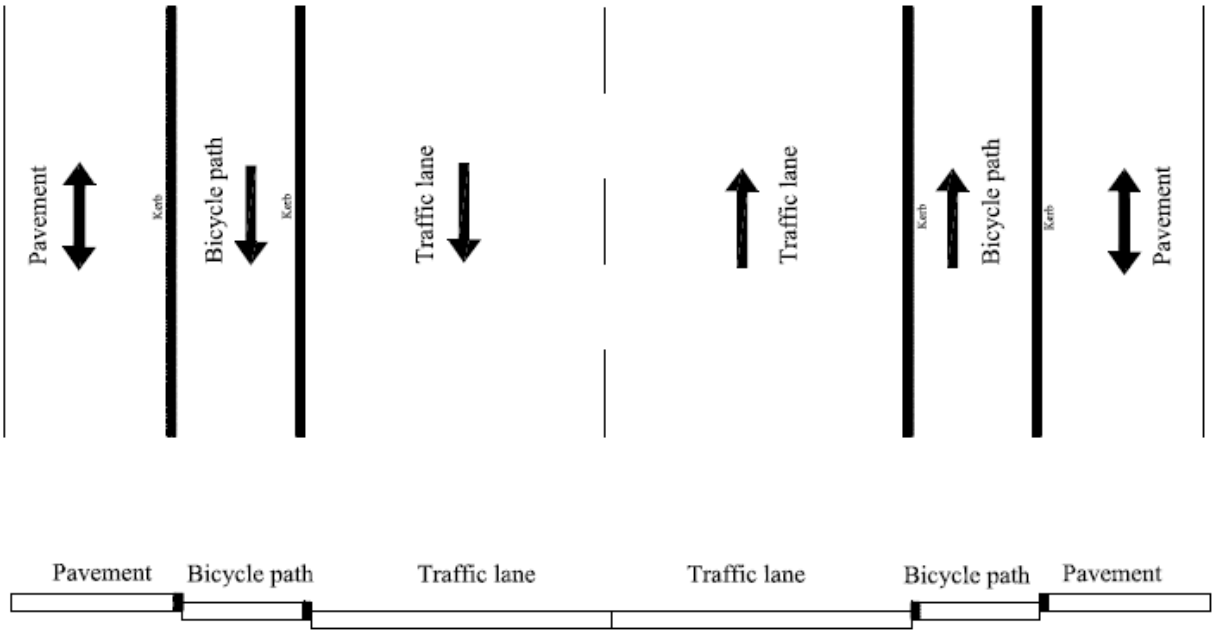

Figure 1. A blue print showing the definition of a bicycle path.

2.1 Research design

The study was carried out as a before and after study with comparison group. When using a comparison group it is presumed, that if the studied sections had no bicycle paths the change in number of accidents would have been similar to the change in number of accidents in the comparison group. Consequently, the expected number of accidents in the after period is calculated by multiplying the number accidents in the before period on the study sections with a correction factor. The correction factor is found by dividing the number of accidents in the comparison group in the after period with the number in the before period. See equation below.

$$C = \frac{I_a}{I_b}$$

Where

I_a is the number of accidents in the after period in the comparison group,

I_b is the number of accidents in the before period in the comparison group, and

C is the correction factor.

Correction factors are calculated on more specific accidents groups according to the type of accidents being studied. For example, when measuring the effect on all accidents, all accidents in the comparison group should be included or when measuring cyclist accidents all cyclist accidents in comparison group should be included.

With this methodology, general trends, changes in accident registration, and improved safety equipment, for example in vehicles, are taken into account when calculating the expected number of accidents. Each road section had a before and an after period attached. The lengths of these periods should be identical for each single road section. The periods should be 3 to 5 years long. This period of time was chosen to avoid or at least minimise any regression effect. For a more basic discussion of this procedure and the selection of correction factors see (Hauer, 1997; Agerholm et al., 2006).

2.2 Road segments and accidents in the study

Nineteen of the largest municipalities and eight counties in the western part of Denmark (Jutland and on Funen) were asked to send in data about bicycle projects for the study. Bicycle projects from the eastern part of Denmark – including Copenhagen were not included in the study. The data were mostly collected via a web based questionnaire. In all, 46 sections with a total length of some 40 km were sent in for the study. These sections are located in 17 of the towns, and the selection criteria were that the sections are on larger roads in built-up areas with bicycle paths on both sides. The bicycle paths were constructed between 1st January 1989 and 31st December 2000.

All accidents included in the study and in the comparison group are extracted from the official Danish accident database, which is based on police reported accidents. One must be aware, that one accident can contain more than one injury or fatality, so the number of accidents is differs from the number of injuries. It means, that theoretically the number of injury accidents can decrease while the number of injured persons can increase.

Moreover, one accident that involved e.g. a moped rider and a cyclist is counted as one accident. However, it is also counted as one accident involving a moped rider, and one accident involving a cyclist. Hence one cannot summarise these two groupings and get the same result as the total number of accidents (The Danish Road Directorate, 2005).

The comparison group is based on general accident data from all roads in built-up areas in the 19 municipalities which were initially part of the study. Accidents that occurred from the beginning of 1986 to the end of 2004, were included. Furthermore, only roads where no changes in the facilities for bicycle users were registered were included. For the size and characteristic of the comparison group see Table 1.

Injury accidents	
In total	16,790
In total with cyclist involved	6,866
In total with moped riders involved	3,347
In total with pedestrian involved	2,848
In total with cars and vans involved	12,804
Injuries and fatalities	
Fatalities	529
Serious personal injuries	9,681
Minor personal injuries	8,702

Table 1. The size of the comparison group.

When effects from a certain measure are studied, it is essential to have a large number of accidents to base calculations on, because it will decrease the effect of accidents' stochastic nature. On the other hand it is essential that only accidents which are affected by the measure are included in the study. The first might result in uncertain results while the latter might cause blurred results. This study was based on accidents on a large number of shorter sections, and accidents located in the end intersection may have a greater effect on the results of the study. It was therefore decided only to include accidents in the end intersection when the collision point was located in the hatched area on Figure 2, hatched 'leg' has a bicycle path. This decision was taken, because it was assessed that only accidents in this area may have been influenced by implementing a bicycle path.

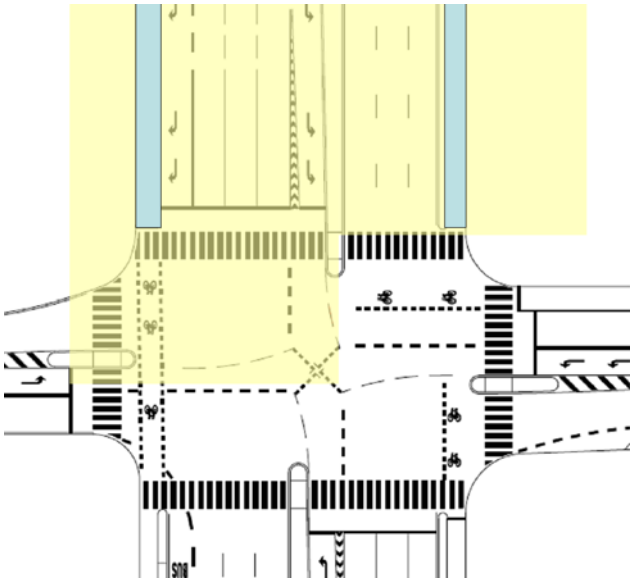

Figure 2. Accidents in the end intersections were included, if the collision happened in the hatched area.

2.3 Statistical Analyses

To assess whether the found results were caused by random variations or not, a significance test was performed. In this study, the significance test was a chi square test. The significance test decides how probable it is that a result is based on randomness, and the following definitions are used:

Increase or reduction - The difference between two numbers of accidents is statistically significant, if the level of significance is below 5%. The increase or reduction is shown in per cent and this percentage states the best estimate of the change.

Tendency for increase or reduction - The difference between two numbers of accidents is stated as plausible albeit uncertain, if the level of statistically significance is between 5 and 10%. The increase or reduction is shown as a percentage and this percentage states the best estimate of the change.

Inexplicable change - The difference between two numbers of accidents is not statistically significant, if the level of statistically significance is above 10%. It can be caused by random variations or by a low number of accidents.

3 Results for bicycle paths in medium and large towns

Table 2 shows the total change in number of injury accidents, and the number of personal injuries for all road users after implementing bicycle paths on the 40 km of roads. One should be aware that small deviations in the comparison groups might result in small differences in the results. It appears that the number of injury accidents has increased by 14%, and that the number of accidents with serious injures or fatalities has increased by 14%, while the number of all injuries has increased by 6%. None of these results are statistically significant.

All road user groups, Intersections and sections	No. of injury accidents	No. of injuries	No. of serious injuries and fatalities
Before	263	304	176
Expected after	222	261	135
Observed after	253	278	153
Changes	+14%	+6%	+14%
Statistical significance	No	No	No

Table 2. Injury accidents, injuries, seriously injuries and fatalities on 46 main roads in built-up areas before and after implementing bicycle paths.

Table 3 shows how the safety has been affected for the vulnerable road users (moped riders, cyclists and pedestrians) after implement of bicycle paths. It is notable that the increased number of injury accidents (25%) is statistically significant. The increase has primarily resulted from a significant increase of injury accidents (34%) at intersections. The number of injured vulnerable road users has increased by 17% (Insignificant). This increase is based on an increase of 28% of injuries at intersections (Tendency for significance). The number of serious injuries or fatalities among vulnerable road users has increased by 24% (Insignificant). In intersections, the increase was 25% and on the road sections it was 20% (Both insignificant).

Vulnerable road users	No. of injury accidents			No. of injuries			No. of serious injuries and fatalities		
	Intersections and sections	Inter-sections	Sections	Intersections and sections	Inter-sections	Sections	Intersections and sections	Inter-sections	Sections
Before	173	103	70	191	110	81	110	59	51
Expected after	139	84	56	155	91	65	79	42	37
Observed after	174	113	61	181	116	65	98	53	45
Changes	+25%	+34%	+9%	+17%	+28%	0%	+24%	+25%	+20%

Statistical significance	Yes	Yes	No	No	Trend	No	No	No	No

Table 3. Injury accidents, injuries, serious injuries and fatalities on 46 main roads in built-up areas before and after implementing bicycle paths. Vulnerable road users (cyclist, moped riders and pedestrians)

Table 4 shows the accident distribution among the different groups of vulnerable road users. Accidents involving moped riders at intersections increased by 94% (Tendency to significant). Also increases by 18% and 63% have been found for cyclist and pedestrian accidents, respectively.

Injury accidents	Moped riders			Cyclists			Pedestrians		
	Intersections and sections	Inter-sections	Sections	Intersections and sections	Inter-sections	Sections	Intersections and sections	Inter-sections	Sections
Before	34	13	21	109	79	30	41	15	26
Expected after	28	10	17	87	65	23	32	12	21
Observed after	42	21	21	105	77	27	45	19	26
Changes	+51%	+94%	+24%	+21%	+18%	+17%	+41%	+63%	+26%
Statistical significance	Trend	Trend	No	No	No	No	No	No	No

Table 4. Injury accidents with moped riders, cyclists and pedestrians on 46 main roads in built-up areas before and after implementing bicycle paths.

Data on Annual Daily Traffic (ADT) were collected for the studied segments. Data on ADT for motorized vehicles were available for most sections while it was only available in a few cases for cyclists and moped riders. No clear change in ADT was found for motorized vehicles nor for cyclists and moped riders. Consequently, there is nothing to indicate that implementing bicycle paths results in an increase in the number of cyclists and moped riders in medium sized and large towns in Denmark. As there has been no increase in the number of users, this cannot be the reason for the increase in the number of accidents. Also the large scale study in 1985 found that implementing a bicycle path did not impact the number of cyclists and moped riders (Bach et al., 1985).

4 Conclusion

Through the years many studies have shown that bicycle paths in built-up areas impair traffic safety. A new Danish study presented in this article confirms these results. It covers bicycle paths in built-up areas in medium and large towns in the western part of Denmark in a before and after study

with comparison group. In general, implementing of bicycle paths increased the number of injury accidents by 14%. This change was not statistically significant. The change was mainly caused by an increase in the number of injury accidents with vulnerable road users i.e. moped riders, cyclists and pedestrians by 25% (Significant). Moreover, the number of injury accidents with vulnerable road users in intersections had increased by 34% (Significant), while the effect on sections was small and uncertain. It was especially a problem regarding moped rider accidents that increased by 51% in total and 94% at intersections. Both results were found tendency to statistical significance. Also for cyclists and pedestrians a similar but lower trend has been observed. So the main results are that bicycle paths impair traffic safety and this is mainly due to more accidents at intersections, and that there has been no improvement in the design of new bicycle paths compared to the older ones.

5 Acknowledgements

A large number of road authorities were contacted to collect data for the first study. They have been essential to obtaining the necessary data. For this reason we wish to thank the staff in the technical divisions/departments in Esbjerg, Fredericia, Frederikshavn, Haderslev, Herning, Hjørring, Holstebro, Odense, Randers, Silkeborg, Sønderborg, Vejle, Aalborg and Århus municipalities and in the former counties of Funen, North Jutland, Ribe, Ringkøbing, South Jutland, Vejle, Viborg, and Aarhus.

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