



Road Directorate Denmark
Ministry of Transport

Safety of Cyclists in Urban Areas

Danish experiences

Traffic Safety and Environment

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Synopsis

This report summarises and describes a series of projects included in the Road Directorate Bicycle Programme. This programme deals with the development of new types of design and the assessment of current types of design

The Bicycle Programme is focusing on the safety of cyclists in urban areas only, as 9 out of 10 recorded accidents occur in cities.

This report consists of four parts, of which the first part outlines the general accident situation in Denmark, with special emphasis on the safety of cyclists. Furthermore, a brief introduction is given to the two analytical methods used in the projects, ie. accident investigations and video recordings of behaviour patterns.

The second part deals with the safety of cyclists at junctions, where new lay-outs of 4-way junctions controlled by traffic lights, and T-junctions controlled by give-way markings, have been developed and tested. It has proved that by reducing the lateral distance between drivers and cyclists, and by demarcating the conflict zone clearly, it is possible to modify road-user behaviour in a way that can be expected to improve road safety. It was also demonstrated in an individual project that recessed stop lines in vehicle lanes at junctions controlled by traffic lights, together with extended cycle paths, significantly reduced the number of accidents involving cyclists travelling straight through the junction and drivers turning to the right.

The third part deals with the safety of cyclists on stretches of roads between major intersections. The safety of cycle lanes is studied and new lay-outs at bus stops are tested. The construction of cycle lanes reduces the total number of accidents to cyclists by approximately 35% and the total number of accidents involving casualties by 40%. It was demonstrated that at bus stops an increased distance between bus passengers alighting from a bus and cyclists, as well as more visible marking of the conflict zone, do change cyclist behaviour in a way that is assumed to improve road safety. However, it has not been possible to change the behaviour of bus passengers.

The fourth part briefly describes other Danish and foreign studies of cyclist safety. In this part, a comparison is made between the recent study of cycle paths described in Part 3 and two earlier Danish studies of cycle path safety.

Finally, advice is given on how cyclist safety can be improved in specific areas of the road network and, in conclusion, a description is given of further research.

Part 3. Road safety of cyclists on road stretches

Chapters 6 and 7 deal with the safety of cyclists on stretches between junctions. The road-safety effects of cycle lanes established in urban areas are described in Chapter 6. Moreover, 3 new designs for cycle paths at bus stops are presented in Chapter 7.

The safety effects of cycle lanes have been analysed through the comparison of accidents occurring before and after the construction of a cycle lane and through comparison of the accident risk on stretches with cycle lanes, cycle paths and stretches without cycle installations. The study of the effects of cycle lanes is limited to stretches between junctions. However, minor junctions, such as driveways, filling stations, car parks, etc., are included.

On urban stretches that have cycle paths, the major part of accidents between cyclists and pedestrians happens at bus stops.⁽¹⁹⁾ Against this background, 3 new designs for cycle paths at bus stops have been developed. Their primary purpose is to make the conflict area visible, to clarify as far as possible who must give way and, finally, to be inexpensive in terms of installation and maintenance.

6. Road-safety effects of cycle lanes on stretches between junctions in urban areas

Over the past 10 years, cycle lanes in Denmark have in many cases been used as an inexpensive way of promoting the safety of cyclists and easing their passage. This has been done in spite of the fact that the road-safety effects of cycle lanes in urban areas have never been studied in Denmark.

In this project, the road-safety effects of cycle lanes on stretches between junctions are investigated. Minor junctions to driveways, filling stations, etc., are included. The study is based on before and after analyses of accidents on stretches on which cycle lanes have been installed after 1984. In the following, this is called the "before/after study". Similarly, a comparison was made of accident risks on stretches with cycle lanes, cycle paths and without cycle installations; this part is called the "lane/path/without study".

In the before/after study, a comparison is made of the numbers of accidents occurring over a period of up to 5 years before and after the installation of a cycle lane.

In the lane/path/without study, a comparison is made of the accident risk on chosen road stretches where the average annual daily traffic (ADT), ribbon development and speed levels are similar, but where cycle lanes, cycle paths or no cycle facilities are installed.

The input data for the lane/path/without study was obtained on 59.3 km of stretches with cycle lanes, 25.3 km of stretches with cycle paths and 34.7 stretches without cycle facilities. Only cycle lanes and cycle paths of at least 100 m have been included.

The before/after study uses the same cycle-lane stretches as the lane/path/without study. However, cycle lanes constructed before 1985 have been excluded. The reason for this is that the traffic statistics in the study are from 1991, and they have been used in interpolated form for the before period (the length of which was 5 years). Here, it was considered that interpolation to before 1980 would give an altogether too great level of uncertainty.

In the before/after study, a comparison is made of the actual number of accidents after reconstruction and the number forecast for the same period. The forecasts were calculated on the basis of accidents occurring during the before period, with correction for the general accident trend. The general accident trend was calculated on the basis of accidents occurring during corresponding before and after periods on 45 control stretches that resemble the cycle-lane stretches but that lack cycle installations. The control group is identical to the stretches without cycle installations of the lane/path/without study.

In this project, a cycle lane is defined as an area marked with cycle symbols (V21) and demarcated towards the vehicle lane by a 0.3 m continuous white line (see Fig. 21). All of the cycle lanes studied have widths of between 1.0 and 1.6 m, including the marking strip. The dependency of accident risk on cycle lane width is studied in this project.



Figure 21. Cycle lane.

6.1 Before and after studies of cycle lanes

Background

In this before/after study, an analysis was made of all accidents involving casualties that were reported to the police, occurring on 37 stretches with cycle lanes (a total of 35 km) during before and after periods of up to 5 years. Based on the number of accidents occurring in the before period, and from the accident trend on a number of control stretches, a forecast was made of the number of accidents that can be expected in the after period, had cycle lanes not been established. The expected number of accidents was then compared with the actual number of accidents occurring in the after period. The control group comprises 45 stretches in urban zones and is the same group that was used in the subsequent lane/path/without study, under the designation "stretches without cycle installations".

Results

Number of accidents involving casualties on stretches with cycle lanes

type	all accidents involving casualties	accidents resulting in injured cyclists	accidents resulting in injured moped riders
before	74	26	13
observed after	41	11	10
forecast after	65	17	21

Table 15. All accidents involving casualties and accidents resulting in injured cyclists or moped riders in the before and after periods, together with the numbers of accidents forecast for the after period.

The overall number of accidents involving casualties and cyclist or moped-rider casualties drops from the before period to the after period (see Table 15). If the observed and forecast numbers of accidents after implementation are compared, it can be seen that there were fewer accidents involving casualties than the forecasts in the case of all road users and in the case of cyclists and moped riders only.

Frequency of accidents

5 different formulae were used to calculate the accident frequencies for all accidents involving casualties, accidents involving casualties to cyclists and accidents involving casualties to moped riders. The formulae are given in Appendix 3. It must be expected that the numbers of accidents involving cyclists and moped riders are dependent on the numbers of bicycles and mopeds and on the number of vehicles. For this reason, the accident

frequencies for cyclists and moped riders, respectively, have been calculated in Table 16 according to traffic density and according to cyclist/moped rider density, respectively.

type	all accidents involving casualties according vehicle ADT	accidents resulting in injured cyclists		accident resulting in injured moped riders	
		according to cycle ADT	according to vehicle ADT	according to moped ADT	according to vehicle ADT
before	0.41	0.76	0.14	3.72	0.07
observed after	0.19	0.31	0.05	2.74	0.05
forecast after	0.29	0.47	0.08	5.86	0.09

Table 16. Accident frequencies for the before and after periods and forecast accident rates for the 3 groups of road user.

The accident frequency for all groups of road user, as well as for cyclists and moped riders considered separately, was lower in the observed after period than was expected, which means that cycle lanes have had a beneficial effect on accidents involving casualties (see Table 16). As the figures are small, it has not been possible to perform a χ^2 -test in order to determine whether or not the differences in the accident frequencies are significant. On the other hand, the differences in the numbers of accidents have been tested for significance.

accidents involving casualties	$U_{\text{obs. after}}$	$U_{\text{frecst. after}}$	number of accidents avoided ($U_{\text{obs. after}} - U_{\text{frecst. after}}$)	significance	level of significance
all accidents	41	65	24 (37%)	significance	2%
accidents resulting in cyclist casualties	11	17	6 (35%)	not significance	30%
accidents resulting in moped rider casualties	10	21	11 (52%)	tendency towards significance	10%

Table 17. Levels of significance and number of accidents avoided through the installation of cycle lanes.

The number of all accidents involving casualties was 37% less in the after period than was expected. This difference is significant at the 2% level (see Table 17). Accidents involving casualties to cyclists are also lower in the after period than was expected, but the difference is not significant. In the case of moped riders, the true number of accidents involving casualties was 52% less than was expected, which is significant at the 10% level.

Age and sex

Many youngsters are injured. The 9 to 29-year-olds comprise 67% and 83%, respectively, of the injured (before and after periods). Of these, the 15-year-olds alone comprise 26% and 29%, respectively. In both the before and after periods, more than 75% of the injured were males.

Degree of severity

The number of cyclists killed or seriously injured dropped from 15 in the before period to 7 in the after period. On the other hand, the number of moped riders killed or seriously injured increased from 7 in the before period to 10 in the after period.

Accident situations

When cycle lanes were implemented, the proportion of single accidents resulting in cyclist or moped-rider casualties dropped (12 out of 39 accidents involving casualties to 2-wheeled road users, in the before period, but only 4 out of 21 in the after period). There has also been a drop in the proportion of cycle/moped accidents in accident situations 3 and 4 (turning right in front of road user travelling straight ahead, see App. 1), where 7 out of 39 accidents involving casualties to 2-wheeled road users were of these types in the before period, in contrast to 1 out of 21 in the after period.

Accidents with parked vehicles

Accidents with parked vehicles comprise a larger proportion of all accidents involving casualties after the installation of cycle lanes (in the before period 13%, corresponding to 5 out of 39 accidents involving casualties to 2-wheeled road users and in the after period 33%, corresponding to 7 out of 21 accidents involving casualties to 2-wheeled road users).

6.2 Lane/path/without study

Background

In this study, a so-called "with/without" analysis method was used to compare road safety on road stretches with cycle lanes and cycle paths and road stretches lacking cycle installations. This study is based on accidents reported to the police that involved casualties over the years 1988 to 1992 incl.. A number of stretches of the above 3 types were chosen, for which the ribbon development, speed levels and average annual daily traffic, etc., were similar. All accidents involving casualties, accident frequencies, accident situations, levels of accident severity, age distribution, etc., were compared for the 3 types of road stretch.

Comparison

design	number of stretches	total length km
lanes	72	59.3
paths	28	25.3
without	45	34.7

Table 18. Number of stretches and their total length.

Table 18 shows that the total lengths of the stretches differ.

The ribbon development of most stretches without cycle installations comprises dwellings, in contrast to the stretches with cycle lanes or cycle paths, where the ribbon comprises mainly industry or is without any facade.

design	vehicles	bicycles	mopeds
lanes	5269	718	81
paths	7128	782	100
without	4852	709	84

Table 19. Average annual daily traffic.

The chosen stretches with cycle paths had a higher average annual daily vehicular traffic (see Table 19) and higher speed limits than the stretches with cycle lanes and without cycle installations. The reasons for these differences are the common practice on then to use cycle

paths, cycle lanes or nothing at all.

The above differences are probably of certain significance to the results of the study.

Results

Number of accidents involving casualties

design	all accidents involving casualties	accidents resulting in injured cyclists	accidents resulting in injured moped riders
lanes	103	27	22
paths	64	21	6
without	75	18	12

Table 20. Number of accidents involving casualties on the 3 types of stretch, for the period 1988 to 1992.

From Table 20, it can be seen that the number of accidents involving casualties on the 3 types of stretches differ quite widely. A direct comparison of the number of accidents cannot be made as the traffic densities and lengths of the stretches are different.

Cyclists are casualties in about 25% of all accidents involving casualties occurring on stretches with cycle lanes and stretches without cycle installations, whereas cyclists are casualties in about 30% of all accidents involving casualties occurring on stretches with cycle paths. Moped riders are casualties in about 15% to 20% of all accidents involving casualties occurring on stretches with cycle lanes and stretches without cycle installations, whereas moped riders are casualties in only 10% of all accidents involving casualties occurring on stretches with cycle paths.

Accident density

Comparisons of accident densities for all accidents involving casualties occurring on each of the 3 types of stretch show that stretches with cycle lanes have the lowest accident density, whereas it is a little higher on stretches with cycle paths and stretches without cycle installations.

Accident frequency

The accident frequency is calculated on the basis of the number of accidents involving casualties relative to the traffic flow. 5 formulae were used to calculate the accident frequency in the project. These formulae are given in Appendix 3.

design	all accidents involving casualties, according to vehicle ADT	accidents resulting in cyclist casualties		accidents resulting in moped riders casualties	
		according to cycle ADT	according to vehicle ADT	according to moped ADT	according to vehicle ADT
lanes	0.20	0.38	0.05	2.73	0.04
paths	0.19	0.58	0.06	1.30	0.02
without	0.24	0.40	0.06	2.26	0.04

Table 21. Accident frequencies based on accidents involving casualties for the 3 types of cycle installation and groups of road users.

For all accidents involving casualties, the accident frequencies on cycle paths and cycle lanes are of almost equal magnitude, but slightly higher on stretches without cycle installations (see Table 21). For cyclists, the accident frequency is a little lower on stretches with cycle lanes than on the other 2 types of stretch. For moped riders, the accident frequency is a little lower on stretches with cycle paths than on the other 2 types of stretch.

The casualty frequencies of Table 22 are only calculated on the basis of the number killed or seriously injured.

design	all killed or seriously injured, according to vehicle ADT	cyclist killed or seriously injured		moped-rider killed or seriously injured	
		according to cycle ADT	according to vehicle ADT	according to moped ADT	according to vehicle ADT
lanes	0.14	0.20	0.03	2.48	0.04
paths	0.10	0.39	0.04	0.22	0.003
without	0.19	0.25	0.04	1.13	0.02

Table 22. Casualty frequencies based on numbers of killed or seriously injured for the 3 types of cycle installation and groups of road users.

For all road users killed or seriously injured, the casualty frequency is lowest on stretches with cycle paths and highest on stretches without cycle installations. In the case of cyclists killed or seriously injured, the casualty frequency is lowest on the cycle lanes, whereas in the case of moped riders it is significantly lower on stretches with cycle paths relative to the other 2 types of stretch.

Significance test

The differences in the total number of casualties on cycle lanes, cycle paths and stretches without cycle installations, corrected for the differences in stretch length and ADT, have been tested. It emerges that the accident risks on the different types of cycle installation are not significantly different. However, there is a tendency for cycle paths to have a beneficial effect for moped riders relative to cycle lanes and stretches without cycle installations.

On the other hand, the differences in the number of seriously injured (all road users) are significantly lower on stretches with cycle paths than on stretches without cycle installations. For moped riders alone, there is a significantly greater number of serious injuries on stretches with cycle lanes than on stretches with cycle paths.

It has therefore not been possible on the basis of this analysis alone to ascertain which of the 3 types of cycle installation is the safest.

Degree of severity

severity	number of casualties in (all accidents involving casualties ?)					
	lane		path		without	
	number	%	number	%	number	%
killed and seriously injured	75	64	34	48	58	60
lightly injured	42	36	37	52	39	40
total	117	100	71	100	97	100

Table 23. Relationship between numbers of serious/light injuries.

Table 23 shows all casualties (including casualties in vehicles) on each of the specified types of stretch, distributed as killed/seriously injured or lightly injured. On stretches with cycle lanes and without cycle installations, 60% to 64% of all casualties were either killed or seriously injured, whereas only 48% were killed or seriously injured on the stretches with cycle paths.

Accident situations

In the case of cyclists on cycle lanes, casualties occur most frequently when they are hit from behind (11 of the 27 accidents involving cyclist casualties). In the case of moped riders on cycle lanes, single accidents or accidents involving parked vehicles are the most frequent types of accident (10 of the 22 accidents involving moped-rider casualties).

No characteristic types of accident were found on stretches with cycle paths and stretches

without cycle installations.

Width of cycle lane

The accident frequency is largely the same for all cycle lanes with a width of 1 to 1.6 m, both in the case of all road users and of cyclists alone. The frequency of accidents involving moped-rider casualties is 3 to 4 times higher on the narrow cycle lanes, with a width of less than 1.2 m, than on the other cycle lanes covered by the study. However, the results were based on very weak data.

Speed levels

On stretches with cycle lanes, the accident frequency for cyclists increases with the prevailing speed limit on vehicles. No relationship was found for all road users together and for moped riders alone.

The relationship between accident frequency and prevailing speed limit was not studied for stretches with cycle paths and stretches without cycle installations.

Bus routes

Where there are bus routes, the accident frequency is higher on stretches with cycle lanes. The relationship between accident frequency and the presence of bus routes was not studied for stretches with cycle paths and stretches without cycle installations.

Conclusions of lane/path/without study and before/after study

The road-safety effects of establishing cycle lanes on stretches between junctions were studied by 2 different methods. In the first study, the numbers of accidents involving casualties before and after the establishment of cycle paths were compared. In the second study, the safety of stretches with cycle lanes, cycle paths and without cycle installations was compared.

One overall conclusion of the 2 studies is as follows:

Before/after study

- The establishment of cycle lanes reduces the total number of accidents involving casualties by about 37%, of accidents involving cyclist casualties by about 35% and of accidents involving casualties by more than 50%. The reduction in the total number of accidents involving moped-rider casualties is significant, whereas the results for cyclists alone are not significant, and there is a tendency towards significance in the results for moped riders alone;

- On stretches with cycle lanes, the number of cyclists killed or seriously injured dropped from 15 in the before period to 7 in the after period. On the other hand, the number of moped riders killed or seriously injured increased from 7 in the before period to 10 in the after period;

Lane/path/without study

- The lane/path/without study shows that stretches with lanes or paths tend to have a lower frequency of accidents involving casualties than stretches without cycle installations, when all casualties are considered. The differences are not, however, significant. Neither are the differences significant in the case of cyclists alone and moped riders alone (see Table 21).
- For all road users killed or seriously injured, the casualty frequency is lowest on stretches with cycle paths and highest on stretches without cycle installations. This difference is significant. The differences are not significant in the case of cyclists alone and of moped riders alone (see Table 22).

Before/after study and lane/path/without study

- In the before/after study, an increase from 13% to 33% in the proportion of accidents involving 2-wheeled casualties and parked vehicles was noted after the establishment of cycle lanes. The lane/path/without study confirms this result.

Overall, the studies indicate that road safety is improved by the implementation of cycle paths or cycle lanes on the stretches between junctions.

The before/after study shows that cycle lanes on stretches between junctions have a beneficial effect on cycle/moped accidents, but that there is an increase in the number of accidents involving 2-wheeled casualties and parked vehicles.

It was not, however, possible to determine whether cycle paths or cycle lanes are safest in the lane/path/without study. However, there are indications that accidents involving 2-wheeled casualties are less serious on stretches with cycle paths than on stretches with cycle lanes.

It has proved that the stretches with cycle paths have higher average quantities of vehicle traffic and higher speed limits than the stretches with cycle lanes and the stretches without cycle installations in the study. This could have an effect on the accident and risk factors found. However, this difference is a general problem that cannot be eliminated immediately, when methods of investigation are based on comparisons of safety on differing road stretches.

Concluding remarks

The projects of the Bicycle Programme and study of the literature have brought new knowledge to light on the safety of cyclists. Certain circumstances should be mentioned in this context.

Stretches between junctions

Several studies have shown that the safety of cyclists can be improved by the implementation of cycle paths or cycle lanes, especially when the quantity and speed of vehicular traffic is high. But it is not possible to prove statistically whether cycle paths or cycle lanes on stretches are the safest approach for cyclists.

Paths are considered to give greater security and the severity of accidents is less than on lanes. Cycle lanes appear to result in an increase in the number of accidents in which 2-wheeled road users and parked vehicles are involved. If a cycle lane installation is too narrow (1 to 1.2 m), there is a weak tendency for the accident frequency of moped riders to increase.

On the basis of present knowledge, it must be considered appropriate to implement cycle paths on stretches of traffic roads between junctions in urban areas, where the quantity of traffic, speed level and the desired service level make it necessary. Cycle lanes can be implemented on other stretches.

The marking of conflict areas at bus stops without islands on stretches with cycle paths, and where there are many cyclists and bus passengers, appears to be a good idea from a safety point of view. Such marking is intended to make the conflict area visible and to clarify who must give way. Proposals for this are shown in Appendix 7.

Junctions

The conventional extended cycle paths at junctions controlled by traffic lights appear to be less satisfactory from the standpoint of safety. The latest experience from new designs indicates that it may be worthwhile to truncate cycle paths 20 to 30 m before junctions and to replace them with, possibly, narrower cycle lanes, or to use profiled markings to reduce their breadth. This measure should be supplemented with a cycle area extending through the junction (see Appendix 7).

At 4-way junctions controlled by traffic lights, with extended cycle paths/lanes in the access

area, it is proposed that the vehicle stop line be recessed by 5 m in all vehicle lanes relative to the cyclists' stop line.

In the case of T-junctions controlled by give-way markings, at which many accidents occur and where there are cycle paths (on the "main road"), it can be a good idea either to mark the conflict area at the entrance to the side road or to establish physical lateral control. Proposals for this are shown in Appendix 7.

Further work

The road safety problems of cyclists have not been resolved with the conclusion of the Bicycle Programme. The designs for cycle installations that have been studied and described in this report have had the purpose of reducing certain specific types of accident in which cyclists are involved. But cyclists are also involved in other frequent types of accident, which should be studied with a view to finding approaches that can reduce their frequency.

The Bicycle Programme will be continued and, as now, split into studies of problems at junctions and on stretches. New measures that are more effective in securing the safety of 2-wheeled road users must be developed for junctions especially, where most of the accidents in which cyclists are involved occur. Some of the problems to be studied include:

Junctions

- Accidents between cyclists travelling straight ahead and oncoming vehicles turning left.
- Accidents in which cyclists turn left in front of vehicles approaching from behind.
- Combination of short cycle path and recessed stop line at junctions controlled by traffic lights or give-way markings, but which lack cycle installations.

Stretches

- Single cycle accidents.
- Systematic identification of cycle accidents, on the basis of casualty-ward records.

The following 3 studies were already in progress when this report was published.

Studies in progress

- The safety effects of cycle lanes at junctions (statistical before/after accident analyses).
- The consequences from the standpoint of accidents of implementing cycle lanes between through lanes and right-hand turning lanes at junctions controlled by traffic lights.
- The safety effects of cycle areas extending through junctions.
- The design of roundabouts.

As was described in the first part of this report, cycle accidents are greatly under-represented in the official accident statistics. The designation of cycle black spots on the basis of casualty-ward records would possibly give another, truer, picture of accidents than is gained from the official statistics. In such case, more widespread use of casualty-ward data could contribute to improving road safety work carried out with a view to reducing cycle accidents.

Finally, much effort will be required to disseminate the knowledge and proposals described in this report, and still to be gained in the future, to the individual highway authorities. Part of this work has already been done, in the form of a supplement to the action plan for road safety policy - a cyclists' package that is based partly on experience gained from the Bicycle Programme. But it will not be possible to improve the safety of cyclists in urban areas until the knowledge we have gathered is used in relevant projects in the road network.