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Infrastructure for safe future cycling

Compact accident research

Unfallforschung der Versicherer
GDV

Content

Preface 4

Methodology 5

Overview of cycle traffic 5

Influence of traffic volume, age and speed 6

Inceasing cycling traffic volume 7

More older cyclists 8

Higher cycling speeds 8

Scenarios of future cycle traffic 8

Recommendations 12

Conclusions 13

Bibliography 14

Preface

Various research projects and accident investigations have provided information on cycling safety such as accident risks, typical accident constellations or behavior of cyclists or motorists involved in cycle accidents. The demographic change, increased use of pedelecs and an increasing share of cycling traffic on total traffic in cities are current changes in cycling traffic. This affects especially cycling traffic volumes, age-structure of cyclists and cycling speeds. In the future, more heterogeneous cycling speeds are expected in urban traffic.

The impact of these changes on cycling safety and possible requirements for a safe cycling infrastructure, appropriate traffic rules and traffic education were not sufficiently researched yet. Therefore, the German Insurers Accident Research (UDV) commissioned a respective study. As a result, recommendations for a safe future design of cycling infrastructure were developed.

This "compact accident research" summarizes the results of the study. Detailed results are described in the research report, which can be downloaded from www.udv.de/publikationen. The report is available in German only.

Methodology

First, a literature review was conducted summarizing the current knowledge on accident risks, typical accident constellations and behavior of cyclists as well as of motorists involved in cycle accidents.

Second, a macro- and microscopic analysis of cycle accidents was carried out and supplemented by behavioral observations. The investigations were carried out separately for intersections and segments. 192 segments with cycling infrastructure in German cities were researched. Third, traffic counts and behavioral observations were conducted including 108,677 cyclist and speed measurements of about 19,000 cyclists.

The behavioral observation identified red light violations, trajectories at intersections and the acceptance respectively the non-usage of cycling facilities on segments.

Possible influences of cyclists' age, cycle type or type of cycling facility on cycling speeds were examined on segments. The results of the traffic counts, speed measurements and behavioral observations were then compared to the amount of cycle accidents with personal injuries of the years 2009 to 2011. Different influencing factors on cycling safety were analyzed within a micro- and macro analysis of cycle accidents. Based on generalized linear models, multi-criterial influences on cycle accidents were identified and summarized in an accident prediction model.

Six scenarios of possible future trends of cycling safety were developed on the basis of the accident analysis and the behavioral observations. The scenarios considered different trends in age structure, cycling speeds and cycling traffic volume. As a result, changes in cycling accident numbers, accident severity and accident types were assessed. Based on a comprehensive evaluation of the scenario results, conclusions were drawn on required adjustments to cycling infrastructure (segments and intersections) in order to ensure a high level of traffic safety under the changing conditions of cycling.

Overview of Cycle Traffic

Since the 1990's a general decline in road accidents with serious injuries could be recorded, but not likewise for cycling traffic. In relation to their population, cyclists aged older than 65 years have a higher risk of fatal cycling accidents in built-up areas [1]. Compared to their traffic volume, male children and adolescents and cyclists over 65 years are more frequently involved in accidents than other cyclists [2].

Previous studies showed an increase in accident density with increasing cycling traffic volume at cycle paths. Similar effects could not be found for cycle lanes or advisory lanes. Cycle paths at intersections and access roads have shown to be a particular risk for cycling safety followed by wrong-way driving cyclists [3].

In a study from 1992, an average cycling speed of 16 km/h was measured [4]; a further study in 2003 showed average cycling speeds of 16.8 km/h [5].

At collision speeds of over 40 km/h between cyclists and motorists, as they occur in built-up areas, the probability of severe injuries (MAIS 3+) increases. Furthermore, it was found that regardless of collision speeds, older cyclists have a higher likelihood of severe injuries compared to younger cyclists [6].

Demographic change could lead to more older cyclists and thus to an increase of cycling accidents, more severe cycle accidents or to different accident constellations. So far, not much is known about the accident risk, constellations and severity of older cyclists.

Furthermore, the influence of increasing cycling traffic on the cycle accident frequency is unknown, as is the possible influence on accident severity and accident types.

Surveys need to determine whether the cycling speeds continued to increase as it was shown between the studies in 1992 and 2003 and to which extent this has an impact on cycle accident frequency, severity and accident types.

Therefore, further research was needed how these changes may affect future cycling traffic. For the cycling infrastructure it needs to be analyzed whether the increase of accident density with rising cycling traffic volume at cycle paths also hold true for cycle lanes and advisory lanes or when guided in mixed traffic with motorists on the roadway and thus results in a need of actions.

Influence of traffic volume, age and speed

In general, the analysis showed an increase in:

- Cycling traffic volumes,
- More older cyclists and
- Cycling speeds.

By analyzing the accident data and the cycling behavior different effects of an increase in cycle traffic volume, more older cyclists and higher cycling speeds on cycling safety were found. Table 1 summarizes the effects on cycle accident frequency, accident severity and accident types. Strong effects are characterized by significant changes of values and which were based on a large data collective, as for example between different age groups. Small effects were defined for effects which could only be found on the basis of small collectives or for relatively low percentage changes of lower than three percentage points. Superimposed effects are effects where the influencing factor correlates strongly with other factors. The-

Table 1: Overview on effects

	Influences at segments (with intersecting minor roads)			Influences at signalized intersections		
Influence factors	Accident frequency	Accident severity	Accident types	Accident frequency	Accident severity	Accident types
Cycling traffic volume	MA, APM (strong effects)	MA (small effects)	MA (small effects)	MI	MI	MI
Cyclists' age	MA (strong effects)	MA (strong effects)	MA (small effects)	MI	MA (strong effects)	MA, MI (small effects)
Cycling speed	MA, APM (superimposed effects)	MA (small effects)	MA (small effects)	MA (small effects)	MA (small effects)	MI (small effects)

Degree of influence
- strong effects
- small effects
- superimposed effects
- No (verifiable) effects

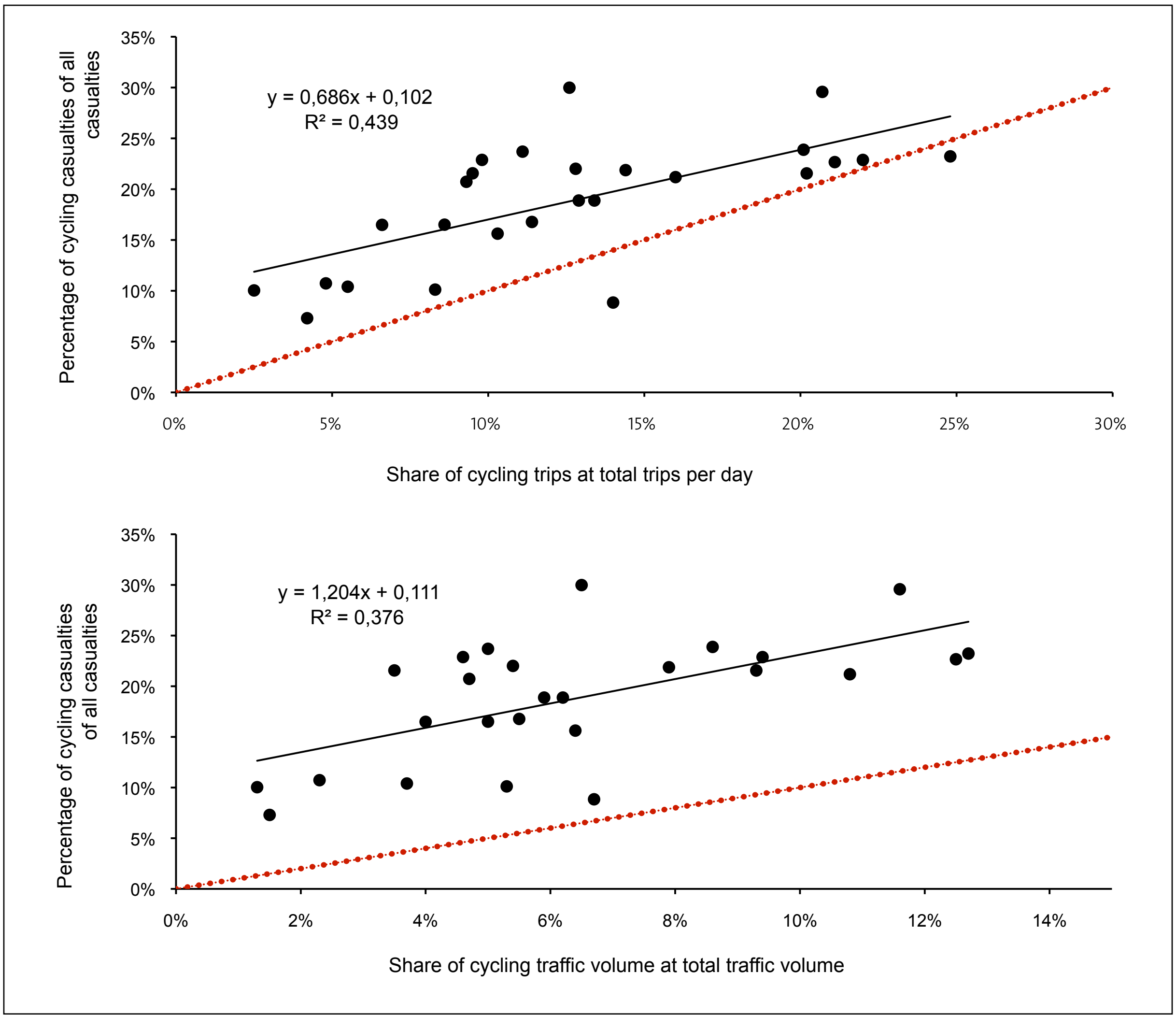
Valuation basis:
MA Macroscopic accident analysis APM Accident prediction model MI Microscopic accident analysis

refore the influencing factor does not exhibit a causal effect on safety, but acts in combination with the others. Superimposed effects could be found for instance between driven cycling speeds and cycle accident frequency. Since increasing cycling volumes could account for a higher share of explained variance in cycle accident frequency than increasing cycling speeds, the causal effect in this case was attributed to the cycling traffic volume.

Increasing cycling traffic volumes

The comparison of modal splits in several German cities showed that cyclist generally are more often involved in accidents than they take part in traffic regardless of the cities' population. The increased cycle accident risk could be shown both in relation to their share at total trips per day (Figure1, upper picture) and their share on traffic volume (Figure 1 lower picture).

Figure 1:
Relationship between daily tripes and traffic volume of cyclists and cycle accidents ([7], [8])



More older cyclists

At segments cyclists older than 65 have an accident rate twice as high compared to 25 to 65 year old cyclists and a higher share of severe accidents both on segments (25 % vs. 13 %) and signalized intersections (27 % vs. 14 %)[1].

At signalized intersections, no relation between cyclists' age and cycle accident frequency could be found.
While there showed to be no significant changes in the distribution of all cycle accident types at segments between the age groups, a significantly higher proportion of driving accidents could be found for accidents caused by older cyclists (30 % vs. 22 %).

Turning-into-, turning-off- and crossing accidents dominate the cycle accidents at signalized intersections regardless of the age groups. However, turning-into-, crossing- and turning-off accidents showed higher percentage shares for age groups older than 65 years.

Higher cycling speeds

With 18.2 km/h the average cycling speed increased by about 1.5 km/h compared to previous studies. A comprehensive analysis of cycling speeds showed significant speed differences between cycle types, cycling infrastructure types and age groups - the latter having the greatest impact on cycling speeds.

Small correlations were found between cycling speeds and the number of cycle accidents. However, within the accident prediction model, which describes the impact of several factors on cycle accidents, this effect could not be confirmed. Due to the superimposition of both effects (segments with high cycling volume were likely to have high cycling speeds) cycling traffic volume was attributed as the original effect since it accounts for a higher share of explained variance in cycle accident frequency.
Concerning the accident types, segments with higher cycling speeds have a higher percentage share of accidents in longitudinal traffic and accidents with parking vehicles (15 % vs 12 %). At segments with higher cycling speeds cycle accidents with killed or seriously injured cyclists were registered more often.

The microanalysis of accident-prone signalized intersections showed a rise in the number of accidents with killed or seriously injured cyclists at intersecting links with high cycling speeds. However, a general influence between cycling speeds and accident severity could not be found at signalized intersections.

Scenarios

Possible trends of changes in cycling were developed on the basis of today's cycle traffic (S0). Following the initially described trends, possible changes of cycling traffic volumes, age structure and cycling speeds were proposed (see Table 2). The characteristics of each scenario are summarized in Table 3.

Using the results of the accident prediction model and the macro- and micro accident analysis, future developments of cycle accident frequency, accident severity and the distribution of accident types could be estimated for segments and signalized intersections. The aim was not to calculate an exact prediction, but to demonstrate future developments of cycling safety on the basis of today's analysis of cycle accidents.

For segments, the calculations lead to the following results (see Table 4, Table 5):

- The increase of cycle accident frequency is mainly influenced by the rise of cycle traffic.
- Cycle accident numbers increase to a lesser extent compared to cycle traffic.

1 The values are based on an additional larger accident collective: accident data of the cities Berlin, Dresden, Chemnitz, Leipzig, Magdeburg, Halle, Münster, Troisdorf, Bonn and Cologne with 27,487 accidents at segments and 15,528 accidents at signalized intersections

Table 2: Scenarios

S1	Short-term moderate increase of cycle traffic
S2-A	Medium-term changes in age structure
S2-A-20	Change in age structure and moderate increase of cycle traffic
S2-A-20-V	Changes in cycling speeds due to changes in age structure and new cycle types, moderate increase of cycle traffic
S2-A-40	Change in age structure and significant increase of cycle traffic
S2-A-40-V	Significant increase of cycle traffic and cycling speeds

- Changes in age structure and cycling speeds show marginal changes in cycle accident frequency.
- Cycle accidents with killed or seriously injured increase in a larger extent with the rise of cycle traffic than cycle accidents with injury.
- Cycle accident severity will therefore rise in the future.
- Changes in age structure and cycling speeds account for the increase of serious cycle accidents to the same extent (by about 3 to 4 percentage points).
- Significant changes in the distribution of cycle accident types are not expected. However, compared to the average increase of cycle accidents, accidents in longitudinal traffic will rise to a greater extent whereas accidents with parking vehicles will rise to a lesser extent.

The next question was to what extent the cycling facilities are able to meet the challenges of future cycling. Future trends in cycling could lead to a shift of cycle accidents at different types of cycling infrastructure. The calculations were carried out for the most common types of cycling infrastructure in Germany:

- Cycling on the roadway in mixed traffic with motorists,
- Cycle lanes,
- Cycle paths and
- Advisory lanes.

Table 3: Characteristics of the scenarios

<table>
<tr><th rowspan="2">Scenario</th><th rowspan="2">Time scale</th><th colspan="2">Age structure in cycle traffic</th><th colspan="3">Share of cycle traffic (modal split)</th><th colspan="2">Cycling speeds</th></tr>
<tr><th>unchanged</th><th>more cyclists over 65 years</th><th>13%</th><th>20%</th><th>40%</th><th>unchanged</th><th>increased</th></tr>
<tr><td>S0</td><td>2014</td><td>X</td><td></td><td>X</td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>S1</td><td>2020</td><td>X</td><td></td><td></td><td>X</td><td></td><td>X</td><td></td></tr>
<tr><td>S2-A</td><td rowspan="5">2030</td><td rowspan="5"></td><td rowspan="5">X</td><td>X</td><td></td><td></td><td>X</td><td></td></tr>
<tr><td>S2-A-20</td><td rowspan="2"></td><td rowspan="2">X</td><td rowspan="2"></td><td>X</td><td></td></tr>
<tr><td>S2-A-20-V</td><td></td><td>X</td></tr>
<tr><td>S2-A-40</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2">X</td><td>X</td><td></td></tr>
<tr><td>S2-A-40-V</td><td></td><td>X</td></tr>
</table>

Table 4: Scenario results on the number of cycle accidents and accident severity at segments

Scenario	Time scale	Age structure in cycle traffic		Share of cycle traffic (modal split)			Cycling speeds		Increase of cycle accidents with injury [%]	Increase of cycle accidents with fatal or serious injury [%]	Share of cycle accidents with fatal or serious injury [%]
		unchanged	more cyclists over 65 years	0%	+20	+40	unchanged	increased			
S0	2014	X		X			X		± 0	0	14
S1	2020	X			X		X		29	36	14
S2-A	2030		X	X			X		1	3	14
S2-A-20	2030		X		X		X		31	40	15
S2-A-20-V	2030		X		X			X	31	43	15
S2-A-40	2030		X			X	X		102	136	16
S2-A-40-V	2030		X			X		X	102	140	16

Table 5: Scenario results on the cycle accident types at segments

Scenario	Time scale	Age structure in cycle traffic		Share of cycle traffic (modal split)			Cycling speeds		Increase of cycle accidents with injury [%]	Increase of cycle accident types [%]						
		unchanged	more cyclists over 65 years	0%	+20	+40	unchanged	increased		Driving accident	Turning-into-/ crossing accident	Turning-off accident	turning-off accident	Accident with parking vehicles	Accident in longitudinal traffic	Other accident
S0	2014	X		X			X		± 0	0	0	0	0	0	0	0
S1	2020	X			X		X		29	29	**25**	**26**	30	30	**32**	28
S2-A	2030		X	X			X		1	2	3	3	1	0	1	2
S2-A-20	2030		X		X		X		31	31	31	32	33	**27**	**36**	**27**
S2-A-20-V	2030		X		X			X	31	32	32	31	**35**	**25**	**39**	**24**
S2-A-40	2030		X			X	X		102	**96**	100	**108**	103	**93**	**117**	**88**
S2-A-40-V	2030		X			X		X	102	99	101	104	**107**	**90**	**122**	**85**

For the calculations it was assumed that cycling traffic increases equally at all types of cycling infrastructure and that the share of each type of cycling facility remains unchanged.

The smallest increase of cycle accidents compared to todays' level was found at segments with cycle paths. With an almost constant share of cycle accidents at advisory lanes, more accidents at cycle lanes and within mixed traffic are expected at segments (Figure 2).

At signalized intersections, the calculations lead to the following results (see Table 6):

- A relationship between cycle accident frequency and cycling traffic volume, cycling speeds or cyclists' age structure could not be found
- A higher percentage of older cyclists, however, lead to an increase of severe accidents
- Although no significant changes could be found for the distribution of accident types, scenarios with more older cyclists showed a disproportionate higher increase of turning-into-/ crossing accidents.

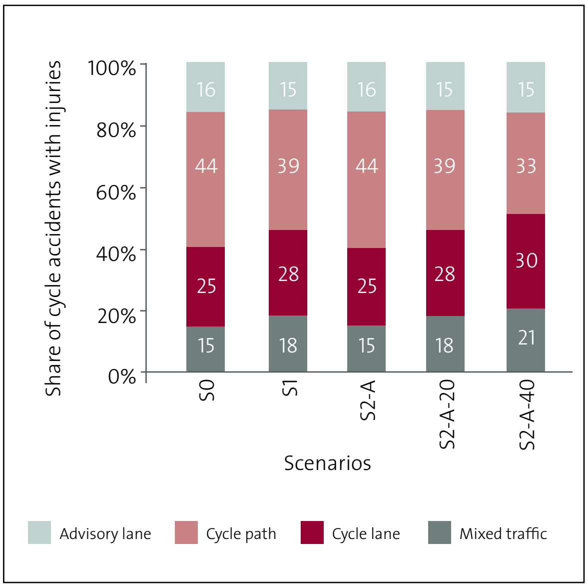


Figure 2: Scenario results on the distribution of cycle accidents between the types of cycling facilities

Table 6: Scenario results on the number of severe accidents at signalized intersections

Scenario	Time scale	Age structure in cycle traffic		Share of cycle traffic (modal split)			Cycling speeds		Increase of cycle accidents with fatal or serious injury [%]
		unchanged	more cyclists over 65 years	0%	+20	+40	unchanged	increased	
S0	2014	X		X			X		0
S1	2020	X			X		X		0
S2-A				X			X		2
S2-A-20					X		X		2
S2-A-20-V	2030		X					X	2
S2-A-40						X	X		2
S2-A-40-V								X	2

Recommendations

Specific recommendations are given for each scenario group (higher cycling traffic volume, more older cyclists, higher cycling speeds). They are based on the knowledge of todays' cycling. Already, there are cycling facilities with high cycling traffic volumes and speeds and special accident features of older cyclists.

Higher cycling traffic volume

The expected increase in cycling traffic volume and thus the increase of cycle accidents, particularly severe accidents, are a key area for actions at segments in the future. Generally, all common cycling facilities like mixed traffic, cycle lanes, cycle paths and advisory lanes are suitable in the future. Especially cycling facilities in accordance with the German guidelines showed to be safe cycling facilities also at high cycling traffic volume conditions. Furthermore, the percentage of wrong-way driving cyclists decreased with increasing cycling traffic volume.

Concerning their low accident rates, cycle boulevards should be implemented as an alternative to common traffic roads if suitable within the road network.

At roads with cyclists guided in mixed traffic and high amounts of accidents in longitudinal traffic (often caused by overtaking motorized vehicles) a reduction of the speed limit should be considered. Sufficient widths at cycle paths should be provided to ensure a safe overtaking of cyclists. Adequate clearances between cycle lanes and parking slots are required.The regulations on the obligatory use of cycling facilities should be adapted taking the width of cycle facilities into account.

More older cyclists

Especially when guided on cycle paths older cyclists should be made aware of the risks of driving the wrong-way. This behavior leads to more turning-into-/ crossing accidents at intersections and road accesses.

At signalized intersections an increase of turning-into-/ crossing accidents can be expected. At locations with high accident frequency possible influences of the signal programs or an insufficient visibility of traffic lights should be investigated since these accidents were mostly due to a disregard of red lights. At intersections with a high amount of turning-off accidents conflict-free signal controlling should be implemented to handle the increase of turning-off accidents.

Higher cycling speeds

Higher amounts of accidents in longitudinal traffic and accidents with parking vehicles need to be expected. Therefore, cycle paths and cycle lanes should be provided with an adequate width. When guided within mixed traffic, a sufficient distance to parking cars needs to be ensured. Cyclists driving at high speeds, like young cyclists and users of pedelecs, should be made aware of the afore mentioned risks.

Cross-scenario related recommendations

Generally, all common cycling facilities like mixed traffic, cycle lanes, cycle paths and advisory lanes are suitable in the future. They should, however, comply with the afore mentioned conditions.

Due to the high accident rates of cycle paths and shared pedestrian- and cycle lanes at intersections, cycle lanes or cycling within mixed traffic are recommended.

Conclusion

Even with an increase of cycling traffic volume, higher cycling speeds and more older cyclists the existing cycling facility types are capable to handle future cycling traffic. Essential is, however, the strict compliance with the current regulations. Cycle paths are safe cycling facilities with regard to the safety at segments but show high accident frequencies at intersections and access roads. Especially due to rising cycling traffic volumes cycling in mixed traffic becomes more important in the future and cycle boulevards should be considered as a possible alternative.

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German Insurance Association
Insurers Accident Research

Wilhelmstraße 43 / 43G, 10117 Berlin
PO Box 08 02 64, 10002 Berlin
E-Mail: unfallforschung@gdv.de
Internet: www.udv.de
Facebook: www.facebook.com / unfallforschung
Twitter: @unfallforschung
YouTube: www.youtube.com / unfallforschung

Author: Dipl.-Ing. Maria Pohle
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GDV
DIE DEUTSCHEN VERSICHERER

German Insurers Association

Wilhelmstraße 43 / 43G, 10117 Berlin
PO Box 08 02 64, 10002 Berlin

Phone: + 49 (0) 30 2020 - 5000, Fax: + 49 (0) 30 2020 - 6000
www.gdv.de, www.udv.de