Design Manual for Bicycle Traffic

About CROW-Fietsberaad

CROW-Fietsberaad is a research centre for cycling policy. The objective of CROW-Fietsberaad is to develop, disseminate and exchange practically oriented knowledge. CROW-Fietsberaad is part of the CROW Knowledge Platform.

CROW devises smart, practical solutions for issues pertaining to infrastructure, public space, traffic and transport in the Netherlands. We do so in conjunction with external professionals who share knowledge with one another and make it utilizable in practice. CROW is an independent, non-profit research organization investing in knowledge for now and the future. We strive towards the best solutions for issues ranging from policy to managing infrastructure, public space, traffic and transport, and work and safety. Furthermore, we are experts when it comes to outsourcing and contracting.

Practical knowledge
Immediately utilizable

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CROW
Galvanistraat 1, 6716 AE Ede
PO box 37, 6710 BA Ede
The Netherlands
Telephone +31 (0)318 69 53 00
Fax +31 (0)318 62 11 12
E-mail klantenservice@crow.nl
Website www.crow.nl

December 2016

ISBN: 978 90 6628 659 7

Foreword

Bicycles are extremely popular with policymakers at home and abroad at present. Encouraging bicycle use is regarded as an effective solution to accessibility problems and risks to health. Cycling (or more cycling) also makes a substantial contribution towards meeting sustainability targets. Furthermore, the many users are increasingly seeing the bicycle as a sustainable, healthy and reliable means of transport. This is evident from (for example) the persistently healthy volumes of bicycle sales (with the electric bicycle being particularly noteworthy) and the growth of bicycle use.

Nevertheless, people will only start using their bicycles more if the cycle infra-structure is in good order. Connections for cyclists have to be attractive and ensure their personal safety. Detours and delays must be kept to a minimum. Thus rendering careful planning of cycle networks and a solid design of facilities essential. Moreover, roads and paths for cyclists must be comfortable and safe for traffic. In all weather conditions. Consequently, in addition to a maintenance programme for road management, attention needs to be given to such matters as winter maintenance.

CROW has been publishing handbooks containing practical knowledge on cycle facilities since as far back as the early 1990s. It is partly down to these publications that cycling and cycle policy are still high on the agenda. Time and again, this ongoing attention to bicycles, as well as the additional interest in them in recent years, gives rise to new developments in terms of bicycles. Which explains why it became necessary to thoroughly revise the Design Manual for Bicycle Traffic from 2006.

The present, revised edition includes 'new topics', such as bicycle highways, forgiving cycle paths and roundabouts for cyclists (primarily referred to as the Zwolle roundabout). Furthermore, trusted measures and facilities are subjected to scrutiny again, sometimes with surprising results. Consider in this regard cycle lanes or bollards barring car traffic from cycle paths.

Just like its predecessor from 2006, this edition of the Design Manual for Bicycle Traffic is *not* a recipe book either; what it *does* present is a wide array of arguments, empirical data, ideas and tips which will assist the designer in affording the bicycle a full place in the traffic and transport system. As the title suggests, the content focuses on design aspects of bicycle traffic: cycle facilities. However, as no facilities are created without policy, the present Design Manual devotes ample attention to policy aspects of bicycle traffic. This also supersedes the Policy Manual for Bicycle Traffic (Beleidswijzer fietsverkeer) from the Dutch Bicycle Council (Fietsberaad).

I would like to take this opportunity to express my gratitude to all those involved in producing this publication, particularly the members of the working group. Without their tireless work and stamina, CROW would not have been able to produce such a voluminous publication.

This CROW project was partly enabled by financing from the Ministry of Infrastructure and the Environment and the Collective Research Fund.

CROW
Dr I.W. Koster
Director

The working group 'Design Manual for Bicycle Traffic Revision' consisted of the following people:

- Rico Andriesse, *Goudappel Groep*
- Stefan Bendiks, *Artgineering*
- Sjoerd Bijleveld, *Drenthe Provincial Authority*
- Ruud Ditewig, *Utrecht City Council*
- Sjors van Duren, *Gelderland Provincial Authority*
- Pieter Goossens, *'cityregion Eindhoven'* (SRE)
- Ria Hilhorst, *Amsterdam City Council - Infrastructure, Traffic & Transport Service* (IVV)
- Peter Kroeze, *Ligtermoet & Partners*
- Marjolein de Lange, *ML Advies*
- Jan-Albert de Leur, *Heerhugowaard City Council*
- Peter Morsink, *Royal HaskoningDHV*
- Jan Hendrik van Petegem, *SWOV*
- Minke Pronker, *Gelderland Provincial Authority*
- Wim Salomons, *Wim Salomons Verkeerskundig Ontwerp*
- Paul Schepers, *Rijkswaterstaat Water, Traffic & Living Environment*
- Herbert Tiemens, *Utrecht Provincial Authority*
- Theo Zeegers, *Fietsersbond* (until 1 June 2015)

Supervision on the part of CROW was taken care of by Hillie Talens, Frans Heijnis and Rowan van de Weerd. Support in terms of content was provided by Hans Godefrooij and Lisette de Wildt (both *DTV Consultants*) and Theo Zeegers. The project was financed by the Ministry of Infrastructure and the Environment, the Collective Research Fund and CROW.

Contents

1 The development of bicycle traffic

This chapter briefly considers the importance and history of the bicycle, before proceeding to discuss government policy vis-à-vis bicycle traffic. The significance of bicycles (including electric ones) for mobility, health and recreation will then be examined.

1.1 The importance of the bicycle

The bicycle is indispensable in the Netherlands when it comes to mobility, quality of life and health [1]. The HEAT model developed by the World Health Organization [2] makes it possible to estimate the health benefits of bicycle use in the Netherlands at some 3% of gross domestic product (GDP) [3]. These benefits alone are many times more than the c. 0.5 billion euros per annum spent on bicycle traffic by the Dutch authorities collectively [4]. The positive effects of cycling on such things as the accessibility of urban centres should be added to this.

Moreover, it turns out that thanks to the prevalence of bicycle use in the Netherlands average life expectancy is around six months longer and absence due to illness is lower than in EU countries where there is less cycling [5]. That said, cyclists are at greater risk than car drivers of being seriously injured in a traffic accident, and what is more, they do inhale a higher quantity of polluted air, but the positive effects on their health of the extra exercise amply make up for these things [6].

The overall benefits of bicycle use are considerable. This is due to the fact that the bicycle, in terms of both requisite space and budget, enables good mobility without adversely affecting urban quality of life. The economic significance of bicycle traffic is evident from (for example) the sizeable proportion of cyclists responsible for retail sales in inner cities [7].

1.2 The history of the bicycle

When the bicycle was introduced at the end of the nineteenth century, the requisite network of connections was already in place in the form of roads, cart tracks and dikes. The main barriers comprised rivers, streams and other watercourses. Numerous foot passenger ferries helped to overcome these barriers.

From a technical perspective, the bicycle was pretty much fully developed around 1900. Dunlop's pneumatic tyre (1888) was the latest revolutionary improvement to the conventional bicycle. The surfacing on roads and paths (or, as was often the case, the lack thereof) was still an issue. The first cycle paths – frequently created by people on their own initiative – were primarily geared towards improving comfort for cyclists.

The advent of the motor car changed a lot of things. Although in absolute terms the number of cars was initially unpromising (in 1930 there were 67,000 passenger cars and 2.5 million bicycles in the Netherlands), the arrival of the car entailed a huge change for the network of roads. The velocity and mass of the different road users suddenly started to vary considerably, which manifested itself in a sharp increase in the number of accidents. In order to improve road safety, cyclists and cars were separated with increasing frequency.
Nevertheless, cycle paths were also created to enable unhindered flow of motorized traffic. Management of bicycle traffic was merely about improving the traffic situation and was primarily geared towards avoiding conflicts with cars. It would be misrepresentative to refer to the approach as an integrated one.

During the postwar reconstruction of the Netherlands, the bicycle played a central role in mobility. It was not until the second half of the 1960s that for the first time more kilometres were being covered by car than were being covered by bicycle. The rapid growth of car traffic in the 1970s led to an extremely high (by today's standards) number of road accident victims. In combination with the energy crisis and the burgeoning environmental problems, this drew an increasing amount of attention to the bicycle. In 1975, this development culminated in the foundation of a nationwide interest group for cyclists. Nowadays it is called the *Fietsersbond* (or Dutch Cyclists' Union in English).

Revolutionary demonstration projects in The Hague and Tilburg – which demonstrated the importance of directness, comfort and reduced delay at traffic lights – revealed that good cycle facilities serve more purposes than just road safety. A demonstration project in Delft showed that a network approach bolsters the competitive power of the bicycle considerably compared to other modes of transport.
It also emerged that in situations with a high degree of bicycle use, neglecting this position results in loss of the bicycle share in the modal split. In other words, lasting policy attention to bicycles is necessary.

1.3 The bicycle and government policy

1993 saw the publication of the first design manual for bicycle traffic, entitled 'Tekenen voor de fiets' ('Sign up for the Bike') [8]. This argued for a properly designed bicycle infrastructure to be created by means of an integrated approach. The aforementioned design manual was an important product of the 'Dutch Bicycle Master Plan', which in turn constituted an elaboration of the second 'Dutch Transport Structure Plan' (SVV2).
The objective of the Master Plan was to increase bicycle use by means of encouraging people to use their cars less (for instance).

In the more businesslike approach of the 'Dutch Policy Document on Mobility' [9] the objectives are divorced from the ideology of the SVV2, but bicycle use remains as important as ever. Nonetheless, a clear, overarching policy is still lacking. At the same time, it has emerged in recent years that the bicycle has the potential to play a significant role in new areas of policy and an even more significant role in existing areas. Consider in this regard reachability, road safety, quality of life/spatial quality, health, air quality and economy.

During the 1980s there was growing awareness that without the bicycle the mobility system would grind to a halt. And that conversely more cycling would result in more space in inner cities. Nevertheless, this insight was not yet being picked up at national level, as is evident from the lack of a clear role for the bicycle in the location and VINEX (housing development) policy.

The Dutch Bicycle Master Plan resulted in change in this regard. Its aim was to give the bicycle policy a boost on a nationwide scale. Subsequently, a great deal of money was invested, particularly in bicycle parking facilities at railway stations, from the 'Make Way for the Bike' programme. In recent years, government policy on bicycles has been more geared towards developing bicycle highways around urban nodes.

The road safety policy is enshrined in the 'Strategic Traffic Safety Plan 2008-2020' [10]. Within this, bicycle safety is cited as an area for attention. The plan is based on the 'Sustainable Traffic Safety' philosophy, which is extremely important for preventing accidents between cyclists and motor vehicles.

A new emphasis is the effort to prevent cycling accidents not involving a motor vehicle, which usually only involve a single bicycle (no collision with other road users). In excess of three quarters of seriously injured cyclists turn out to have been involved in an accident in which no motor vehicle was involved. From the perspective of the Strategic Traffic Safety Plan, knowledge has been amassed on these accidents in recent years. The present publication makes this knowledge usable by highway authorities.
They will be able to use the information for such purposes as formulating a 'Local Cycling Safety Impetus' [11].
The Association of Netherlands Municipalities (VNG) and the Minister for Infrastructure and the Environment have agreed that each local authority will develop such a local approach.

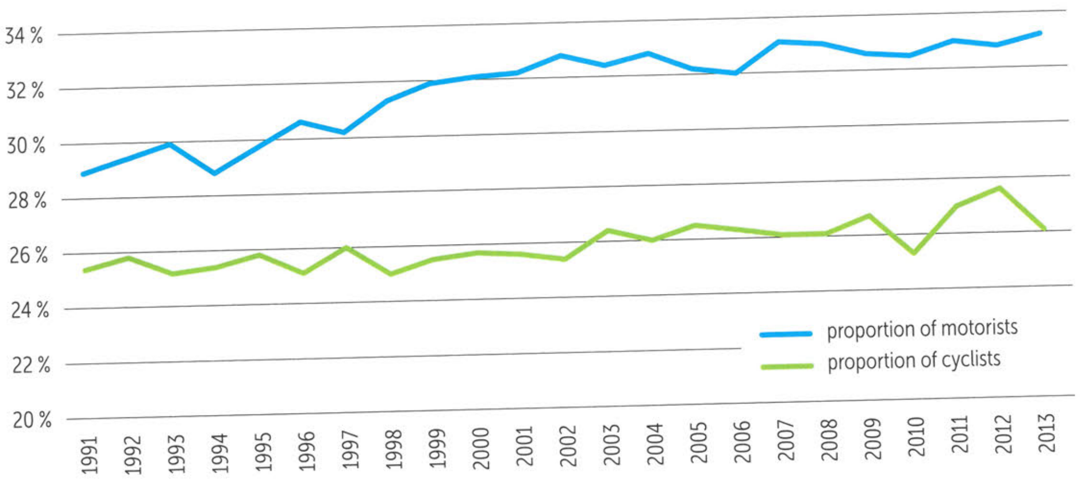

Figure 1-1. Development in the proportion (in %) of car drivers and cyclists respectively in all journeys, 1991-2013 [20]

1.4 The role of the bicycle

The bicycle fulfils an important role in mobility. Figure 1-1 shows that for many years now around 26% of all journeys made in the Netherlands have been by bicycle. Despite the short distance entailed by the average journey by bicycle, the annual kilometrage of cyclists is on a par with that of train travellers (14.5 billion kilometres travelled by bicycle compared to 17.7 billion kilometres travelled by train in 2013). In recent years there has been a sharp increase in bicycle use, particularly in the major cities, though it would appear that bicycle use is declining in the countryside.

Table 1-1. Development in the proportion (in %) of bicycles in all journeys for each distance category in the Netherlands, 2010-2013

Year	0 to 2.5 km	2.5 to 5 km	5 to 7.5 km	over 7.5 km
2010	35.9%	34.1%	21.9%	5.9%
2011	39.1%	37.2%	22.6%	7.2%
2012	38.7%	37.2%	25.0%	5.9%
2013	36.9%	37.2%	21.9%	7.1%

Bicycles play a significant role primarily over shorter distances. In structural terms, the bicycle use proportion for the total number of journeys up to 2.5 km and between 2.5 and 5.0 km is around 37% (see table 1-1).

For all ages and reasons

Throughout the Netherlands people of all ages and income levels and with all sorts of reason for travelling choose to do so by bicycle. To illustrate this point, some data on reasons for travelling has been included below (see figure 1-2). At 44%, the bicycle share is exceptionally high for the reason 'education'. One explanation for this is that children often have no other option than to walk or cycle. Pupils in secondary education in particular go to school by bicycle. Primary schools are often within walking distance. Incidentally, the reason 'education' only encompasses a small proportion (10%) of all journeys made in the Netherlands. For the reasons that constitute much more of a decisive factor for overall traffic the bicycle use proportion still approximates to the general average: from 22.0% for 'work/work-related visit' to 29% for 'shopping'.

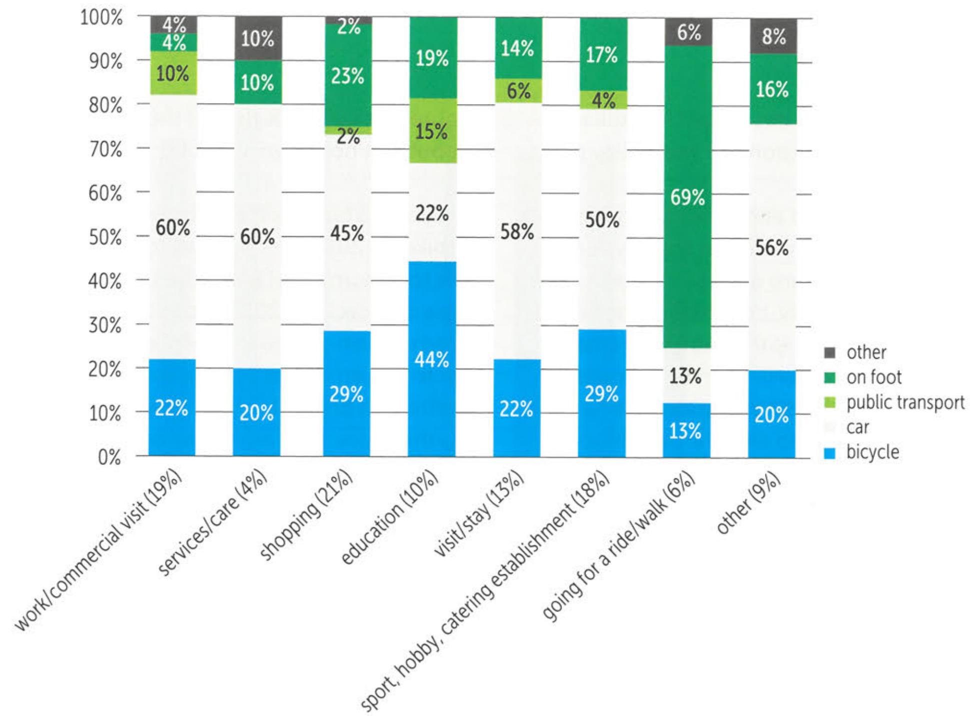

Figure 1-2. Relative proportion of reasons for journey (in %) and the role of the bicycle for each reason, 2013 [20]

Development of number of bicycles

The number of bicycles in the Netherlands has grown from around 18.0 million in 2004 to around 22.3 million in 2013 (see table 1-2). Assuming a total population of 16.8 million inhabitants in 2013, it may be asserted that the average inhabitant has 1.3 bicycles.

Table 1-2. Development of the overall number of bicycles in the Netherlands, 2004-2013 [12]

Year	Approx. no. of bicycles in millions	Year	Approx. no. of bicycles in millions
2004	18.0	2009	19.0
2005	18.0	2010	20.0
2006	18.0	2011	20.8
2007	18.0	2012	22.3
2008	18.0	2013	22.3

Bicycles and health

Over the past decade lack of exercise has had a considerable impact on human health. The consequences are manifest in such phenomena as obesity, adult-onset diabetes mellitus, cancer, cardiovascular disease and depression. It has also become clear that it is much easier for people who do not exercise enough to get active by cycling than it is for them to get active by joining a sports club. For people who are overweight, cycling is an ideal way of fitting regular exercise into daily routines. For the elderly, a bicycle with pedal-assist functionality presents a good solution for keeping active. To be sure, the effect of cycling on weight is scant, but the affects on the other pathologies are considerable, being not only preventive but also, to a certain extent, curative. The positive effects of cycling on health are certainly ten times as much as the sum of negative effects of cycling. Nevertheless, this insight has still not been adequately incorporated into policy plans.

Cyclists are concerned about exhaust gas emissions. And with good reason, as the physical activity in which they are engaged forces cyclists to inhale deeply, breathing in the air pollution. In this regard, it is the extremely small particulate matter in particular, the so-called ultrafine particles, causing considerable harm, both to the lungs and to the heart and blood vessels. The latter is due to the particles being so small that they penetrate deep into the lungs and end up in the circulatory system [13]. The ultrafine particles stem pretty much exclusively from vehicles' combustion engines. They spread over distances of between 1 and around 10 metres, depending on a number of factors. Separating cycle and car routes ('disentwining') can immediately contribute significantly to limiting the burden on cyclists [6].

The economic importance of the bicycle

Recently, recognition of the economic importance of cycling and cyclists ('bikeconomics') has been growing. The production, sale and maintenance of bicycles create jobs. The importance of bicycles to customers is far more significant than retailers estimate [14]. Increased free time has led to tremendous growth in recreational cycling. Cycling and the country's bicycle infrastructure are one of the attractions that bring tourists to the Netherlands.

The electric bicycle

1,051,000 new bicycles were sold in 2014. 21% of these were e-bikes. Figure 1-3 reveals a falling trend in the number of bicycles sold since 2007, but a continuing increase in the number (and particularly the proportion) of e-bikes sold. In 2015, some 5% of the Dutch population had an electric bicycle; at the tail end of 2007 this figure was still at 3% [15]. Of those aged 60+, about 10% now own an e-bike [16].

Around 1.3 billion kilometres were covered on e-bikes in 2012. This equates to around 9% of the total number of kilometres covered by any type of bicycle. In 2012, those aged 60+ covered nigh on one quarter of the kilometres they cycled on an e-bike. In the case of e-bike kilometres it is primarily about new mobility (38%). Furthermore, they are replacing their usual bicycle kilometres (34%) and car kilometres (18%). Within the compass of commuter traffic these latter two percentages are slightly lower (33% and 16% respectively).

Sharp growth in bicycle traffic in cities

Volumes of bicycle traffic in Dutch cities appear to be increasing. For example, bicycle traffic jams and congested bicycle parking facilities in cities such as Amsterdam and Utrecht are increasingly common topics raised in social debates.

Incidentally, there are considerable differences in spatial distribution of bicycle traffic, even within cities. Here, growing bicycle use is often concentrated in certain locations, on certain routes and at certain times. Thus bicycle use in Amsterdam increased by at least 40% over the past decade, albeit chiefly in the historic centre and neighbouring districts. The sharpest growth occurred on the most important routes, particularly those to and from railway station areas [17].

The increasing volume of bicycle traffic in urban areas is not found in nationwide statistics. As stated earlier, the proportion of bicycles in overall mobility has been at around 26% for decades. Meaning that for quite some time one in four journeys made by inhabitants of the Nether-

Figure 1-3. Numbers of new bicycles and e-bikes sold, 2004-2014 [12]

Increasing range e-bikes

Irrespective of their age, e-bike users cover an average of 31 kilometres a week, which equates to more than one and a half times as much as the average cyclist. The rise of the electric bicycle presents opportunities to further enhance the role of the bicycle and to safeguard quality of life. Thanks to pedal-assist functionality, the bicycle is becoming an increasingly obvious choice of transport for larger distances too.
Market research shows that the average distance cycled using an electric bicycle has risen from 6.3 to 9.8 kilometres [15]. The range of the (electric) bicycle is being enhanced as well due to improvements to the quality of the network, e.g. by creating bicycle highways. These will enable a 20% increase in overall bicycle traffic in urban regions. Consequently, the e-bike could become an increasingly important mode of transport in regional mobility – primarily in urban regions, where lots of day-to-day destinations are accessible by means of high-quality cycle infrastructure.
However, the e-bike could even make a significant contribution towards quality of life and accessibility beyond urban areas. Particularly in areas of shrinkage, where accessibility of facilities to those without a car is low when public transport is infrequent.
The *S-Pedelec* is an electric bicycle also offering pedal-assist functionality over 25 km/h. Thus enabling speeds of around 45 km/h to be achieved with this mode of transport, assuming the user pedals briskly. After extensive research, the Ministry of Infrastructure and the Environment decided to classify the S-Pedelec as a moped in the eyes of the law. What this means is that users are required to wear helmets, hold a moped licence and satisfy all other rules and requirements applicable to mopeds. All the same, the S-Pedelec presents good opportunities for further enhancing the range for active and (relatively) clean modes of transport.

lands has been by bicycle. Recent research carried out by the University of Amsterdam [17] has homed in on various spatial environments and social groups. It revealed that there are significant variations within the otherwise constant nationwide figures: in some places bicycle use is booming, whereas elsewhere there is stabilization or even a decrease in bicycle use. Furthermore, it turns out that growth and decline within such environments are concentrated among certain social groups.

Hence bicycle use emerges as being partly determined by spatial and social circumstances. This gives policymakers 'dials to turn' in order to influence the conditions for bicycle use. Figure 1-4 shows the changes in bicycle use according to degree of urbanization. Among those inhabitants in the 'non-urban' category (slightly less than one fifth of the population) bicycle use has fallen, whereas it has remained constant or risen in other groups [18].

The sharp growth in bicycle use in (parts of) cities is leading to (for example) [19]:

- a significant shortage of bicycle parking facilities, particularly at railway stations, in shopping areas and in nightlife areas. Even the spatial quality of public space is being affected by large numbers of bicycles that have been dumped in bicycle parking facilities;
- congested cycle paths, causing displacement of vulnerable groups of cyclists (the elderly and children);
- an increase in the number of cycling accidents involving a single cyclist and no other road user;
- a tense relationship with road traffic (which often has to give way to cyclists and/or take a detour);
- bicycle traffic jams, particularly at traffic lights.

Decrease in bicycle use in the countryside

The fact that residents in rural areas are cycling less is predominantly due to a decline in the population: fewer people equals less mobility. In some peripheral areas it would appear that the scaling up of facilities and the attendant impoverishment play a role. Countryside residents who have to cover greater and greater distances in order to meet their day-to-day needs (consider in this regard supermarket, school, cash machine) are often forced to choose to travel by car. Incidentally, recreational cycling in the countryside is on the up, for reasons that include the rise of the electric bicycle. Hence the decrease in bicycle use among countryside residents does not mean that the volumes on cycle paths outside of the city have waned.

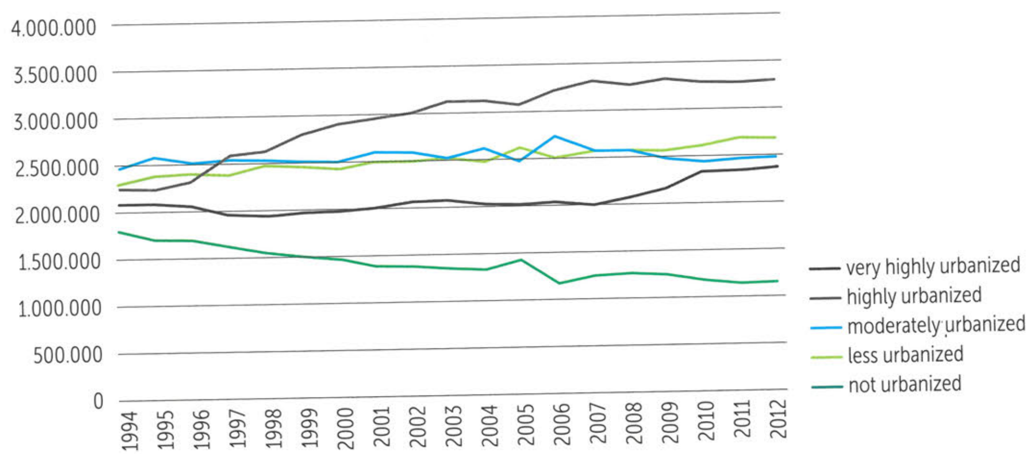

Figure 1-4. Numbers of journeys by bicycle per day for five types of area with a different degree of urbanization

Recreational cycling

Aside from day-to-day, functional journeys, the bicycle also plays a significant role in recreational activities. Research carried out by Statistics Netherlands (CBS) reveals that the Dutch population cycled in excess of 14.5 billion kilometres in 2013 [20], or an average of about 820 kilometres per person.
Thus giving the bicycle a share of 7.3% in the total number of kilometres travelled, measured according to distance covered. In 2007, 52% of the Dutch population (more than 8.5 million people) went on recreational bicycle rides of a minimum of 1 hour. In total, 205 million recreational bicycle rides were taken that year, with this figure encompassing both recreational bicycle rides (just cycling around, day trips and suchlike) and bicycle rides to a recreational destination (beach, sports ground and suchlike).

The Dutch Travel Survey (OViN) is primarily geared towards measuring journeys from A to B and not so much towards bicycle trips ('from A to A'). Maas & Schepers [21] have produced an estimate of the scale of bicycle traffic for recreational purposes. To this end, they combined data from the Mobility Survey of the Netherlands (MON) with that from the Dutch Recreation Day Trips Survey carried out by Statistics Netherlands until a few years ago (incidentally, the latter source is blighted by under-reporting too, but this is much smaller for recreational traffic than in the MON). The results show that roughly one fifth of all kilometres cycled are ridden for recreational purposes and that this proportion is higher among the elderly than it is among young people. In the elderly the figure is in excess of one third of all kilometres cycled. According to the OViN, the number of kilometres cycled for recreational purposes was just 10% between 2010 and 2013. Hence this is a considerable underestimate of both the mobility and the importance of recreational bicycle traffic for such things as restaurants and cafés in rural areas.

The rise of the electric bicycle is occasioning a further increase in recreational bicycle trips in terms of number and length [15]. Recreational cycling is something people do first and foremost for fun, though often for health reasons too. In order to be able to go on bicycle trips, good cycle facilities and an attractive environment are necessary. If these things can be found close to home, then this bolsters quality of life and therefore the quality of the residential environment.

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Figures in square brackets in the text – e.g. [1] – refer to the numbers in the bibliography below.

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2 Cycle-friendly design

This publication describes all steps to arrive at a cycle-friendly infrastructure, from the policy proposal to promote cycling to the physical implementation of measures. Cycle infrastructure is taken to mean all technical facilities intended for cyclists.

Traffic handbooks provide guidelines for designing cycle infrastructure. Which is useful, but they also have the following drawbacks:

- They provide examples and/or templates which encourage their use without reflection.
- They strive towards integration with requirements set by other modes of transport, which results in compromises being made at an early stage.

In order to avoid these drawbacks, the present publication aims to encourage designers to heed the following recommendations during every assignment and at each stage of the process:

- Put yourself in the shoes of the cyclist as future user of the design, also taking into account vulnerable groups of cyclists, such as children and the elderly.
- Ensure that facilities fulfil the policy objectives so that they support the policy.
- Devote attention to the (spatial planning) integration of cycle facilities in the surrounding area.
- See to it that the function, design and use of infrastructure are in equilibrium.

This way of working will force the designer to reflect on and formulate the consequences of the choices inherent in his design.

2.1 Policy as foundation

In order to be able to achieve cycle-friendly infrastructure, technical (design) skills are required. But that is not enough. Countless interests in scarce resources are in conflict with one another on the long road from policy to implementation. The interests of the bicycle are best served by adopting a systematic approach. This means that, in order to achieve a cycle-friendly infrastructure, skills in relation to public administration and economics are needed, as is being alert to the financial reality.

Although a systematic approach clearly pays dividends, cycle policy is often ad hoc in nature. To a significant extent this is due to the fact that cyclists do not cause much problems themselves, only entering the picture if problems surrounding other road users have to be resolved. Furthermore, cycle policy in itself is relatively uncontroversial. Another factor is that people choose to use bicycles for a myriad of (largely positive) reasons. For them, cycling is something pleasant: it is quick, healthy, flexible, good for the environment, fun, normal and reliable. For these reasons, *permanent* policy attention should be self-evident. Furthermore, it turns out to be a success factor for achieving cycle policy [1].

In general, it holds that *local* traffic and transport policy is anchored in the traffic and transport policy of a regional or provincial authority, which in turn is anchored in national policy. The same goes for cycle policy. Nevertheless, in addition to this administrative and policy-related

harmonization, 'harmonization on the street' is necessary. The vast majority of cycle links are local links, which must be developed and if need be resolved at local scale. This includes many links that go beyond municipal boundaries. Thus necessitating harmonization in terms of policy and measures between local authorities.

Cycle-friendly infrastructure should preferably be developed from the perspective of an integrated traffic and transport plan. Only then will it be possible to weigh up the interests of different modalities properly and use the various modes of transport in situations that best do justice to them. Design philosophies such as 'reversed design order' and 'design for all' can go a long way towards anchoring cycling interests in general traffic policy. These approaches do not entail first designing the infrastructure for motorized traffic and then 'shoehorning' the bicycle into it, but instead doing things the other way round.

Although it is not possible to offer a blueprint for the policy process, in general it is possible to distinguish six phases. Keep in mind that these steps present a simplification of the actual state of affairs. In practice it turns out that the design process has a markedly cyclical character and that each of the phases described is actually a subprocess. Within a phase, procedures are run through iteratively. Moreover, it can be necessary to revert to a previous phase of the policy process.

Figure 2-1 presents a schematic depiction of the policy process as outlined by Hoogerwerf and Herweijer [2]. Steps I-IV from the left-hand circle are described on the following pages. In the case of step II, the underlying steps 1-8 from the right-hand circle are also examined.

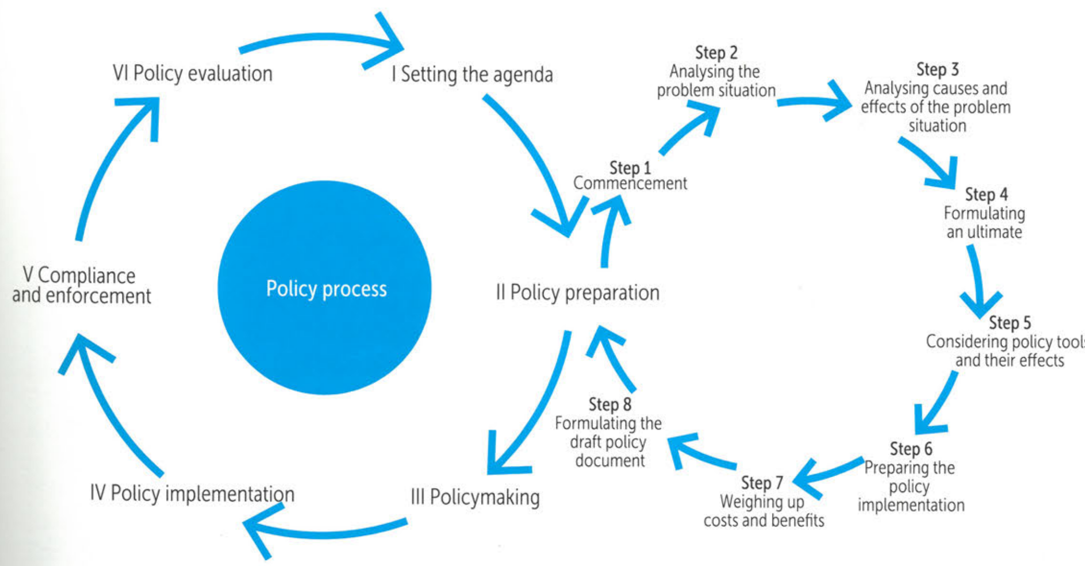

Figure 2-1. Approach to the policy process according to Hoogerwerf and Herweijer [2]

I Setting the agenda
Government policy can be regarded as a response to a societal issue. During the agenda-setting phase such an issue will be brought to the attention of policymakers and politicians. To a significant extent, the options for dealing with a topic (problem) in terms of cycling are determined by the prevailing 'cycle climate', or the positive (or otherwise) attitude towards bicycles on the part of policymakers, politicians and officials (see also the box 'Cycle culture').

'Cycle culture'
In itself, drawing up a plan for cycle policy provides no hard and fast guarantees for a good cycle climate in a municipality. Nevertheless, experience in the Netherlands and abroad does show that *ongoing* and *structural* attention to cyclists in traffic planning will pay dividends in the long run. Developing a broad-based 'cycle culture' within a government organization (both politically and administratively) is frequently more important than the financial resources. Such a culture evolves from an interplay of government (politicians and officials), users (residents and visitors) and social organizations.

II Policy preparation
The policy preparation (and policy formulation) phase entails plans being developed.
This process features a number of steps. The most important of these are specified below in relation to the planning for cycle policy.
1 Commencement
2 Problem analysis
3 Problem cause and effect analysis
4 Formulating an ultimate objective
5 Considering policy tools and their effects
6 Preparing the policy implementation
7 Cost-benefit analysis
8 Formulating the draft policy document

Step 1: Commencement
This step entails objectives being formulated. It is often the case that a project organization is set up too. Objectives are quantified to the fullest extent possible. Abstract objectives are expressed in the form of verifiable standards as best they can be. Additionally, how the policy to be developed relates to existing policy and to the policy of higher authorities – such as provincial authorities, the government and the European Union – can also be scrutinized.

Steps 2 and 3: Problem analysis and problem cause and effects analysis
In essence, a problem is the difference between the desired situation and the current situation (or a future situation). Problem analysis generates insight into the current situation, the desired situation and relationship between the two. When drawing up cycle policy, the basis of this comparison frequently comprises a network analysis and a bottleneck analysis. It is extremely important for the cycling aspect to be charted in 'general' traffic policy too; when ascertaining the quality of road surfacing, for instance, cycle paths must be inspected as well.

For the purposes of establishing the current situation, transport links for existing and potential cyclists are analysed and the most commonly used routes in the network are identified. To figure all this out, an understanding of the pattern of cyclists' origins and destinations is required. Based on a *network analysis*, new connections are selected that to a significant extent will limit detours, reduce the number of encounters with car traffic and foster a cohesive structure for the network.

A *bottleneck analysis* is used to test the quality of the roads and cycle paths on which cyclists are allowed to ride against the programme of requirements. The more important the connection within the main structure, the higher the quality must be (or become) in terms of finish. Once all bottlenecks have been inventoried, they are ordered according to urgency, enabling solutions to be sought out for the most serious bottlenecks first.

During this phase of the design process it is also possible to look for optimal and perhaps even alternative routes. For example, there is little point in improving a shortcut if a slightly longer parallel route has the capacity to offer a greater degree of quality. Any routing through car-free shopping areas will be discussed during this phase of the planning process too.

Steps 4 and 5: Formulating an ultimate objective and considering policy tools and their effects
Once it has been established what the bottlenecks are and what improvements are necessary, the objective of the policy and the choice of measures can be finalized. With a view to the subsequent evaluation of the policy's effects, it is important during this step to make the ultimate objective as measurable as possible.

Once it has been established what the bottlenecks and the objectives are, the focus shifts to the policy tools to achieve these objectives. Important questions in this regard are:
- What improvements are required to achieve the quality formulated in the programme of requirements?
- What facilities will this entail?

The answers could include the following (the following measures will be fleshed out in chapters 4-8):
- constructing segregated cycle paths;
- adjusting signal control;
- reducing the volume of motorized traffic on a route;
- reducing the number of parking spaces for cars on a route;
- constructing a flyover;
- reducing the speed of motorized traffic;
- constructing cycle lanes;
- reprofiling;
- modifying a junction (e.g. turning it into a roundabout);
- improving a crossing;
- improving the road surface;
- constructing bicycle parking facilities;
- resurfacing a bicycle connection (asphalting).

Steps 6 and 7: Preparing the policy implementation and cost-benefit analysis
When preparing the policy implementation, consideration is given to who will be implementing the policy and how this is to be done. The desired measures are implemented in order of priority, with costs and benefits (the efficacy) playing a role. After the programme of facilities has been drawn up, an estimate is made of the total costs of implementing this.

In the case of sizeable investments in mobility in particular, the question as to whether the plans are 'worth all the money' is an important one. Are solutions that will have more of an effect possible? Or perhaps cost less? Or both? In order to answer these questions, a (social) cost-benefit analysis (CBA) is required. In this regard, the so-called 'Wikken en Wegen' tool, developed by CROW-KpVV and available to consult at www.wikken-wegen.nl, can be useful for the purposes of weighing up the pros and cons. For a wide array of issues pertaining to mobility, this will enable better, more efficient and at any rate more thoroughly substantiated decisions to be made.

The measures can subsequently be financed from a variety of sources. It may be possible to include a proportion of the measures under 'regular maintenance'. If improvements fall within the compass of regional or provincial policy, then it will be possible to obtain a contribution from the Provincial Fund. Costs of infrastructure to and in new areas can (or preferably: must) be included in the estimate of the costs and revenues of developing those areas. Other measures will have to be included as 'new policy' in the periodic budget cycles that each and every highway authority has to deal with. It is precisely at that juncture that the value of running through the above steps and having a plan as a foundation will become evident.

Step 8: Formulating the draft policy document
The agreed policy is set down in writing in a draft policy document. This could be a complete cycle policy plan, but it could also be an elaboration of one or more aspects from one (e.g. an elaboration of fiscal measures to incentivize the cycle policy). In practice the draft policy document will vary from an official memorandum to a comprehensive policy document.

III Policy decision
This phase entails decisions being made on the plans that were fleshed out during the policy preparation phase. The plans could be accepted in full, in part or in amended form. Policy decision/decision-making comes down to taking action and earmarking resources. The policy decision phase is tripartite, entailing: securing support, reaching agreement and actually deciding (these three activities are closely interrelated and are not always done in a set order).

IV Policy implementation
This phase sees the set policy measures being implemented. As a result, the social effect of the policy becomes appreciable (or more appreciable).

V Compliance and enforcement
Compliance and enforcement are essential components of the policy cycle. The government has a variety of tools to ensure compliance with policy. These include legal remedies (enforcement of traffic regulations by enforcement officers), communication (campaigns), economic tools (subsidies) and technical resources [3].

VI Assessment of policy
Assessment of policy focuses on the content of the policy, on the processes worked through and on the intended effects. A key question centres on the extent to which the objectives have been fulfilled. It is also possible for a new situation, which has arisen as a result of the policy being operated, to be tested against the (changing or changed) current situation: is the solution chosen at that juncture still the right one? Policy plans should preferably be subjected to an evaluation after five to eight years.

Alert to signals
The quality of a cycle network is indicated by the scores for the five main requirements (see section 2.4). Concentrations of accidents provide a clear signal that function, design and use are not in equilibrium with one another. Nevertheless, it is necessary to also be alert to other signals that the cycle network might not be functioning optimally. Consider in this regard the fact that only a small proportion of cycling accidents are recorded. Furthermore, it could also be that mobility is being suppressed. For example, it is possible that some (vulnerable) users are avoiding a route because they perceive it as being excessively dangerous. The upshot of this could be (for example) that elderly people are staying at home because they do not feel like they can cope with the pace of contemporary (bicycle) traffic. Children are taken to school by car 'for safety reasons'. And due to the reduced personal safety during the evening, some people are not keen on travelling by bicycle.

The actual behaviour of cyclists could deviate from the behaviour that the designer had in mind when envisioning his design. The following signals could point to this being the case.

- Cyclists are dismounting, even though they have right of way. Other forms of informal behaviour in terms of right of way belong in this category.
- A lot of cyclists are riding through a red light, because they perceive waiting to be pointless in the relevant situation.
- Segregated cycle paths are not being used much because another route is quicker, handier or more attractive.

Finally, there could be near misses. These conflicts can be recorded by means of conflict observation techniques. Research shows that near misses amassed in this way can be a good predictor of accidents actually happening [4].

Comfort and discomfort can be measured objectively when it comes to the quality of the road surface. Other forms of discomfort can enter the picture by looking at near misses. Asking cyclists where things are less than optimal is another possibility. Their answers will (consciously or otherwise) indicate the limits of their physical and mental capacities. For a designer of cycle facilities, user complaints provide valuable information on perception of comfort.

2.2 Cycle-friendly infrastructure

Cycle-friendly infrastructure is indispensable if the bicycle is to retain its full place in the traffic system and if this place is to be further reinforced. In other words, infrastructure that enables direct, comfortable journeys by bicycle in a safe and attractive (traffic) environment. Only then will it be possible to compete with the car. Various studies have demonstrated that good cycle infrastructure results in a higher bicycle share in the modal split [5, 6, 7].

Achieving a high proportion of bicycle use by means of a good-quality network requires perseverance and ongoing policy attention. This is evident from an analysis of the cities with the highest level of bicycle use in the Netherlands [8] as well as from research abroad [9].

2.3 The cyclist as a measure for the design

Cycling is physically and mentally demanding. Furthermore, controlling a bicycle requires motor skills to manoeuvre and keep one's balance. In children who are still learning to ride a bicycle, the effort these things demand can come at the expense of their attention to surrounding traffic [10].

Physical exertion is needed to get a bicycle moving and to maintain the momentum. This exertion means that cycling is a salubrious activity. Nevertheless, the strain should not become excessive (and unpleasant). Steep inclines, though also having to ride over poor surfaces for several minutes (for example), can place an excessive strain on cyclists' physical capabilities.

Mental and perceptual competence is essential for operating a bicycle safely in traffic. Particularly in complex traffic situations, such as turning left at a right-of-way junction or in busy traffic, mental resilience is a point for attention in the design. Mental effort is required for the purposes of steering the bicycle, keeping balance and holding course too.

Furthermore, the interaction with other traffic takes a lot of concentration. The less time there is to notice things, e.g. due to a short visibility range or high speeds, the more mental stress is experienced. This increases the probability of information being missed or misjudged. The need to combine tasks is another factor increasing mental stress. Consider in this regard focusing on bumps to avoid hitting them with

the bicycle's wheels and at the same time trying to concentrate on intersecting motorized traffic emerging from a side street. Moreover, cyclists must ensure that they are sufficiently visible to other road users and that they are noticed on time. For example, it is important for cyclists to avoid ending up in the blind spot of motorized traffic as much as possible [11, 12].

Conversely, it goes without saying that cyclists need to be capable of noticing other road users and that they must be able to see and follow the road alignment in all conditions [13, 14]. It is imperative that the road alignment, the edge of the roadway and any unevenness and obstacles are readily visible to the cyclist.

Presented in 1992, the 'Sustainable Traffic Safety' concept is based on the fundamental principle that the road user is central to safe road design. A sustainably safe traffic system has an infrastructure whose design has been adapted to the limitations of human capabilities [15]. Sustainable Traffic Safety originally focused on the role of motorized traffic as a source of danger. Consequently, the same function was assigned to cyclists and pedestrians, namely that of *residential*. It has recently been acknowledged that this approach omitted to consider the *flow function* of the bicycle [16]. Indeed, a road with a residential function for motorized traffic (residential road) could have a significant flow function for bicycle traffic. Bicycle streets show that such a combination can work well.

The starting point for designing cycle facilities within the compass of Sustainable Traffic Safety is 'Design for All'. Cyclists have few standard characteristics. On the contrary, cyclists in the Netherlands are a variegated bunch, in terms of age, sex, physical fitness and reasons for travelling.
In some circumstances, rapid commuting is central to the design (e.g. with regard to design speed). Often it will be vulnerable groups, such as older cyclists or children, who will determine the boundaries. Older cyclists have limited physical fitness, one result of which is that requirements are set in terms of permissible gradient or crossing time. Children are small, inexperienced and sometimes rash. Which is why limits must be set in terms of such things as the height of road signs, discipline at red lights and the complexity of junctions.

Simplifying tasks is something that contributes to fostering a (permanently) safe traffic system as well. Minimizing the probability of mistakes being made and making the infrastructure as 'forgiving' as possible – in case mistakes are made anyway – will considerably improve road safety and bolster cycling comfort. To a significant extent, the philosophy underlying the categorization of roads within the compass of Sustainable Traffic Safety is based on these principles [17].

Research has shown that comfort (or improving comfort), in addition to perception and environmental factors, is an important precondition for fostering bicycle use [18]. Discomfort, or the extent to which comfort is lacking, is strongly related to 'subjective perception' and 'subjective risk'. Complaints about traffic situations arise whenever a critical level of stress is reached between the requirements set by the situation (the stressor) on the one hand and the personal options in terms of satisfying those requirements [19]. The harder it is for the road user to be able to satisfy the requirements, the sooner the critical level is reached. Stress can be caused by such factors as lack of experience and overconfidence (young people), undeveloped capabilities (children) or diminished capabilities (the elderly). If the stress level increases, then so too does the probability of mistakes being made.

Characteristics of cycling

It goes without saying that the designer of a cycle-friendly infrastructure must be au fait with the technical possibilities and limitations of cyclist and bicycle. He will know that cycling has a number of more or less paradoxical characteristics. Thus muscular strength serves as a natural speed limiter, whilst at the same time a certain degree of momentum is indispensable to maintain stability. In addition, the bicycle is vulnerable on the one hand and nimble and extremely flexible in traffic on the other. Furthermore, the bicycle is classed as and considered to be slow traffic, even though it is actually one of the quickest modes of transport in the

Table 2-1. Characteristics of bicycle, cyclist and cycling

1.	**Bicycles are powered by muscular strength**
	For that reason, energy losses are kept to a minimum in a cycle-friendly road design. This is only very slightly applicable in the case of the electric bicycle, as the capacity of the auxiliary motor is much greater than that of the cyclist. That said, the electric bicycle is never of decisive importance when it comes to designing cycle infrastructure.
2.	**Using a bicycle is a balancing act**
	To a large extent, the road safety issues that the bicycle presents relate to its instability. At low speeds in particular (and when standing still) the bicycle is unstable and quick to topple. Crosswinds, slipstream and turbulence caused by lorries, bumps in the road surface and compelled low speeds determine its stability and therefore the requisite room for manoeuvre.
3.	**The bicycle does not have a crumple zone**
	The cyclist's vulnerability is more than evident from accident figures. Nonetheless, the highway authority can have significant influence on this. For example, it can give the cyclist a 'spatial crumple zone', allowing for emergency manoeuvres. Indeed, by 'actively steering', a cyclist can balance along a strip measuring 0.20 m in width, but this is entirely inadequate to the task of enabling comfortable cycling. When a door is swinging open, extra room on the cycle lane could save a life. This vulnerability also means that cycle traffic cannot be mixed with rapidly moving cars and busy lorry traffic.
4.	**The bicycle has very little suspension**
	For that reason an even road surface is necessary to satisfy the requirements in terms of cycle-friendliness (an uneven road surface is perhaps not as much trouble to bicycles with suspension, but even then it will require extra energy).
5.	**The cyclist is riding in the open air**
	This has disadvantages, though it has some advantages too. Shelter from wind and rain will eliminate some of the disadvantages. The advantages must be maintained in the design. Consequently, it will be necessary to devote attention to the attractiveness of the environment in which the cyclist is riding.
6.	**Cycling is a social activity**
	What this means is that cyclists should be able to ride two abreast. This particularly applies on paths where a large volume of recreational cyclists can be expected. Furthermore, the possibility of cycling alongside one another enables parents to supervise their children safely.
7.	**People are the point of departure**
	The number of tasks that a road user is capable of performing and their complexity are not limitless. The probability of mistakes being made increases if the design does not dovetail with the expectations of road users. The designer must respect these limits, and whilst doing so take into consideration slow (less experienced and less capable) cyclists and quick cyclists.

city. Table 2-1 lists a number of characteristics of bicycle, cyclist and cycling.

Quality aspects

When designing roads for motorized traffic, the properties and limitations of the vehicle and its driver are recognized points of departure. Comfort and safety go hand in hand. Such an approach is also appropriate when designing cycle facilities. The cyclist may be regarded as one of the customers within the overall traffic and transport system. His wishes may be regarded as quality aspects for the infrastructure. The task of the designer is to take these things into consideration as best he can when creating facilities.

Taking into consideration the technical and physical characteristics of bicycle and cyclist, the following quality aspects are important when it comes to achieving a cycle-friendly infrastructure:

- Provide space to be able to swerve (even the verge is important), cycling side by side and cornering safely.
- Minimize the resistance cyclists experience when cycling.
- Take cyclists' limits of physical and mental strain into account (optimize mental stress).
- Take cyclists' vulnerability into account.
- Take cyclists' perception into account.
- Devote attention to the spatial planning integration of cycle infrastructure in the surrounding area.
- Ensure a comprehensive, comprehensible cycle infrastructure.

Do also bear in mind that cycling has significant added value in social and economic terms. This could have a decisive effect in a cost-benefit analysis.

Primary requirements for decision-making

When preparing a design the interests of cyclists set out above must be weighed up against the interests of other road users and a variety of functions. At a highly abstract level there are three criteria on which a design can be assessed, namely efficacy, efficiency and fairness [20].

Efficacy
Efficacy is determined by the answer to the question: to what extent does the design do what it is required to do? When it comes to traffic designs, it is possible in principle to measure in terms of quantities like traffic capacity, emissions, safety and sustainability. For many standard designs, knowledge is available in handbooks, including the present Design Manual.

Efficiency
A design's efficiency is determined by balancing its answer to the efficacy question with the costs in a broad sense. In the event of equal efficacy, the least expensive (more efficient) design will be given preference.

Fairness
It is possible for a policy measure to score well in terms of the criteria efficacy and efficiency and yet not be in the interests of a particular group of road users. Supposing (for example) a measure were to entail elderly people no longer being able to cycle. Many people would find this unfair. Despite its efficacy and the efficiency, such a measure would be unacceptable. Looking at the 'unfairness' of decision-making improves public consultation and therefore the (democratic) decision-making. Van Wee has submitted a proposal to chart the criterion fairness better and to operationalize it; to this end, see the box 'Fairness Fairness' [20].

2.4 Main requirements cycle-friendly infrastructure

The fundamental principles and wishes described in section 2.3 can be transformed into five main requirements that cycle-friendly infrastructure must satisfy:

- Cohesion
  The cycle infrastructure forms a cohesive whole and links all origins and destinations that cyclists may have.
- Directness
  The cycle infrastructure always offers the cyclist as direct a route as possible (detours kept to a minimum).
- Attractiveness
  The cycle infrastructure has been designed and fitted in with its surroundings in such a way that it is appealing or attractive.

Fairness Checklist
In his paper 'Ethiek en KBA: naar een checklist voor het meenemen van ethische consequenties van potentiële beleidsopties' ('Ethics and CBA: towards a checklist for the consideration of ethical consequences of potential policy options') [20], Bert van Wee presents the following Fairness Checklist.

1 What is the problem or the challenge?
2 What are the possible options?
3 What are the important advantages and disadvantages of these options?
4 Who are the winners and losers?
5 Can losers be compensated and will this actually be done too?
6 Are there any specific trade-offs?
7 Are there any 'irreplaceable' things / irreversible effects?
8 Will an outcome have to be maximized or not?
9 Is there any 'closed partiality'?
10 Are there any additional values at issue?
And if so: what, for whom and in what way?
11 Are there any duties or obligations?
12 Are there any additional ethical considerations?
13 Is a decision even necessary?

The paper – a contribution to the Colloquium Transport Planning Research (Colloquium Vervoer-splanologisch Speurwerk) in 2013 – explains these questions and possible answers in more detail.

- Safety
  The cycle infrastructure guarantees the road safety and health (minimum exposure to harmful substances) of cyclists and other road users.
- Comfort
  The cycle infrastructure ensures that cyclists experience minimal nuisance (vibrations, extra exertion due to height differences, trouble from other traffic) and delay (stops).

In general it holds that if the minimum level cannot (or can no longer) be met for one (or more) of the five main requirements, then the infrastructure will need to be modified. The main requirements have been formulated generically in this chapter. Chapters 4, 5 and 6 flesh out the requirements for networks, road sections and junctions respectively.

Main requirement cohesion
The network of bicycle connections must form a cohesive whole offering links between all origins and destinations that cyclists may have. In other words, cohesion is about the possibility of getting somewhere by bicycle. In this regard, integration with other modes of transport is important (linked journeys). Elements playing a role in this regard include door-to-door completeness, wayfinding, consistency in terms of quality, freedom in terms of route choice and barriers. The latter – in the form of large-scale infrastructure

such as motorways, railways and waterways – presents a direct threat to the growth of bicycle use. The Dutch Environment and Planning Act, which is scheduled to come into effect from 2018, is intended to control these.

Main requirement directness
Directness means that the cyclist is always offered a route that is as direct as possible and that detours are kept to a minimum. Due to the fact that the bicycle is propelled by muscle power, limiting detour distances is extremely important. If journey time by bicycle exceeds journey time by car, then many people will consider this a significant reason to abandon their bicycles and go by car instead [5]. On the other hand, many motorists seem to be willing to use their bicycles for short rides when this is quicker and handier. All factors influencing journey time have been brought together under the main requirement directness. Possible criteria in this respect include traffic flow speed, delay and detour distance.

Main requirement attractiveness
A myriad of factors influence the attractiveness of a cycle facility, and therefore cycling behaviour. These could have an exceedingly different weighting for each individual when it comes to deciding whether or not to take the bicycle, as well as when it comes to choice of cycle route. It is even the case that certain aspects of cycling are deemed positive by one person and yet negative by another. Nevertheless, there are also all kinds of factors that on average enhance the attractiveness of a route to cyclists.

Research into routes' attractiveness points to the fact that, in general, cyclists can appreciate greenery, water, open spaces and aesthetically appealing architecture, whereas exhaust fumes, congestion and subjective risk have a detrimental effect on a route's attractiveness [21].

Attractiveness partly pertains to the cycle infrastructure itself. Positive examples include an even road surface, well-designed junctions and clear signage. Furthermore, the attractiveness is also determined by the integration of the infrastructure into its environment. Apart from the spatial quality (nature, architecture), the attractiveness is affected by the presence of the right (urban) functions; consider in this regard recreational and shopping facilities (for example) [22]. Trouble from motorized traffic (smell and noise, physical proximity) has a detrimental effect on attractiveness. Bicycle use can be made more attractive at network level by disentwining bicycle traffic and car traffic.

Attractiveness is also connected to personal safety. Here, this refers to the extent to which cyclists perceive their route and its surroundings to be safe. Research shows that personal safety has a considerable impact on bicycle use, particularly during evening hours. This is dealt with in more detail in chapter 7.

Main requirement safety

The main requirement safety is about the cycle infrastructure guaranteeing cyclists' health and road safety. It is permissible to require of good cycle infrastructure, in whatever way, that (assuming normal usage) it does not cause accidents, helps to prevent accidents and – if an accident nevertheless occurs – the chances of serious injury are limited. Consider in this regard use of edge markings, creating smooth transitions onto the verge and limiting the number of bollards along cycle routes (for example). The requirement that cycle infrastructure must be safe for cyclists is not as trivial as it sounds: two thirds of all serious accidents involving cyclists involve a single cyclist, and half of these cycling accidents involving a single cyclist turn out to be related to the infrastructure [23].

Accident figures show that preventing conflicts with motor vehicles which could result in serious injury is another factor that continues to be as important as ever. For that reason it is essential for (cycle) infrastructure to be designed in such a way that the probability of collisions (particularly with motorized traffic) is minimized and the severity of unforeseen injury is mitigated. The speed differential between the parties involved in the collision is a dominant factor for both of these aims.

Cycling is associated with different health aspects. On average, people are living longer and staying healthy for longer thanks to bicycle use. The positive effects of cycling on health, particularly due to the additional physical exercise, are around ten times greater than the negative effects [24]. Of the negative effects on health, exposure to emissions (especially ultrafine particulate matter) is at least as harmful as the unsafe traffic situations. Which is why it is increasingly being argued that *all* effects of traffic on cyclists' safety need to be considered, i.e. not just road safety, but also traffic health [25]. Furthermore, groups other than cyclists must be considered too. If (short) car journeys are made by bicycle instead, then fellow road users will be less exposed to the risks presented by motor vehicle emissions.

The most significant observation for the designer is that any design leading to more cycling and less motorized traffic (car or public

transport) will be contributing to a better (on average) level of health among the populace. The second observation is that it is not only unsafe traffic situations that have to be minimized but also exposure to emissions. By taking cyclists' exposure to harmful emissions into consideration in the design, the health benefits of bicycle use can be further enhanced.

One thing that the above implies is that cycling right next to busier (distributor) roads will lead to a greater impact on health than cycling on quiet (residential) roads [26]. This is due to the fact that the concentration of ultrafine particles is directly linked to the presence of combustion engines. By plotting cycle routes through residential areas instead of along busy roads (disentwining), cyclists' exposure to exhaust fumes will be reduced. Siting cycle paths some distance from the main carriageway will also reduce exposure, because it increases the distance to the source [27].

Figure 2-2 shows the effect on health of the components exercise, diminished road safety and air pollution. Note that of these three factors diminished road safety has the least effect.

Safety is important at a variety of levels and can be influenced in various ways. The requirements that have been formulated within the compass of a sustainably safe traffic system can serve as a guideline. As far as the bicycle is concerned, this pertains to the following points for attention [16]:

- adapting the infrastructure in residential areas to cyclists;
- adapting the organization of distributor roads to cyclists;
- ensuring proper ride quality (even smooth surfacing) and shelter;
- ensuring adequate, skid-resistant road surface, free of bumps that could make it more unsafe;
- avoiding obstacles on and alongside the carriageway and ensuring a safe verge;
- only permitting the mixing of bicycles and motor vehicles where speed differentials are minimal and the volume of car traffic is low;
- minimizing points of conflict between motorized traffic and bicycle traffic;

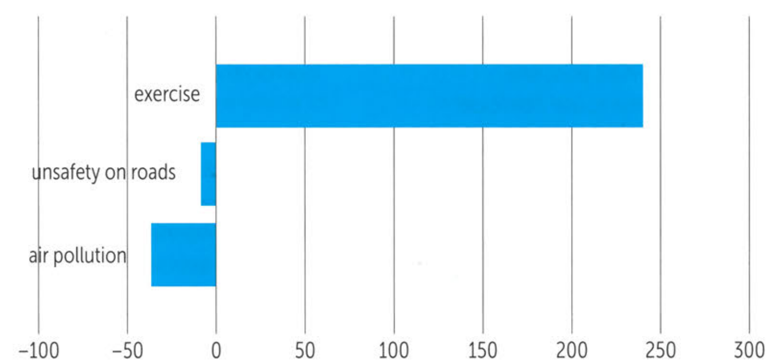

Figure 2-2. The effects on health (life expectancy in days) of cycling, divided into various components [24, adapted by Theo Zeegers].

- separating different types of users on the basis of speed, size, mass and manoeuvrability;
- ensuring a recognizable road alignment;
- ensuring recognizable cycle facilities;
- arranging infrastructure such that one's own behaviour in traffic and that of others are predictable (this can be done by making deliberate choices in terms of road surface, road alignment, street furniture and environment);
- making infrastructure 'forgiving';
- making journeys as short as possible;
- having shortest and safest route coincide;
- limiting the number of traffic solutions and designing these unambiguously;
- avoiding conflicts with oncoming traffic;
- avoiding conflicts with intersecting and crossing traffic;
- avoiding situations in which cyclists have to search to find their way;
- reducing speeds at potential points of conflict;
- avoiding concentrations of ultrafine particulate matter;
- constructing cycle paths sufficiently wide to enable safe cycling and to prevent conflicts between users of the cycle path (fine-tuning width to the function and width of the cycle path);
- creating good, guiding facilities to encourage cyclists to stay on course (and not stray from the cycle path or stray onto the wrong half of the cycle path unnecessarily);
- creating verges that can be cycled onto and off of (thereby creating room for error correction on the part of the cyclist).

Main requirement comfort
The main requirement comfort encompasses factors pertaining to nuisance and delay, caused by bottlenecks and/or shortcomings in the cycle infrastructure, demanding extra physical exertion on the part of the cyclist as a result. This main requirement stems from the knowledge that it is not just high levels of stress but also irregular stress (repeatedly having to stop and start again) that detract from the pleasure of cycling. Vibration and steep inclines also take some of the pleasure out of cycling. Criteria playing a role in comfort include how even the surfacing is, how sloped the route is, the chances of stopping and discomfort caused by weather and traffic.

2.5 Integrated designing

The positive effects of cycling go beyond mobility and sustainability. The bicycle is the cleanest and quietest mode of transport. In proportion to other infrastructural measures, cycling is an inexpensive way of driving down CO_2 emissions and safeguarding accessibility. Cyclists live longer, have lower rates of absence from work and arrive at work more refreshed and energized. In general, investments in cycle infrastructure are cheaper than investments for motorized traffic and public transport. Moreover, cycle-friendly cities are rated higher in terms of quality of life. A good cycle climate is increasingly becoming an important consideration for young, well-educated people and for companies when it comes to them choosing to establish themselves somewhere [28].

Hence there is tremendous potential for bicycles. Not only for efficient and inexpensive transport, but also for boosting health, sustainability and quality of life of a city, town or region as well as the chances of people or businesses wishing to settle there. The bicycle is a potential catalyst for improving the living environment as a whole.

In order to make the most of the added value that cycling presents for the various aspects of (urban) life, an integrated approach is required. Designing cycle infrastructure means working on an accessible, sustainable, healthy, habitable and attractive living environment. Consequently, cycle infrastructure is inextricable from its spatial planning and social context. Cycle infrastructure is directly correlated with spatial planning and urban development: the mix of functions, the (short) distances to facilities, job opportunities and residential areas, as well as the demographics, have a significant effect on bicycle use and vice versa. In addition to the questions as to where cycle infrastructure (new or otherwise) is to be created and how it will be fitted into its environment, it is also important to consider for whom the cycle infrastructure is intended, and how and why cyclists will be using it.

Hence creating cycle infrastructure is not just a traffic planning task; it is also a spatial planning and social task. It is about working on cycle facilities in integrated fashion, taking the specific local situation into consideration. This is why the design process must also involve criteria pertaining to the infrastructure's relationship with its surroundings, such as the spatial integration and cyclists' perception of it, as well as with the added value of cycling in social and economic terms. As a minimum, the design's integrated approach entails the following:

- The cycle infrastructure has been designed carefully and has been integrated into the spatial planning context, ensuring that the cycle facility forms a whole with its immediate surroundings.
- The cycle infrastructure provides the cyclist (and others too, such as local residents) with a positive experience. This is not just about the organization and the aesthetic qualities of the cycle route itself, but also about perception of surrounding area.
- The cycle infrastructure generates added value for the surrounding area in the social and economic sphere. When constructing a cycle route, consideration is given to the wishes of users and local residents as well as the relationship with amenities, such as shops, schools or nurseries [22].

Ideally, the cycle infrastructure will not exist in a vacuum, instead being designed in such a way that it is connected with its environment – as part of the city's public space, or as part of the landscape. A cycle infrastructure designed in integrated fashion will unite the (traffic) function with the spatial quality and the economic and social potential of cycling. This will enable cycle facilities to go beyond their primary traffic function and have a structuring, enriching effect on their environment in its entirety.

This approach calls for an open, inquisitive mindset and cooperation with professionals from other disciplines, such as architects (including landscape architects) and planners, as well as the users of the infrastructure and local residents.

Designing cycle infrastructure encompasses three spatial planning levels, namely those of network, connections and facilities. Specific design problems are germane at each level. The task for the designer at all times is to strike a balance between function (functional requirements), design and use.

Prior to a designer commencing work on a design, he will have to carefully examine what the functional requirements are for both the cycle facility and the surrounding area. The designer must ask himself (for example) whether the matter at hand pertains to a high-quality, fast main connection or a cycling shortcut as a missing link at local level.

The requirements set by the surrounding area are also important influencing factors for a good design. A different type of cycle path will be constructed through a vulnerable nature reserve than through a highly urbanized setting. During this phase of the design process it is imperative to seek to harmonize things with designers from other disciplines, such as landscape architects and planning designers. Only once the landscape or planning function of the environment and the traffic planning function of the facility have been properly fine-tuned to one another will there be an integrated design.

Basic characteristics have been formulated for the purposes of designing both junctions and road sections [29, 30]. These basic characteristics serve as a point of departure. Based on the requirements set by the surrounding area, the design is further refined. Incidentally, for the purposes of a solitary cycle path the basic characteristics offer little to go on; in such cases, the facilities in chapter 5, 'Road sections', can serve as a point of departure.

Due to space claims made by other parties, it will not always be possible to achieve the design desired on the basis of function and use. Cycling interests will then be in competition with other interests. This dilemma crops up in the case of spatial planning conflicts between networks for different modes of transport, for instance. In such a situation, it is imperative to first examine how significant the other interests are. It is important to team up with the designer of facilities for public transport or motorized traffic and look at how functional such things as the requisite space, the priority procedures or the priority at traffic light control systems are for the other mode of transport. The results of this will need to lead to an adjustment to the original design.

If the design fits the function adequately, then the use will be in line with expectations. The cyclist will exhibit the desired (traffic) behaviour organically. The use (or expected use) can be studied. Depending on the phase in the planning process (preparation or evaluation), this study will be based on calculation (future situation) or empirical observation (current situation).

A design's quality is determined by the extent to which it satisfies the five main requirements for cycle-friendly infrastructure and the requirements set by the surrounding area. The main requirements comprise the criteria for evaluation of the design. It should be clear that optimum harmonization will only be possible within the compass of an iterative process. The three 'dials' of function, design and use must be tweaked repeatedly to obtain an optimum design. If function, design and use are not in proper equilibrium, then there are three options for restoring equilibrium:

- adapt the design;
- influence use/behaviour;
- adjust the functional requirements (and therefore the quality).

Design

The most self-evident starting point for modifying a design is to look for an alternative design that dovetails with the functional requirements and use. However, it turns out in practice that external factors can also influence the equilibrium being sought between function, design and use. In such cases, consultation with partners in the field of landscape design and planning are apt. The pages on facilities in part two of this publication describe alternative organizational forms.

Use

If the interests of the external factors are sufficient to warrant not implementing the design of the cycle infrastructure in accordance with the guidelines from this Design Manual, then it will have to be examined whether the use of the facility can be influenced. It goes without saying that the use of facilities for other modes of transport can also be influenced. If (for example) the speed and volume of motorized traffic makes it desirable to construct cycle paths, but there is no space for these, then reducing the volume of car traffic and/or reducing their speed are obvious alternatives. Furthermore, the cyclical nature of the design process makes it possible to revert to the design for connections in the event of problems at the level of facilities. Developing an alternative, high-quality connection (for example) enables use of the 'problem connection' to be minimized.

Function

Adjusting the objectives may be considered as a last resort. What this means in practice is that the facility is implemented with a lower level of ambition than is desirable based on the programme of requirements. Hence it is about finding compromises in terms of the cycle-friendly nature of the facility. Designers and policymakers will (have to) realize that by no means all facilities will be able to fulfil all functions that are desirable. Adjusting the function is the final option. It will not be used until all alternatives have been explored and the change of function has been properly justified.

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3 Basic data

3.1 Bicycle dimensions

Bicycles come in all shapes and sizes. When designing cycle facilities, therefore, it is unreasonable to assume *average* dimensions, as doing so will make the probability of a facility not sufficing for a substantial proportion of bicycles too high. The statutory requirements present a better framework. A two-wheeled bicycle is allowed to be no more than 0.75 m wide (with or without luggage). The maximum width for a light moped ('snorfiets') is 1.00 m (not including mirrors) and for moped ('bromfiets') 1.10 m. The width of tricycles is allowed to be no more than 1.50 m. No statutory requirements have been set in terms of bicycle length, though mopeds are not permitted to exceed 4.00 m in length and 2.00 m in height.

When designing cycle facilities (including bicycle parking facilities), the dimensions from table 3-1 can be adhered to. These are derived from CROW publication 279 'Karakteristieken van voertuigen en mensen' ('Characteristics of vehicles and people') [1]. They reveal that the length of the 'design bicycle' is 1.95 m; incidentally, 1.80 m serves well as a starting point in practice. The length of children's bicycles in particular can vary considerably from the benchmark vehicle.

Table 3-1. Characteristics of the of the design bicycle [1]

	standard bicycle *)
length (m)	1.95
width (m)	0.64 **)
handlebar height (m)	1.23
seat height (m)	0.90
number of axles	2
number of wheels	2
wheel base (m)	1.11
wheel diameter (m)	0.72
mass (kg)	20

*) The characteristics specified also apply to bicycles with pedal-assist. The only difference is that the mass of the latter varies from 25 to 30 kg.
**) The statutory maximum width (in the Netherlands) is 0.75 m

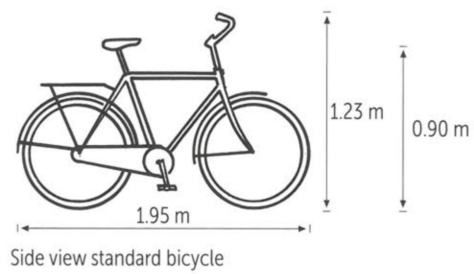


Figure 3-1. Dimensions of the design bicycle

The height of the standard bicycle is determined by the position of the handlebars. As a rule, these are between 1.00 and 1.20 m off the ground. Apart from when bicycles are being parked in two-storey bicycle parking facilities, their height is usually not particularly relevant. More important is the height of the bicycle including its rider; on this, the reader is referred to section 3.3, 'Clearance'.

The dimensions presented in table 3-1 have been based on the design bicycle. What this means is that a small group of unusual bicycles (such as bicycles with trailers, cargo bikes and suchlike) have not been taken into consideration. The designer should at all times ask himself whether the design bicycle will suffice or whether bicycles with anomalous characteristics will need to be factored into the equation. In this respect, routes to schools merit extra attention, for instance. For the exact dimensions of specific bicycles please see [1].

3.2 (Design) speed, accelerating and braking

Cyclists are always having to overcome two forces, namely the rolling resistance and the air resistance, as well as gravity when cycling up slopes. Rolling resistance is predominantly determined by the tyres and the road surface. Air resistance is dependent on the form (streamlining) of the bicycle, including its rider, and the wind speed and direction. The gravity component will be discussed in more detail in section 3.5, 'Inclines'.

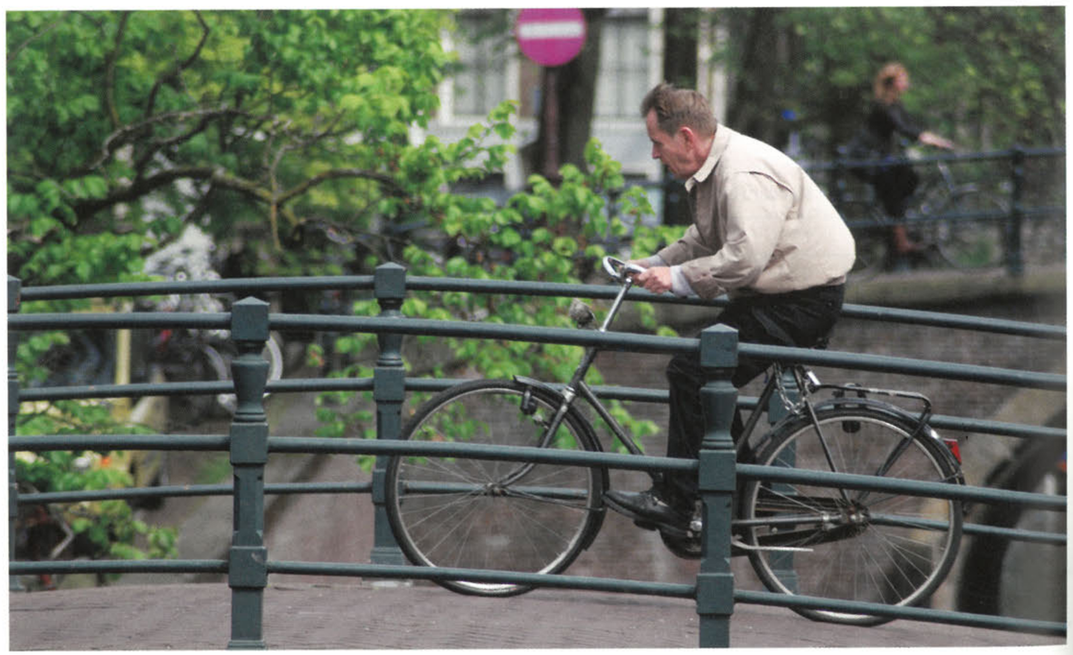
When designing cycle facilities it is essential for no convergence or direct contiguity of critical design elements to arise. Inclines (both upward and downward), sharp bends, poor road surfaces, wind-sensitive locations and lateral conflicts are examples in this regard. Where unavoidable, such elements must be spread out as much as possible.

Resistance

Bicycles are propelled by their riders' muscular strength. Nevertheless, the power that a cyclist can produce is limited. Any additional resistance must be compensated by extra physical exertion. If this extra physical exertion is not forthcoming, then the consequence of this will be decreased velocity. For that reason it is important for potential energetic losses to be minimized in a cycle-friendly design.

The primary factors causing energy loss are:

- friction caused by bearings and chain;
- rolling resistance, determined by tyre pressure and tyre width as well as by the quality of the road surface;
- air resistance, determined by the cyclist's velocity;
- headwind component, determined by meteorological conditions;
- gradient.



To a significant extent, these factors collectively determine the total energy loss experienced by the cyclist (a tailwind will, of course, provide the cyclist with some of the requisite energy).

If a bicycle is well maintained, then the friction factor will only make up a fraction (1 to 1.5%) of the total resistance. Naturally, the road designer has no influence on this. However, the extent to which the other factors play a role is (partly) dependent on the road design. Meaning that the road designer has considerable influence on the effort cyclists will be required to make.

Figure 3-2 presents the resistances in relation to velocity [2]. It will be self-evident that resistance caused by gravity is only relevant where there are differences in height. The energy consumed when cycling up a slope is partly recovered when cycling down a slope.

Rolling resistance and losses due to vibration are primarily caused by the quality of the road surface and any bumps in it. In the case of a well-inflated tyre on an even road surface, the rolling resistance will be 0.06 N/kg, whereas on a poor road surface it could be many times this. From the scant literature in this field it can be inferred that evenness and joints have an effect and that skid resistance (i.e. how rough the surface is) and texture have less effect on rolling resistance. The latter two properties do matter for the purposes of stability, and therefore for cyclists' safety.

Air resistance is chiefly dependent on velocity and only starts to play a serious role at speeds in excess of around 20 km/h. By contrast, a headwind (from straight ahead or diagonal) is already a significant resistance factor at low velocities, increasing as wind speed increases as well as in proportion with the cyclist's velocity. Unlike yachtsmen, cyclists cannot benefit from cross-

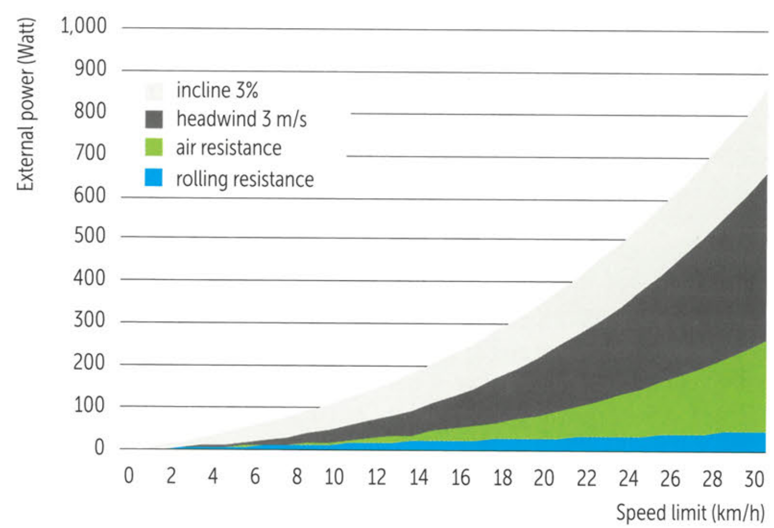


Figure 3-2. External power to be produced by cyclist for different resistance components [2]

winds. Crosswinds produce friction for cyclists, which is experienced as resistance, partly due to the unfavourable aerodynamic form of bicycle plus rider. In the case of significant turbulence, e.g. between buildings, the variable wind strength will cause additional inconvenience for the cyclist because he will constantly find himself being slowed down and then have to accelerate again. The subjective perception of wind also plays a role. A test in which a wind screen was installed received negative feedback from cyclists – despite a considerable reduction in wind nuisance – because they could still feel wind and perceived this in a negative light [3].

Options for the designer

Road designers and highway authorities can influence cyclists' energy loss to a significant extent. The objective must be to minimize unnecessary energy loss.
There are myriad ways of doing so. One important point of departure must be to minimize the number of times that cyclists are required to stop. A single stop takes up as much energy as cycling 75-100 metres (depending on speed). For each stop, be this due to a red traffic light or another traffic-related cause, the kinetic energy built up by human effort is wasted. This subsequently has to be built up again during acceleration by overcoming resistance due to friction and mass inertia.

Speed

A pedalling rate of around 70 revolutions per minute will produce a 'normal' cycling speed of 15-23 km/h, depending on the characteristics of bicycle and cyclist as well as the prevailing conditions. For the purposes of the Bicycle Balance [4] study a cruising speed of 18 km/h was adopted. Sports cyclists achieving speeds of 30 km/h are a common sight on cycle paths. This is also the speed limit for mopeds on cycle/moped paths in built-up areas. Consequently, a design speed of 30 km/h is recommended for normal situations. One point for attention is speed on inclines. Cyclists going down a slope can reach speeds of around 35 km/h.

On cycle/moped paths outside of built-up areas, a design speed of 40 km/h is recommended (this is also the maximum speed for moped users). In the case of a design with an excessively low design speed (e.g. tight bends or restricted view), it is possible that cyclists come off the road or fail to notice oncoming traffic on time.

The speed a cyclist will choose is dependent on the duration of the stress, the resistance he has to overcome and the reason for the journey. Hence in a headwind on a commute he will more readily accept a higher degree of stress (people want to get to work on time) than he would on a recreational trip.

Accelerating and braking

For acceleration from a state of inertia one may assume a value of 0.8 to 1.2 m/s^2. Deceleration depends on a variety of factors, but one may assume around 1.5 m/s^2 (comfortable) to roughly 2.6 m/s^2 (emergency stop).

Design task

As stated earlier, propulsion by muscle power means that energy losses should be kept to a minimum in a cycle-friendly road design. Not all energy losses occurring during cycling can be influenced by the designer and highway authority, but rolling resistance can be. After all, this is largely determined by (the evenness of) the road surface. In order to minimize energy losses, preference is given to even, smooth surfacing, such as asphalt or concrete.

Other significant measures that a designer can take to prevent (unnecessary) energy loss for cyclists include:

- preventing or minimizing height differences;
- preventing unnecessary stops and starts;
- providing shelter from wind nuisance;
- anticipating possible katabatic winds.

3.3 Stability, deviation and clearance

(Two-wheeled) bicycles are unstable in the absence of appropriate action on the part of the rider. When standing still and at low speed, they fall over. It is only once they reach a moderate speed that they remain upright [5, 6]. The precise value depends on the construction, but for a normal city bike is around 15 km/h. The rider can keep the bicycle balanced by steering into the direction of fall. In this way the points of contact with the road will be under the centre of gravity of the bicycle plus rider, ensuring the combination remains upright.

Sideways body movements will not have any net effect on overall balance; only steering will have such an effect. Crosswinds, slipstream caused by lorries, gusts of wind (including as a consequence of high buildings), bumps in the road surface, slipperiness (ice, snow, wet leaves) and compelled low speeds will interfere with balance and increase the amount of room for manoeuvre required.

As stated, a speed of around 15 km/h is necessary to be able to cycle stably without excessive effort. If the speed declines, then as a rule the bicycle will become unstable, as a result of which the swaying motion will increase. This phenomenon occurs in such situations as accelerating from a state of inertia, navigating tight bends and cycling up slopes.

In the case of a velocity in excess of 15 km/h, the rider will find it easy to maintain balance with gentle steering movements. This equilibrium can be disturbed by external factors such as wind and an uneven road surface. What this means for the designer is that he will have to endeavour to protect cyclists from freight traffic passing them nearby, to shield them from gusts of wind and to ensure an even road surface.

One factor that ruins balance is slipperiness [7]. Slipperiness causes cyclists to fall because steering in the direction of fall no longer works: the wheels' points of contact no longer return to the centre of gravity when steering into the skid. The cyclist loses grip. A sufficiently skid-resistant road surface (and front and rear tyres with sufficient tread) are a prerequisite for cyclists' stability.

Deviation

When seeking to maintain their balance, or constantly correcting the (threat of) imbalance, even those cyclists who pedal most vigorously always have a gentle swaying motion. This phenomenon is termed deviation. The swerving that characterizes deviation depends not only on velocity but also on age and experience, physical capabilities, disturbances in the road surface (such as potholes and transitions between different road surfaces) and crosswinds. Crosswinds mainly disturb cyclists' balance when there are significant differences in wind strength (e.g. when in the proximity of large buildings). Slipstreams, too, caused by large vehicles driving right alongside cyclists, can exacerbate cyclists' swaying motion.

As far as the deviation is concerned, the designer can take the user's characteristics into consideration. At normal cycling speeds in normal conditions, the lateral deviation is around 0.20 m. Anomalous data may apply to specific groups, however.
For example, young, inexperienced cyclists and the elderly often have a greater difference in steering than average, for a variety of reasons. Additionally, in situations where cyclists are forced to cycle more slowly than 15 km/h, more free space is required to maintain balance. This is the case at (for example) traffic lights, where cyclists have to accelerate from a state of inertia, and on upward inclines. In such situations, the requisite lane width due to the deviation can be as much as 0.80 m. A relatively large width is also needed for stopping and dismounting.

Although the sideways swerving during the deviation is generally small and the requisite space for this could in theory be 'subtracted' from the

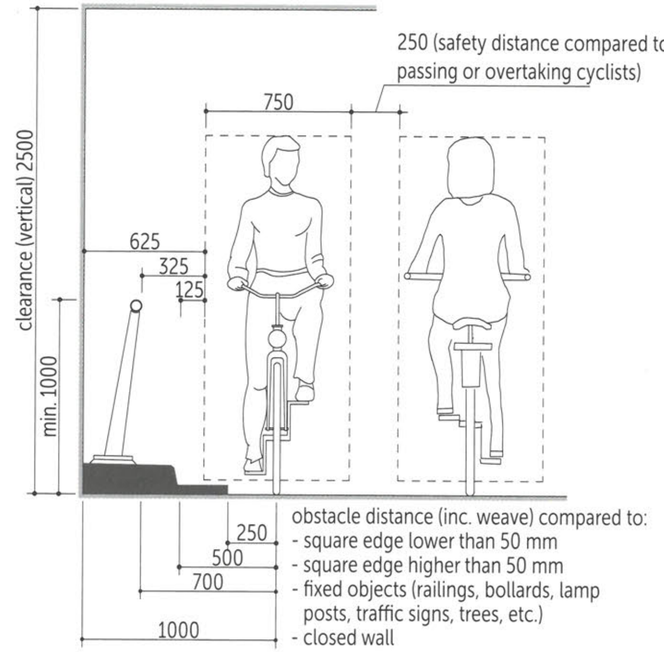


Figure 3-3. Clearance for bicycle with rider (measurements in mm) [8]

vehicle path, this is undesirable in practice. After all, following a narrow lane requires a great deal of mental effort. In busy traffic this distracts from the task of driving, thereby reducing attention to other traffic. In the case of recreational cycling, a great deal of effort expended to follow a narrow lane will generally reduce the fun of cycling.

Clearance

Aside from the deviation, consideration must be given to fear of obstacles. In the case of green verges and low kerbs, a clearance of 0.25 m should be maintained, whereas in the case of higher kerbs a clearance of 0.50 m should be maintained. The combination of clearance and the deviation produces a minimum carriageway width of 0.75 m.

The lane width of the deviation affects the *clearance*: this is the space (width) that the designer has to take into account in his designs. The clearance is determined by the actual width required for the cyclist plus rider *and* necessary margins, particularly those for deviation and fear of obstacles. These margins can overlap. For instance, a sufficiently large clearance could also cover the margin required due to deviation – see figure 3-3.

Naturally the various margins for each situation (road section, junction, incline) must be harmonized. The designer should also take into consideration the fact that the clearance in bends is more than the clearance on straight sections, particularly at higher speeds. Although research data is not available for this point, taking an extra width of approximately 0.50 m into account in bends is advisable, depending on velocity.

Due to the fact that cycling is not just about getting from A to B but can also be a relaxing and social activity, one general starting point for a design is that cyclists must be able to ride two abreast. Furthermore, from a road safety point of view it holds that parents must be able to ride alongside children. This has to be factored into the equation when calculating space for cyclists.

3.4 Bends and view

Horizontal bends

Bends are necessary to connect road sections with one another smoothly. The radius of a curve affects the speed at which a cyclist can ride in that location. The minimum radius of the curve (the horizontal radius) will depend on the nature of the cycle path.
The lower limit for curve radii is 5.00 m (see figure 3-4); in the case of smaller values the cycling speed will fall below 12 km/h and the cyclist will have to exert more effort to remain upright. The higher the design speed, the bigger the radius will have to be.

Research has revealed the connection between radius and cycling velocity shown in figure 3-4. Based on this figure it is possible to assert that:

- bicycle connections forming part of the basic network ought to have a radius of ≥ 10 m, fine-tuned to a design speed of 20 km/h;
- cycle routes and main cycle routes ought to have a radius of ≥ 20 m, fine-tuned to a design speed of 30 km/h.

Table 3-2. Route, design speed and radius

Route	Design speed	Minimum radius
Lower limit	12 km/h	5 m
Basic network	20 km/h	10 m
(Main) cycle route	30 km/h	20 m

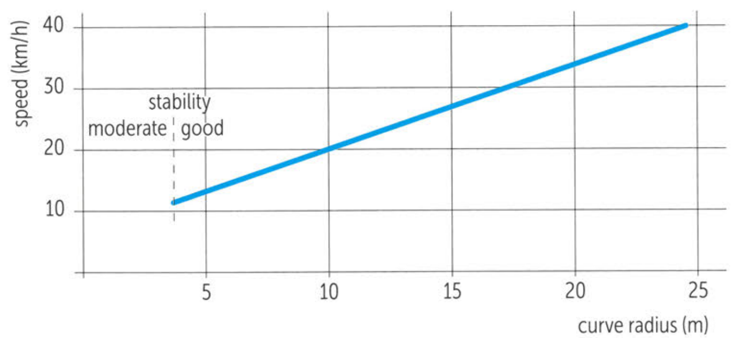


Figure 3-4. Relationship between radius and cycling speed [9]

Curve radii less than 10 m generally entail cyclists having to brake.
The lower limit for curve radii is 5 m; in the case of smaller values the cycling speed will fall below 12 km/h and older cyclists in particular will have to exert more effort to remain upright.

In the case of long, downward slopes, some cyclists can achieve speeds of around 40 km/h. Due to the fact that cyclists cycling at high speed in bends are not in an upright position but are slightly leaning into the curve, bends where this situation could arise will need to offer around 0.5 m extra width.

Cyclists' sight distance

In order to be able to participate in traffic safely, it is imperative first that the road alignment, obstacles, other road users and other critical elements are amply visible. Furthermore, it is necessary for cyclists to be able to see these elements properly, even if they are riding at higher speeds. Poor visibility and inadequate sight distance increase the probability of single-vehicle bicycle accidents and collisions [10,11]. For the aspect 'sight distance' a distinction can be made between sight distance in motion, stopping sight distance and visibility splay.

Sight distance in motion
A cyclist must have an adequate view of the road section, cycle path or junction in front of him from a satisfactory distance in order to be able to cycle safely and comfortably. For the purposes of calculating a comfortable sight distance in motion, the distance covered in 8-10 seconds can be taken as a starting point; the minimum required sight distance in motion is the distance covered in 4-5 seconds.

Stopping sight distance
Secondly, consideration must be given to stopping sight distance. This pertains to the distance covered during a braking manoeuvre. This manoeuvre encompasses the reaction time and time for the subsequent action of braking. At a speed of 30 km/h the stopping sight distance is 40 m; at 20 km/h it is 21 m (assuming 2 s reac-

tion time and deceleration of 1.5 m/s^2). Stopping sight distance is particularly important at junctions. Based on the values in table 3-3, the designer will be able to calculate how much unobstructed view a cyclist will need to come to a complete halt if a vehicle is approaching.

Table 3-3. Sight distance in motion and stopping sight distance for cyclists

	Main cycle network (design speed 30 km/h)	Basic structure (design speed 20 km/h)
Sight distance in motion (minimum)	35-42 m	22-30 m
Stopping sight distance (minimum)	40 m	21 m

Visibility splay
Visibility splay is important at junctions and connections. In order to be able to cross a road safely, cyclists have to have an adequate view of the traffic on the road to be crossed.
They must also be in a position to estimate the distance and speed of this traffic. The requisite visibility splay is calculated from 1 m away from the edge of the main carriageway, i.e. from the point at which the cyclist is positioned approximately. Visibility splay is determined by:

- the approach speed of the intersecting traffic;
- the time that the cyclist needs to cross safely;
- the recoil time (safety margin).

The time a cyclist needs to cross the road from a state of inertia (second factor) will depend on the distance to be crossed and the physical attributes of the cyclist. The elderly and young children require more time than cyclists in good shape.

Table 3-4 presents a few guide values for visibility splay for the average cyclist. These assume acceleration of no more than 0.8 m/s^2, a reaction time of around 1 s and a maximum speed during crossing of about 10 km/h (= 2.8 m/s). Due to the fact that visibility splay relates to cyclists wishing to cross the road from a state of inertia (or near enough), the distance does not depend on the function level of the bicycle connection. The recoil time (third factor) depends on the approach speed of the intersecting traffic and varies from 1 s at 30 km/h to 5 s at 80 km/h.

Table 3-4. Requisite visibility splay (m) for various crossing lengths and various approach speeds on the part of intersecting car traffic (v_{85})

		Requisite visibility splay (m)			
crossing length (m)	crossing time (s)	30 km/h	50 km/h	70 km/h	80 km/h
4.0	4.2	45	100	180	205
5.0	4.5	45	105	185	210
6.0	4.9	50	110	190	220
7.0	5.1	50	115	200	225
8.0	5.5	55	120	205	235

Sight distances
In practice, the requisite sight distances are not always achievable. Where this is the case, consideration must be given in the design to compensatory measures that will serve to reduce the speed of the cyclist and/or intersecting traffic. Putting additional warnings in place could also form part of the solution.

3.5 Inclines

Upward inclines
Upward inclines require extra effort on the part of the cyclist and for that reason, from the perspective of a cycle-friendly infrastructure, they must be prevented to the fullest extent possible. Obviously this is not always possible, however. In the Netherlands, inclines are mostly artificial and are associated with viaducts, bridges or tunnels. In such cases there is a clear connection between the height to be overcome and the gradient. The steeper the incline, the more effort a cyclist will be required to produce in order to overcome gravity. Over a short period of time the human body is capable of more exertion per unit of time than it is over a long period of time. This means that if a slope is

steep but short, the level difference can usually be overcome, with a bit more effort but without much trouble. If the extra exertion needs to be kept up over a longer period of time, then the same gradient will be much more tiring.

In addition to the level difference to be overcome and the cyclist's fitness, the wind is another decisive factor when it comes to that cyclist's comfort (or discomfort) riding up a slope. It will be self-evident that cyclists will have to work harder if there is a lot of wind nuisance. See figure 3-5 for the recommended gradients in different wind conditions. This pools data from three previously published sets of guidelines.

Downward inclines
One point for attention in the case of downward inclines is the speed of the descending cyclist, with this potentially rising to 35 to 40 km/h on longer inclines in particular. For that reason, there must be ample clearance at the bottom. There must be no junction, sharp bend or obstacle right at the bottom of a slope. Hairpin bends in the middle of a descending slope are also risky. They can cause single-vehicle bicycle accidents and, on bidirectional cycle paths, accidents involving multiple bicycles [12].

Determining the gradient
In places where inclines are unavoidable, the immediate question pertains to how steep they may be from the perspective of bicycle traffic. Nevertheless, setting an absolute upper limit or establishing a single, ideal gradient is unrealistic as many factors affect comfort (or perception thereof) on a slope. For example, there are many different types of cyclist, including in terms of age, sex and physical and mental capabilities. Furthermore, there are many types of bicycle (city bike, racer, cargo bike, mountain

bike, electric bike), with characteristics such as weight, rolling resistance, gears and pedal-assist functionality playing a role. Aside from user and bicycle, the surroundings and conditions also play a role; consider in this regard factors such as temperature, wind, sight lines, safety and atmosphere (green, urban, industrial). As stated, the myriad variables make it difficult to provide unequivocal rules for how steep a slope should be.

Gradient

It is, however, possible to make recommendations for steepness in combination with the length of an incline, or the *severity* of the slope [8]. The longer and steeper a slope, the more trouble cyclists have with it. In this respect, the average gradient has greater significance than the length of the incline. The severity of a slope (S) experienced by a cyclist can be calculated as the square of the (average) gradient times the length of the incline or, to put it another way, the level difference squared divided by the length: $S = (H/L)^2 \times L = H^2/L$.

Table 3-5 shows how this formula works out based on a few sample variables. This reveals that (for example):

- if the level difference is doubled and at the same time the gradient is halved (cf. lines 1 and 3), then the severity remains the same. The length of the incline will then be four times (2^2) as long;
- if the level difference stays the same and the gradient is doubled (cf. lines 2 and 3), then the severity will also be doubled. The length of the incline will then be halved.

Table 3-5. Examples of height, length, gradient and severity of slopes

H (m)	L (m)	%	S (m)
2.50	31	8.0	0.200
5.00	250	2.0	0.100
5.00	125	4.0	0.200

Recommendation

Given a level difference H, the factor severity can be used to make a recommendation for the length and the gradient of an incline. This will result in *target values* pertaining to the average cyclist, middle-aged, in normal conditions (situation involving average wind nuisance). In situations involving less wind nuisance (tunnels/underpasses), steeper inclines can be chosen. Conversely, in situations involving considerable wind nuisance (bridges in open landscapes), preference is given to inclines that are less steep. It goes without saying that the latter can also be chosen to boost comfort in the case of normal or little wind nuisance. Figure 3-5 provides an impression of the target values (the central line) and the bandwidths.

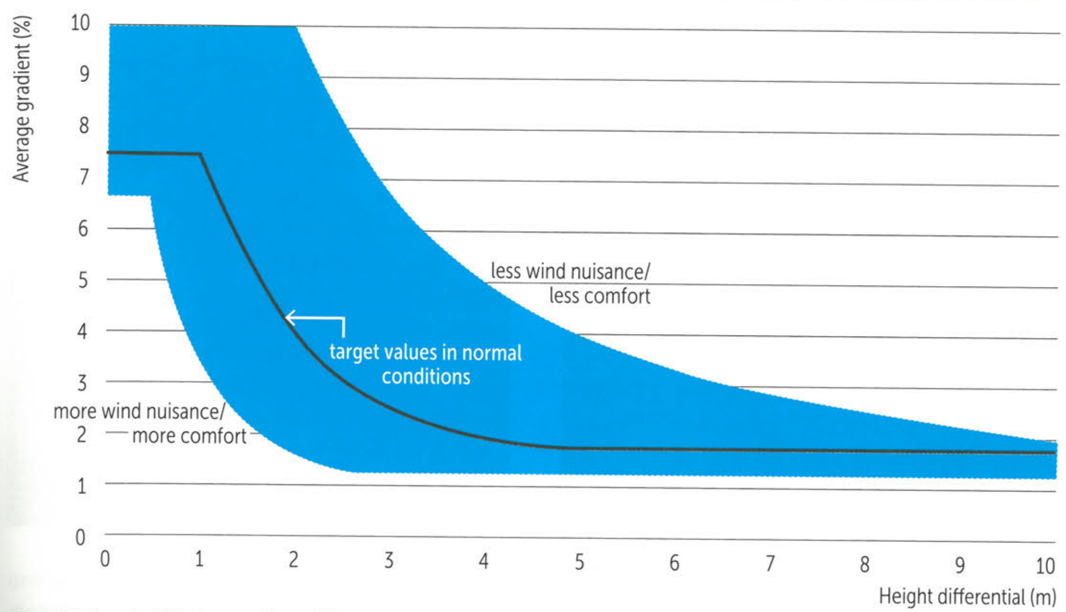


Figure 3-5. Bandwidths for gradients [8]

The following constitutes an explanatory note to figure 3-5:

- Lower limit. Delimitation of the bandwidth 'more wind nuisance / more comfort' is based on S = 0.0333, with a maximum of 6.67% and a minimum of 1.25%. Even smaller gradients would not be worthwhile, serving as a 'false flat'.
- Target values. Starting point is S = 0.075 resulting in $L = H^2/S = H^2/0.075$. In this regard, a maximum of 7.5% and a minimum of 1.75% apply.
- Upper limit. Delimitation of the bandwidth 'less wind nuisance / less comfort' is based on S = 0.200, with a maximum of 10.0%.

In order to calculate the requisite length of an incline, the level difference in centimetres can be divided by the average gradient in percent.

If a less comfortable gradient is chosen, then this could mean certain users being excluded. Consider in this regard such groups as the elderly, children, parents with child and/or shopping. It could force them to dismount or choose a different route.

Course of the incline

Aside from the average gradient, the course of the incline plays a role. Hence an upward slope might be a little steeper at the start than it is further up. The idea here is that the speed of a cyclist's approach will enable him to proceed up the first part of the slope faster due to momentum ('free height'). A descending gradient will ensure a constant cycling speed and effort overall.

Where level differences of in excess of 5 m have to be traversed, then the recommendation is to

Wind nuisance
Wind can be a disruptive factor on flat ground and particularly on upward inclines. Extra measures to limit this effect could be necessary. It is not without reason that the Netherlands has had wind screens consisting of trees since time immemorial. In relation to bicycle traffic, one point requiring consideration at all times will be whether the costs of a customized wind screen can be justified compared to the benefit conferred on users. Current projects show that wind screens provide indisputable protection, though also, or especially, that wind is a tricky topic to understand. Although there is often a clear prevailing wind direction, it is far from being the case that the wind is always blowing from that direction only. Furthermore, it turns out that theoretical benefits differ somewhat to the benefits perceived by the user. This is partly due to the fact that a lot of people think that a semi-open structure does not work, even though research shows that such structures do indeed minimize disruption to the (cycle) climate. Moreover, cyclists are also inconvenienced by crosswinds (drifting) and particularly from variable wind (gusts), which have an adverse effect on their stability.

interrupt the incline with a plateau around 25 m in length. Such an interruption should be considered from level differences as low as around 3 m. This will enable the cyclist to catch his breath and build up speed again.

3.6 Patterns in bicycle use

Bicycle use varies over the days of the week and hours of the day. Figure 3-6 provides insight into the variations in volume of traffic. Friday turns out to be the least busy working day. Far less cycling is done on weekend days than on working days.

The most reliable method of ascertaining cycling intensities is to count over a number of 24-hour periods. This approach is expressly recommended in order to acquire a full understanding of bicycle traffic on busy routes. In

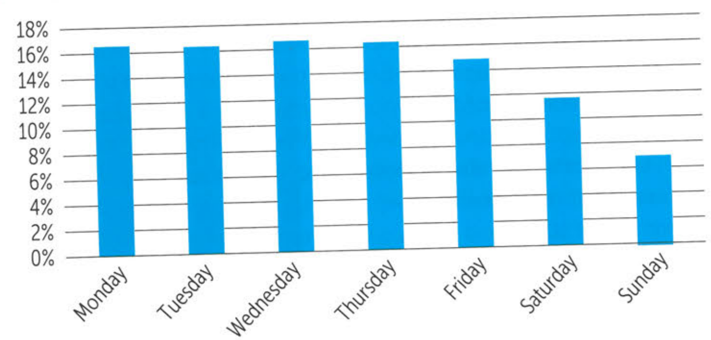


Figure 3-6. Weekly pattern of intensities of bicycle traffic within the built environment

order to still be able to make reliable judgements about cycling intensities with limited resources, random samples can be used. In this regard, consideration must be given to the marked variation in traffic volumes throughout the day.

3.7 Fellow users of cycle facilities

Apart from 'normal' cyclists, other types of cyclist and road users can be reliant upon cycle facilities for the purposes of their journey. Some brief details of the main groups are provided below.

Cargo bikes and bicycle trailers
In principle, the same rules apply to cargo bikes as to other bicycles. What is different, however, is the stipulation that users of bicycles with more than two wheels (including cargo bikes) and bicycles with trailers which, including load, exceed 0.75 m in width are allowed to use the carriageway; the same thing applies in situations where a mandatory cycle path is present.

Skateboards, rollerblades, roller skates, scooters and go-carts
The Dutch Road Traffic and Traffic Signals Regulations 1990 (RVV) stipulates that people travelling with the aid of objects that are not vehicles are to use cycle paths, cycle/moped paths, pavements or footpaths. They are to use the carriageway where the aforementioned facilities are lacking. Skaters and similar road users are therefore entitled to choose whether they will use footpaths or cycle paths (if both are present). Where there is no pavement or footpath, skaters will have to use cycle paths or cycle/moped paths. Skaters coming from the right do not have right of way over drivers coming from the left. If, in structural terms, a lot of skaters are using a cycle path and it turns out that there are regular conflicts between cyclists and skaters, then the recommendation would be to widen the cycle path, thereby reducing the chances of them getting in each other's way. The group skaters is taken to include rollerbladers, roller skaters and people with a scooter, go-cart or skateboard.

Light mopeds
As far as their place on the road is concerned, light mopeds (v_{max} = 25 km/h) are on a par with cyclists. The provisions of the RVV 1990 pertaining to bicycles and cyclists also apply to light mopeds and their riders. Nevertheless, the advisory cycle path is off limits to light mopeds with a combustion engine that is in operation. What this means is that electric light mopeds are entitled to use advisory cycle paths. The same goes for situations in which underplates feature the bicycle symbol (e.g. in partial one-way traffic and in pedestrianized areas where bicycles are permitted), i.e. only electric light mopeds are permitted there.

Motorized quadricycles
A motorized quadricycle is a moped with more than two wheels, fitted with an enclosed body. Article 2a of the RVV 1990 stipulates that the rules regarding motor vehicles and drivers and passengers of motor vehicles apply in part to motorized quadricycles and drivers and passengers of motorized quadricycles. This means that, in contrast to riders of 'normal' mopeds, drivers of motorized quadricycles are required to adhere to the rules set for drivers of passenger cars in the RVV 1990. In other words: motorized quadricycles use the carriageway (and not the cycle path or cycle/moped path) and are not allowed to park on cycle paths or pavements [14, 15].

Cars for wheelchair users/mobility scooter
Pursuant to Article 7 of the RVV 1990, drivers of these vehicles are entirely free to choose where to drive. They are allowed to use pavements, footpaths, cycle paths, cycle/moped paths or roads. However, if the road has a cycle lane, then they must use it.

Horse riders
Horse riders are considered drivers within the meaning of the RVV 1990. Their place on the road is the bridle path. If there is no bridle path, then they are to use verges or the road. In view of the fact that the carriageway is defined as 'any section of roadway intended for moving vehicles with the exception of cycle paths and cycle/moped paths', they are not entitled to use cycle paths. In practice, however, riders do tend to use cycle paths frequently. In situations where this is occurring a lot (e.g. within the vicinity of a riding school), the recommendation would be to create a bridle path. After all, riders and their horses are potential hazards and causes of discomfort to riders and vice versa, with a lot of horses reacting unpredictably to cyclists.

Literature
Figures in square brackets in the text – e.g. [1] – refer to the numbers in the bibliography below.

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4 Design of the cycle network

4.1 The basis of any design

The most abstract and at the same time most essential activity entailed in the design of cycle-friendly infrastructure is developing a cycle network. The cycle network is an important policy tool. After all, to a significant extent its quality determines the quality of an area's 'cycle climate'. Moreover, it holds that a proper design for a junction or road section can only be produced once the designer is aware of the function of the relevant junction or road section *within the overall cycle network* and within the structure of the other modalities. In that sense, the network constitutes the basis of any design. It goes without saying that a network is more than an aggregate of lines on a map. Coherent policy should also have been formulated, specifying what is meant by 'cycle network' status and what requirements in terms of quality are related to this.

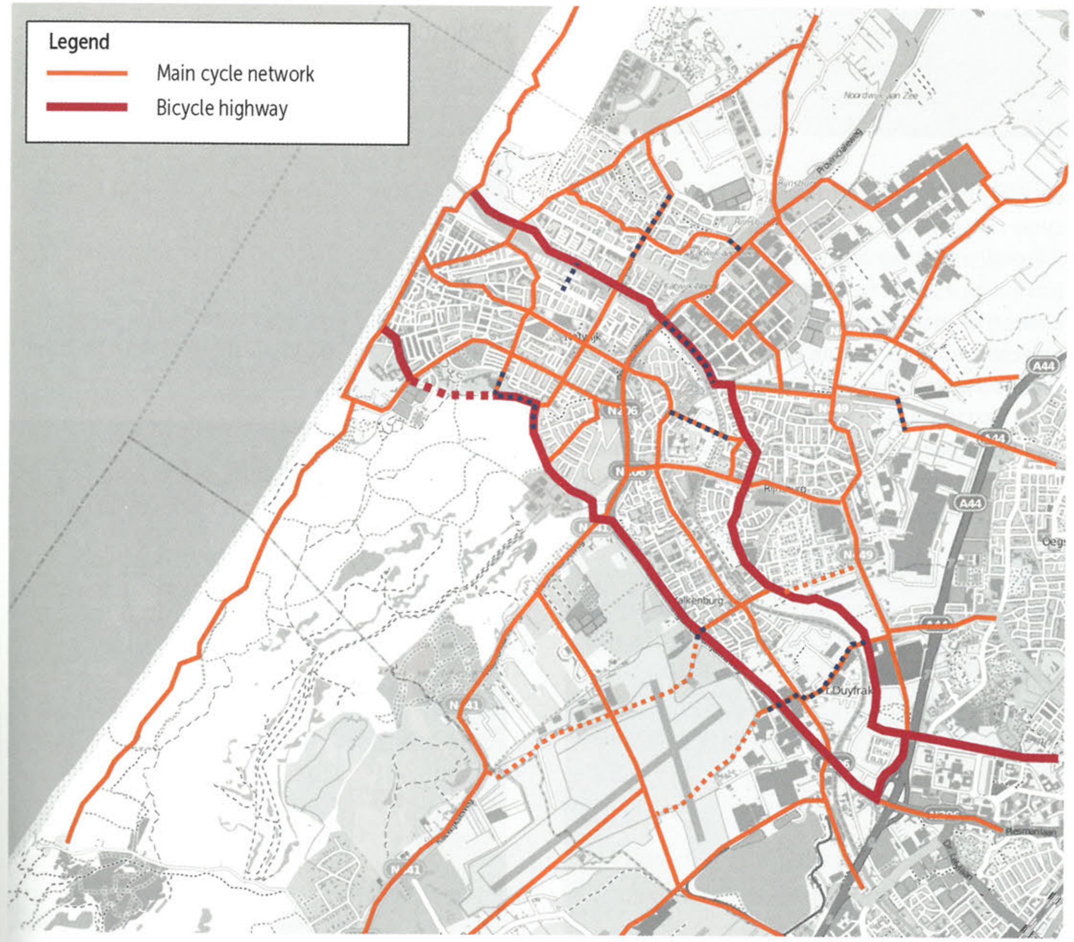

Figure 4-1. Example of a cycle network

A variety of reasons for updating the existing cycle network are possible, e.g. new cycle policy, new policy for traffic in general, new urban planning projects (such as a new connection or district) or restructuring of existing areas. Even bicycle innovation could be a reason, if this means that this mode of transport is used differently and that the new use has to be supported by a suitable network. Naturally, complaints and cues from the population could lead to scrutiny of the cycle network.

In numerous towns and cities cycle networks have ensured that the cycle infrastructure has been brought up to the desired level of quality step by step over the decades. An increasingly comprehensive network of good cycle routes is an important reason for the growth in bicycle traffic.

4.2 Levels in quality

The power of the bicycle lies in its flexibility, speed and convenience. These benefits can only be made the most of if as many roads, streets and paths as possible are suitable for bicycles. It is advisable to distinguish between various levels of quality. Higher levels entail higher standards in terms of quality due to the greater importance of the function within the network. In that regard, a parallel can be drawn with the categorization of roads for motorized traffic. There too a distinction is made, based on network quality, between three functions, with the degree of quality of traffic flow having to be higher the higher the function is.

Within the compass of the present Design Manual, the following three levels are distinguished for cycle infrastructure:

- *Basic structure*
  In built-up areas this pertains to the residential connections at neighbourhood level, broadly corresponding in practice to each path and each street usable by cyclists; outside of built-up areas it relates to the network of roads and paths that ensure rural areas are connected. Cyclists must be offered the basic quality on these routes.

- *Main cycle network*
  In built-up areas this pertains to the connections at district level which ensure that all districts and neighbourhoods and important functions are connected ('distributor paths'); outside of built-up areas it relates to the connections between centres, villages, towns and important functions. These routes must offer cyclists maximum quality and (in busy locations and on busy stretches) the calculations need to factor in a high volume of cyclists.

- *Bicycle highways*
  These are regional main cycle routes with a high-quality finish to enable efficient, comfortable cycling for those cyclists covering longer distances (up to around 30 km) at a fast pace. In effect, motorways for cyclists. Bicycle highways are intended to help travel by bicycle compete with travel by car in terms of journey time. In that respect they are built on relevant stretches and do not necessarily need to form a coherent network.

Collectively, these three levels constitute the overall cycle network. The lower-ranking subnetworks function as ramifications of the higher-ranking networks. It is not the case that each level in and of itself is required to form a definitive or coherent network. Practical experience shows that the basic structure is primarily about the physical presence of connections, by way of regular streets and paths. These residential connections constitute a kind of cross-beam. Optimization of this basic structure consists in improving and building shortcuts and surfacing tracks in the grass and suchlike - in short, implementing measures that are tricky to plan.

4.3 Requirements for the main cycle network

Four requirements are key when developing a main cycle network: cohesion, directness, safety and attractiveness. In addition to these, there are also requirements vis-à-vis comfort, though at the level of network development this aspect is less relevant; it is more important at the design level for routes and road sections.

4.3.1 Cohesion

Cohesion is the most elementary requirement for a main cycle network. It means that all branches are (readily) accessible by means of proper interconnection. This applies not only to road sections in the cycle network but also to significant destinations, such as public transport stations.

Cohesion and grid size

A network's cohesion is largely determined by the combination of grid size and interconnection. The grid size is the distance between (more or less) parallel connections in a network. The extent of interconnection is determined by the number of interchange points (junctions) between the network's branches.
The greater the grid size and smaller the interconnection, the lower the cohesion. On the other hand, it would be impracticable (and undesirable) to create a very small grid size and a plethora of nodes. After all, cyclists would have to pass junctions constantly. Consequently, it is advisable to find an optimum scale in terms of grid size and interconnection for the main cycle network.

The secret of a good main cycle network is to ensure it facilitates a high volume of cycle route kilometres using a limited number of connections and nodes. If around 70% of the cycle route kilometres can be covered through the main cycle network, it may be inferred from this that the network is fulfilling transport needs. Targeted investment in the main cycle network is desirable to enable a high standard of quality to be offered in this regard. Thus ensuring that the attractiveness is maintained for cyclists (including new cyclists).

A simplified indicator for the extent of cohesion within the built environment is the grid size of the main cycle network. A grid size of 300-500 m is usually assumed within built-up areas. Outside of built-up areas the cycle network has to primarily ensure the most important bicycle connections between regional centres, schools, industrial estates and public transport stops. In practice, this often boils down to a grid size of 1,000-1,500 m.

Cohesion with networks of other modalities

In addition to the internal cohesion of a cycle network, cohesion with the networks for car, public transport and pedestrians also plays a role. With regard to the car network, it is important for park-and-ride facilities and car pool sites to be accessible by bicycle.

Harmonization with the public transport network (railway stations, transfer points and bus stops) is relevant as the bicycle fulfils an important role as a preliminary means of transport for the purposes of (main) journeys by public transport. For example, 40% of rail passengers in the Netherlands get to the station by bicycle. Whether or not the main cycle routes pass through the same streets as the main routes for car and public transport is something that depends on the location and calls for careful consideration. There are potential benefits of having main routes for different modalities coincide, such as cyclists sharing the priority afforded to public transport at traffic lights; there are potential disadvantages too, however, such as lack of space, reduced road safety, exposure to emissions and nuisance.

Proper harmonization with the pedestrian network is particularly applicable to urban centres and pedestrianized zones. Cyclists must be able to approach these areas where they are at their least dense and preferably be able to use them (see also 5.6.3). Incidentally, main connections of the cycle network will only be sited in pedestrianized areas if there is specific space for cyclists here, thereby keeping the extent of conflict with pedestrians to a minimum.

4.3.2 Directness

Two components are important for the requirement directness, namely directness in terms of distance and directness in terms of time. In principle, due to the fact that the cyclist is 'his own engine', his preference will be the shortest route. In urban areas in particular, however, many cyclists will be considering journey time as well. Routes with right of way and without traffic lights will generally be quicker.

Incidentally, journey time is a relative term. If the cyclist is able to have routes that are as direct as possible and the car driver has to take a detour, then travelling by bicycle will be quicker than travelling by car, thereby often rendering it the most attractive mode of transport. Direct routes for cyclists, with car traffic having to take the long route, are achievable by:

- using traffic bollards (enabling cyclists to pass a barrier but not cars);
- creating a one-way traffic situation for cars;
- creating passages and bridges for exclusively slow-moving traffic.

Furthermore, giving priority to cyclists within the compass of a traffic light control system can bolster the competitive position of the bicycle.

The stated forms of directness can be applied not only to individual journeys but also to a complete network. In such a case, the average detour factor (see box), the average time lost and the average journey time ratio of bicycle versus car are calculated.

Directness in terms of distance

In principle, a detour factor pertains to a specific link (route). Directness in terms of distance is primarily relevant in the capacity of network size, i.e. the extent to which a network (taken to mean an aggregate of routes and connections) makes it possible to take as direct a route as possible from origin to destination. A network value can be obtained if the detour factor is calculated for a large number of randomly selected links (e.g. between the most important origins and destinations in a network) and these values are subsequently plotted against those links as the crow flies. The 'cloud of points' thus obtained will enable a regression line to be drawn which can be regarded as a network characteristic. Incidentally, the average detour factor (calculated over all links) is also a characteristic of the network's quality.

Directness in terms of time

Apart from being related to distance, directness in terms of time is down to the extent to which connections guarantee smooth flow of traffic.

Detour factor

The detour factor is the ratio between the shortest distance along the road and the distance as the crow flies. The significance of the detour factor is related to the distance of the journey. In the case of a long distance, a high detour factor has greater severity than it would in the case of a short distance, because then the absolute detour distance would be considerable.

For a perfectly rectangular pattern of streets ('Manhattan'), the average detour factor can be calculated exactly, coming to 1.27 for every distance. A well-designed main cycle network, however, must offer more direct connections, therefore having to score better (i.e. lower) than 1.27. Perfectly rectangular road networks (grids) are a rare occurrence in the Netherlands. Consequently, to ensure a well-designed main cycle network in the built environment a target value of 1.2 must be used for the average detour factor across the network. For kilometres beyond the main cycle network the average detour factor is allowed to be 1.3 to 1.4. In the case of a well-used main cycle network this will produce an overall detour factor of at most 1.26.

In practice, the average detour factor turns out to dip with the distance as the crow flies. For that reason, the recommendation is to adjust the specified standard for journeys within built-up areas with a distance as the crow flies of 1 km or more (assuming a grid size of 500 m and network usage of 70%). Such a standard is ambitious, but proves to be feasible in practice [1].

Outside of built-up areas the average detour factor is markedly dependent on the type of landscape. In the case of sandy soils, for instance, where a lot of direct connections are possible, a detour factor of 1.2 turns out to be possible. This figure is considerably higher in polder landscapes, this being due to the many watercourses, far from all of which can be bridged. At a distance of 2-10 km, such detour factors prove to be no longer dependent on the distance as the crow flies. In more challenging surroundings, such as old polder landscapes, a guideline value of 1.25 can be adhered to for the main cycle network's detour factor [1].

It is important for cyclists at route level to be able to pass through with as little disruption as possible (or with minimal waiting time). What is known is that the lion's share (85%) of time lost by a cyclist in a built-up area is caused by traffic lights. Reducing the number of traffic lights (or poorly set traffic lights) and improving right of way are measures to bolster directness in time. At uncontrolled junctions where cyclists have to give way to passing motorized traffic, the waiting time can be driven down considerably by installing a refuge island.

4.3.3 Safety

Safety can be described as the absence of physical or psychological danger or the threat thereof. In relation to cycle traffic it pertains to the following aspects: road safety, personal safety and (traffic) health. Personal safety will be discussed under the main requirement 'Attractiveness' (see 4.3.5).

Road safety

The following requirements apply at network level as far as road safety for cyclists is concerned:

- *Avoiding conflicts with intersecting traffic*
  Every encounter with an intersecting traffic flow is a potential conflict. The risk entailed in those encounters depends on the volume, the velocity and the mass of the intersecting traffic, as well as the complexity of the junction. When defining the main cycle network, efforts must be made to minimize the adverse effects of this aggregate of factors. When defining routes for the network, preference will be given to routes with as few junctions as possible that feature car traffic; junctions with heavy, high-speed traffic flows are to be avoided to the fullest extent possible. Incidentally, it is safer on balance to cross a busy junction once than it is to cross a quiet one twice if in that regard the total volume of car traffic being crossed is the same. The converse is also true: it is safer to increase the volume of bicycle traffic than to split it up. Both insights are the consequence of the universal law of safety in numbers [2].
- *Segregating vehicle types*
  Cyclists and motor vehicles have different features and characteristics. The greater the differences in speeds, the more benefit there is from segregating cyclists from motor vehicles and enabling them to use separate or independent cycle facilities. Given that most collisions occur at junctions, the segregation of vehicle types is not a measure that should be restricted to road sections.
- *Reducing speed at points of conflict*
  In places where the cycle network intersects with networks of other types of traffic, speed differences between these are minimized. The speed of the slowest mode of transport (usually the bicycles) is taken as the point of departure in this respect.
- *Ensuring recognizable road categories*
  Recognizability is chiefly of importance in connection with the use of specific facilities. In that regard, it is a requirement that pertains more to road sections and junctions than it does to networks. All facilities should be recognizable as such to all road users. Continuity of solutions, particularly on distributor roads, is a network property, however.
- *Ensuring uniform traffic situations*
  At network level, uniformity in traffic situations can primarily be fostered by using characteristic solutions for each road type. In principle, then, cyclists *do* have right of way when riding on roundabouts in built-up areas and *do not* have right of way when riding on roundabouts outside of built-up areas.

Disentwining bolsters health and safety
It is often desirable to allow different modalities to converge. Nevertheless, it can be desirable between junctions to actually disentwine the infrastructure for different modalities. Not every route is equally important for each modality. Each modality sets different requirements of its environment. Disentwining can enhance road safety and limit exposure to exhaust fumes and noise nuisance. Incidentally, there are also routes that are important for every modality. Consider in this regard (for example) paths that are the only ones in the wider area to overcome a barrier (water, railway line, motorway) by such means as bridges, viaducts, tunnels with approach ramps and exit ramps. It is often difficult to disentwine infrastructure for different modalities on such paths.

(Traffic) health
The following requirements apply at network level as far as (traffic) health for cyclists is concerned:
- *Ensuring minimal pollution due to emissions and noise*
  This means minimizing the extent to which cycle routes are sited alongside busy roads, siting segregated cycle paths some distance from car traffic, keeping traffic with combustion engines away from bicycle connections and creating stacking spaces for bicycles in front of waiting motorized traffic.
- *Ensuring minimal physiological stress*
  This entails avoiding steep slopes on cycle routes (for example). Another factor to be avoided is protracted medium-intensity or high-intensity vibration (e.g. due to block paving).
- *Ensuring minimal stress level*
  What this means in particular is that segregated cycle paths are available alongside busy roads.

4.3.4 Comfort
Aside from the requirements in terms of cohesion, directness and safety, a network must also satisfy the requirements of comfort and attractiveness. Although these requirements are sometimes regarded as less important, perception and convenience cannot be underestimated. Cyclists also wish to enjoy cycling. All the more so in the case of recreational cyclists, as well as 'new' cyclists, such as commuters who previously travelled by car.

Comfort at network level pertains to the degree to which the aggregate of connections can be used comfortably by the cyclist. In this regard, minimal nuisance, being easy to find and being comprehensible are three important elements. However, having an even road surface that is enjoyable to ride on and limiting the amount of turning off are factors that will bolster comfort.

The following requirements apply at network level as far as comfort for cyclists is concerned:
- *Avoiding traffic nuisance*
  Avoiding traffic nuisance (insufficient space, excessive noise) is an important condition for comfortable use of the infrastructure. The health aspect comes into play here too: emissions caused by motorized vehicles can lead to health problems, in both the short and long terms. Consequently, when constructing a cycle network, combining bicycle connections with busy flows of motorized traffic (longitudinally, transversely) must be avoided as much as possible.
- *Avoiding or limiting stops*
  Each and every stop causes discomfort. The energy required to build up momentum after each stop is comparable to cycling 75-100 m (depending on velocity). Limiting the number of stops will therefore enhance comfort. The number of stops is not the same criterion as time lost by waiting (see directness). It is preferable to have one stop with a longer waiting time than two stops with half that waiting time, for reasons of comfort (braking and accelerating one time fewer).
- *Optimizing wayfinding*
  Cyclists need to be able to find their way around.
  At network level it is relevant for cities, towns, villages, districts, facilities and amenities to be included in a system of signage (including for cyclists). Through routes with (for example) a staggered junction can be made easy to find by means of continuous paving and markings. Alternative routes can also be indicated.
- *Comprehensibility*
  It is imperative that a network be comprehensible to its users. The use of 'natural' landmarks helps in this respect.
  It used to be that routes would run between villages from church steeple to steeple. In that regard, the steeple constituted a natural signpost. Landmarks in a network enable the cyclist to form a mental map of the surrounding area, bolstering the network's comfort (as well as its attractiveness). Taking the other main requirements into consideration, a designer can endeavour to plot a route in such a way that it passes recognizable, striking and attractive urban design and landscape elements.
- *Even road surface that is enjoyable to ride on*
  The road surface must not be bumpy and there should be no unexpected crossings. Preference is given to surfacing consisting of asphalt or continuous concrete. Nuisance caused by tree roots and holes must be kept to a minimum. To the fullest extent possible, slip-

periness caused by fallen leaves and winter precipitation must be prevented, or otherwise remedied as swiftly as possible, particularly on main cycle routes. The road alignment and any edging alongside the surfacing must be readily visible.

- *Limiting the amount of turning off*
  Turning off at junctions inevitably results in braking and accelerating and therefore to discomfort. Hence a network in which cyclists can predominantly keep cycling straight on over junctions and do not have to keep turning off to reach their destination is a more comfortable one.

4.3.5 Attractiveness

What makes a cycle climate attractive is subjective. In general, however, it holds that personal safety and an attractive environment are fundamental factors contributing to making cycling enjoyable. At network level this means that utilitarian connections pass through lively areas, in a varied environment, with a well-maintained public space, and that the connections are lit as much as possible. To an extent, other requirements apply for the purposes of recreational connections - to this end please see section 4.6.

Personal safety

For a sense of personal safety it is important for bicycle connections to ensure sufficient visibility of the surrounding area and of fellow road users. 'Tight corners', shrubbery right alongside the route and inadequate sight distance through tunnels are undesirable. Eye contact with fellow road users and the presence of homes can contribute to personal safety. Furthermore, bicycle connections must be adequately lit. Where it is not feasible to have the most direct route (in the evening and at night) satisfy all stated requirements, an alternative route should be available which is conducive to users' personal safety.

4.4 Establishing main cycle network

The main cycle network encompasses the connections that are desirable from the perspective of functional considerations. This pertains to reasons for travelling such as home, work, education, shopping and socially or culturally motivated visits. For the purposes of putting together a main cycle network, the so-called adapted grid method can be used. This entails looking at the most important cycle links. Three steps can be distinguished in this regard, namely:

- charting the most important areas in terms of cyclists' origins and destinations and the links between these (step 1);
- converting desire lines into routes (step 2);
- confronting the routes with the infrastructure for other modes of transport (step 3).

This method assumes that cyclists will benefit from as comprehensive and complete a network of connections. If a grid of connections is constructed over an area (neighbourhood, district, town, city, region), this will give rise to a comprehensive infrastructure – depending on grid size (the grid size).

4.4.1 Determining origin and destinations and links

The first thing done during this step is to chart the most important origins and destinations. The size of the study area plays a decisive role in this regard. At provincial level, a hub can be regarded as a single origin, whereas for the network within that hub neighbourhoods and districts are considered to be separate origins.

Origin areas are usually connected residential areas, railway stations and parking facilities with a function for incoming commuters (who will be continuing their journey by bicycle), locations where regional routes enter the area and (major) camping sites. The level of scale for which the cycle network is being prepared is central when it comes to the question of whether or not a certain origin or destination is to be included.

Destinations are all those functions, buildings, activities and facilities that attract (lots of) cyclists, such as:

- shopping areas and town and city (or district) centres;
- buildings (including government buildings) with an important public function;
- schools and universities;
- sports facilities: swimming pools, sports grounds, recreational areas and activity centres;
- focal points for jobs, e.g. larger companies or industrial estates;
- important public transport hubs (stations for trains, bus, tram, underground);
- points of connection with the surrounding regional or provincial cycle network and the recreational cycle network;
- activities that are not of an everyday nature, but that are capable of attracting a lot of cyclists, such as market, theatre, cinema, church, event, catering establishments, nightlife areas.

Special attention must be given to the edges of the sphere of activity being considered. Network links to connections outside of the sphere of activity should be marked as a destination on the edge of the network.

Usually there will already be a cycle network there. In such cases, it is important to check whether any major changes have occurred in terms of residence, employment, education or recreation since the most recent cycle plan was drawn up. It is also important to establish whether such developments can be expected within the next five to ten years. If this is the case, then the new origins and destinations will have to be added to the cycle network; if substantial (future) changes are not anticipated, then step 1 from the step plan can be skipped.

Once origins and destinations have been ascertained at the right level of scale, the links between them are established. Desire lines are used to indicate the (ideal) links between origins and destinations. Desire lines constitute an abstract representation of the journey pattern, without taking spatial structure or the available network into account. Due to the multiplicity of links (primarily in an urban environment) it is possible to combine desire lines adjacent to one another (see figure 4-2).

For a large city the desire lines can first be set at the macro level (entire city), with the centre, subcentres and destinations for the entire area being interconnected. Next, this can be fleshed out in more detail at the micro level (district/neighbourhood). It is important to achieve good interconnection between the different levels of scale and the surrounding areas (e.g. neighbouring municipalities).

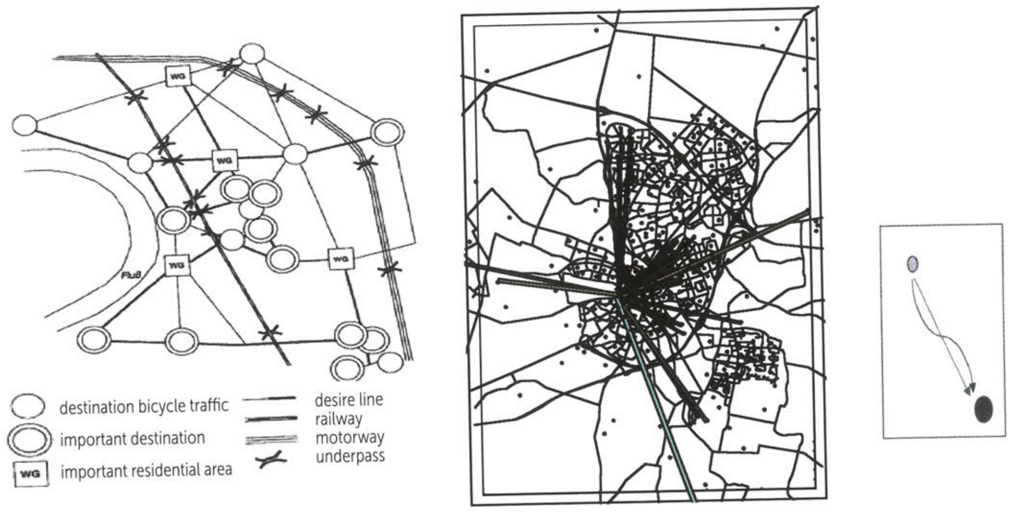

Figure 4-2. Examples of desire lines between destinations

Within a cycle network it can be desirable to distinguish levels of quality, for such reasons as making improvements to the cycle network more targeted. This will give rise to a hierarchy within the network. If this distinction is desirable, then step 1 is run through again to determine what specific links are involved.

4.4.2 Transforming desire lines into routes

This step sees the links between origins and destinations specified in the desire lines being transformed into possible routes. In this respect, maximum use is made of existing infrastructure. Often several routes are possible between an origin and a destination; in principle, the most direct route will be given preference in such cases. That shortest route will then be tested against the set route criteria. If the route does not satisfy these, but there are options in terms of making improvements, then the route will be included in the network and the process can move on to the next step, which entails confrontation with the network of other modes of transport.

If a route does not satisfy the criteria and there are no options to improve the route, then the next best route will be sought. One criteria in this respect is that the distance of the second choice is not permitted to be significantly longer than the first choice.

Sometimes it is not possible to project a desired line between an origin and a destination on an existing connection in the network, or this will only be possible by means of a connection with a high detour factor. In such cases, a new connection will have to be considered for the relevant link, particularly if it has a function for a large group of cyclists.

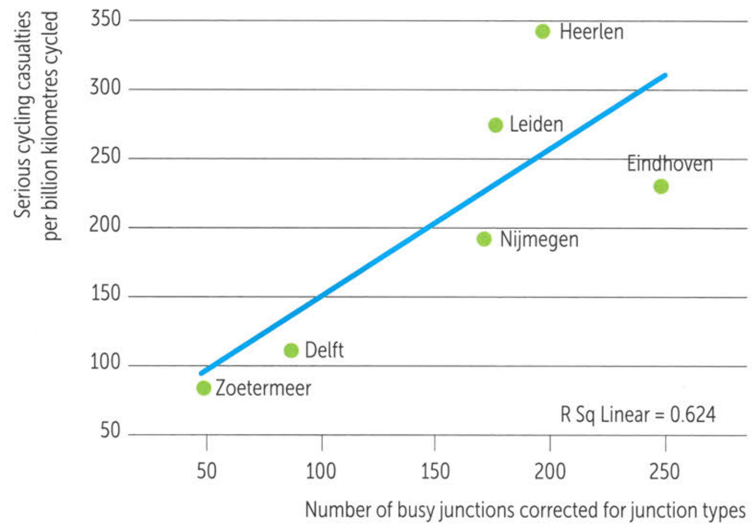

Figure 4-3. Relationship between the number of serious casualties in cyclists and the number of busy junctions (within the built environment)

4.4.3 Confrontation with other modes of transport

Once the routes have been determined and interconnected, they are confronted with the networks for other modes of transport. In particular, this pertains to the network of distributor roads and flow roads for motorized traffic and to the network of (connecting) public transport. Criteria playing a role in the assessment of these kinds of point of conflict include:

- the function (or intended function) of the connections;
- the extent to which bottlenecks can be remedied, therefore achieving an improvement in quality for the cycle network;
- the consequences of the decision to not implement the desired facility or to do so at a lesser standard of quality.

In practice, it turns out that relatively little attention is given to the confrontation between the cycle network and the networks for other modes of transport. Nevertheless, to a significant extent it is precisely this confrontation that determines the cycle network's quality and safety, which is why it must not be overlooked. On average, the casualty risk for cyclists turns out to be considerably higher in municipalities where cyclists are riding along busy distributor roads more often, and/or have to cross these more often, than they are in municipalities where that is not the case. Figure 4-3 shows that in cities with relatively few junctions the casualty rates for cyclists are relatively lower than in cities with a large number of busy junctions [3]. Consequently, proper harmonization between the networks for motorized and bicycle traffic constitutes an important tool for enhancing cyclists' safety.

At network level, disentwining routes for bicycle traffic and car traffic is a possibility. The situation for bicycles can be optimized if there are major residential areas being built with a limited number of arterial roads, preferably with a peripheral location, with the cycle routes being fed through those residential areas as far as possible. This can be done with a diffuse network of distributor roads for motorized traffic (and, therefore, large residential areas) and with a dense, high-quality cycle network that makes routes through residential areas more attractive. Such a structure entails cars going more round the outside and cyclists going more through the inside. Thereby reducing cyclists' exposure to fast-moving motorized traffic. This limits both the quantity of exhaust fumes being inhaled and the probability of serious accidents involving cars and bicycles. In the ideal situation within built-up areas, there will be a disentwined alternative for cyclists for any connection in the car network, making the cycle network twice as intricate as the car network [4, 5].

4.4.4 Doing away with (and preventing) barriers

When checking a network in terms of cohesion and integration, it is also advisable to test it in terms of severance.

Physical barriers

The number of physical barriers for cyclists has been on the increase in recent years. This is down to such factors as:

- the construction of ring roads around cities;
- the implementation of major infrastructural works;
- the upgrading of distributor roads and regional flow roads (reduction in the number of junctions);
- doing away with ferry connections;
- erecting barriers at level crossings.

Barriers are also being removed, due to such factors as the construction of bridges, new ferry services, new passageways and the restructuring of industrial estates resulting in cycle routes being

created. In the case of major infrastructural work, it is always important to investigate whether cycle and pedestrian connections will be jeopardized as a result and whether there are any opportunities to 'include' cyclists in the work to be done.

Other barriers

In addition to physical barriers, there are visual and psychological barriers. Examples include industrial estates and motorways. In the case of a motorway, the physical barrier is formed by the embankment; the psychological barrier, however, is many times bigger and consists of the zone in which the road is perceived to be a nuisance. In the case of motorways this could be due to noise, which is readily audible from a considerable distance, though also to 'legibility' of the environment and orientation being rendered trickier for cyclists. Central areas and pedestrianized zones can also present a barrier to cyclists. For this particular form of barrier, please see section 5.6.3.

Doing away with barriers

Within the design of the cycle network it is advisable to take the various barriers mentioned into consideration. When testing the networks, large barriers (arterial roads, railway lines, waterways and canals, rivers and suchlike) are often taken as a given (and an immutable one at that), presumably because doing away with them would require considerable effort (and financial resources). Nevertheless, it is certainly worthwhile looking at the specifics of the matter. CROW publication 299 'Barrièrewerking van lijninfrastructuur' ('Severance of Line Infrastructure') [6] provides an assessment framework for this with specific criteria. Incidentally, doing away with barriers is not just important for utilitarian networks; it can also be important to remove barriers for recreational routes, e.g. by means of tunnels. Such solutions are not the exclusive preserve of utilitarian facilities!

Measures

Various measures are possible to prevent barriers being sited or to remove existing barriers. As a minimum, the following options must be considered.

- Restoring connections interrupted by the construction of new infrastructure. The costs of this should be included in the budget for the new infrastructure project.
- Performing an *integrated* safety analysis prior to erecting barriers at a level crossing. A safety analysis must not be restricted to individual level crossings (see also the fifth item in the following list).
- Linking facilities for cyclists (and pedestrians) to construction work for trains, cars or shipping. Examples include 'attaching' bicycle bridges to railway bridges, widening floodgates to enable a (cycle) path to be created over the top, and creating new bicycle connections under viaducts.
- Joint use of ecological connecting passages, such as ecoducts and wildlife tunnels. The defragmentation of the countryside by building wildlife corridors between nature reserves also presents opportunities for bicycle traffic. It is possible for ecoducts and wildlife passages to be used by cyclists as well. Joint use is often possible without problems, because the wildlife primarily passes through at night.
- Creating small-scale shortcuts and links for cyclists and pedestrians.
- Creating simple cable ferries that people can operate themselves.

It will not always be possible to prevent or do away with barriers. In such cases, the problem must be mitigated to the fullest extent possible. To this end, the following measures are appropriate:

- Creating large residential areas. This will limit the number of arterial roads, thereby minimizing the number of barriers to be crossed.
- Creating good crossing facilities (refuge island, roundabout).

- Creating grade-separated crossings (bridges, tunnels) over or under line barriers (roads, waterways, canals, railway lines and suchlike). Please see chapter 6 for an elaboration.
- Opening up parallel roads and paths (existing or to be constructed) along waterways, dikes and railway lines to slow-moving traffic. Although parallel facilities do not cross the relevant barrier, this measure can sometimes shorten the detour distance.
- Settling for partial barriers for motorized traffic at a level crossing at which barriers are to be erected. After all, casualties on level crossings are mainly the occupants of motor vehicles. The level crossing could be converted for exclusive use by cyclists, pedestrians and riders. The same goes for bridges. This measure is particularly cost-effective.
- Making pedestrianized areas accessible to cyclists. A few shortcuts could suffice in this regard.
- Making private land accessible to cyclists (and any pedestrians and other slow-moving traffic).

4.5 Bicycle highways

4.5.1 What is a bicycle highway?

A bicycle highway is a regional main cycle route with a high-quality finish geared towards facilitating journeys by bicycle over longer distances (between 5 and around 30 kilometres). Bicycle highways are of a higher standard of quality and a different phenomenon to the through routes and connecting routes in the regional network. They can be built from scratch, but it is also possible to upgrade existing cycle routes to create them.

Bicycle highways were being experimented with as early as the 1970s, e.g. in Tilburg and The Hague. Whereas these bicycle highways were primarily created in urban areas, current bicycle highways are constructed between the most important locations in a region (cities, hubs, large facilities, places of work and suchlike). Hence bicycle highways function at a regional level of scale. They run 'from gateway to gateway' or into the city.

The approach to bicycle highways is different and less sectoral than it used to be. When constructing new bicycle highways it turned out that more is required than simply application of the maximum quality guidelines. Lessons have been learned in recent years with regard to both the design and the process and communication. A bicycle highway spanning a significant distance calls for extra ambition in terms of (design) speed and delay prevention. A bicycle highway that will (or potentially will) be heavily used needs to be wider. Incidentally, the five main requirements for cycle-friendly infrastructure (cohesion, directness, attractiveness, safety and comfort) also form the basis of swift cycle infrastructure (see figure 4-4).

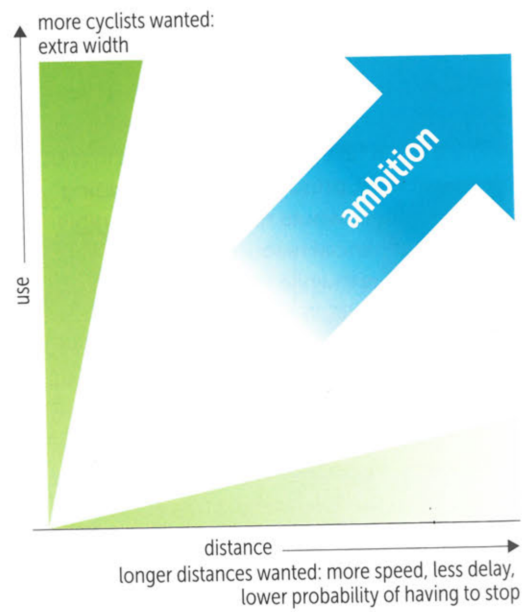

Figure 4-4. The greater the use (or anticipated use) and length of a bicycle highway, the higher the ambition level in terms of quality required

4.5.2 Bicycle highways at network level

Bicycle highways function within a network, in conjunction with both the existing cycle infrastructure and other modes of transport. The importance of a network approach for bicycles, with government subsidies, has been demonstrated in Delft. There, a cycle route plan was developed in which the network perspective was key. It emerged that a dense, cohesive network of cycle facilities encourages bicycle use.

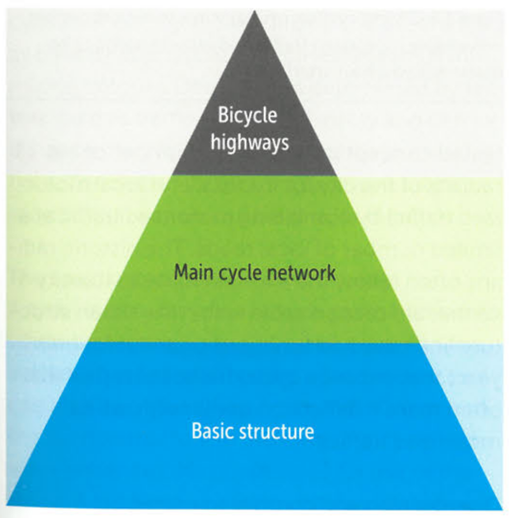

Figure 4-5. Pyramid of a functional, hierarchically structured cycle network

Bicycle highways play a role in terms of various aspects of a cycle network:
- as part of the overall cycle network;
- in conjunction with the origins and destinations;
- in conjunction with public transport structures;
- in conjunction with car networks.

Bicycle highways as part of the cycle network
Network quality for bicycles must be in good order. A bicycle highway functions within the aggregate of an hierarchically structured cycle network. The bicycle highway constitutes the main artery in the aggregate of urban connections and in the dense system of other connections. A bicycle highway is the point of the pyramid in a functional, hierarchically structured cycle network (see figure 4-5).

As such, a bicycle highway should be recognizable and fit logically into the system of other bicycle connections. It is the main connection in the network, the highest order within a functional hierarchy. A bicycle highway does not exist in a vacuum, but is properly linked up to bicycle connections of a lower order.

Bicycle highways in conjunction with origins and destinations
A bicycle highway not only fits in with the network of other cycle links but also constitutes a logical connection between significant origins and destinations in an area. These could be office parks, educational facilities, hospitals, city/town centres and residential areas. In that respect, a bicycle highway does not have to open up all significant facilities directly, and can do so indirectly instead.

In practice, the bicycle highway is not used in its entirety for many journeys, but does constitute a pleasant portion of the overall journey. In many supralocal journeys (spanning longer distances) the bicycle highway ensures a considerable reduction in journey time and improved attractiveness.

Bicycle highways and public transport structures

When designing bicycle highways, it is advisable to give as much consideration as possible to the existing public transport structures. A bicycle highway can enhance a railway station's catchment area. Districts and hubs that are situated further away will be put within cycling distance of the station. This could be at the expense of enabling public transport or smaller railway stations. Harmonization with station areas is essential; after all, a station area is an important origin/destination for many cyclists.

Bicycle highways and car networks

Bicycle highways and car networks present a challenging combination. Bicycle highways should preferably not be sited alongside main routes for motorized traffic, due to air pollution and noise pollution. Separating the networks for bicycles and motorized traffic will also boost road safety and the perception factor. One important task is to disentwine the bicycle highways. The bicycle street presents a good solution in this respect: look for low-traffic streets for the cycle route and give bicycles primacy there (see figure 4-6).

One requirement for a bicycle highway, however, is straightness of the route, and it is also important to ensure it is recognizable and easy to find. A winding route through a maze-like neighbourhood will not provide the requisite quality for a bicycle highway. One tried-and-tested concept is to reserve a number of old radians of the city for cyclists (and local motorized traffic) by combining motorized traffic at a limited number of local roads. The historic radians often follow the shortest route to the city centre, are recognizable within the urban structure and have had functions on them for many years that enhance cycle-friendliness (but that often make it difficult to genuinely restrict motorized traffic).

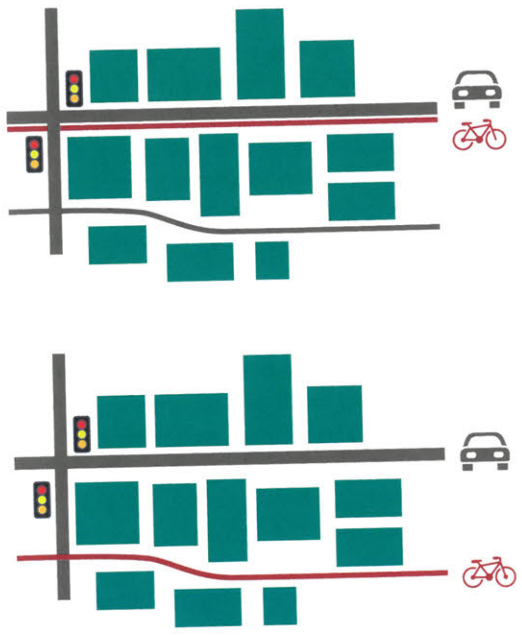

Figure 4-6. Giving cyclists primacy in a low-traffic street will enable motorized traffic and bicycle traffic to be disentwined on an arterial road.

Disentwining and combining routes

Disentwining is not always a success. Furthermore, in some situations combining motorized traffic and bicycle traffic adds value. This is the case where the motorized traffic route is well lit, for example. Thereby increasing cyclists' personal safety. There is also a certain degree of social control with slow-moving traffic in the evening hours. Lending combined routes a greater degree of personal safety during evenings as well.

Outside of built-up areas there are opportunities to create bicycle highways that do not run alongside motorways by combining them with other linear infrastructure, such as railway lines and canals. Disentwined bicycle connections have also been created on former railway lines or tramlines. An example of this is the 36 km-long Baronnenlijn between Apeldoorn and Hattem. Further examples can be found in such places as the Achterhoek and Langstraat regions of the Netherlands, in the provinces of Gelderland and North Brabant respectively.

4.5.3 Route selection bicycle highways

The route for a bicycle highway should connect cyclists' most significant origins and destinations as directly as possible. Directness means minimizing detours. Directness is determined by factors such as traffic flow speed, delay and detour distance; they influence the cyclist's journey time. The detour factor for a journey using a bicycle highway should be smaller than 1.1.

The basic choice: one or more routes

A high-quality bicycle highway can be assumed when projecting routes. When it comes to the availability of parallel routes, a ladder structure can also be utilized (see figure 4-7). Constructing such a structure in the case of bicycle highways enhances the possibilities for use of the route. A ladder structure combines (for example) a fast, attractive daytime route through a quiet area with a fast, direct route or with a route with attractive facilities. The ladder structure thereby improves the robustness of the system. If one of the routes is not available or unsuitable at that juncture (too dark, too much headwind), then there will be an alternative.

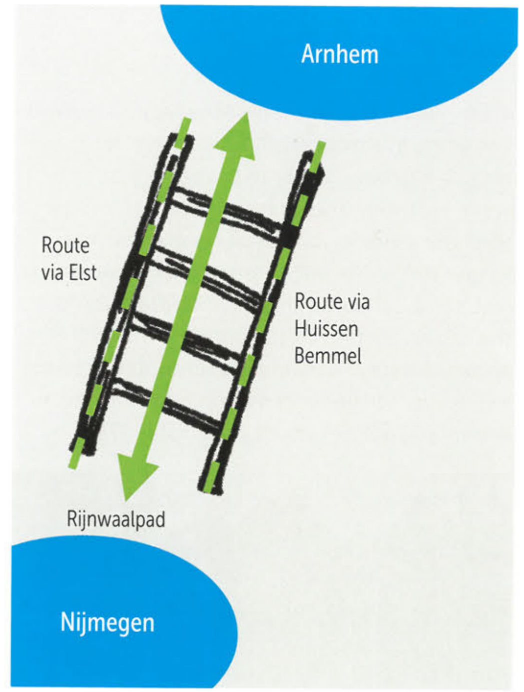

Figure 4-7. Ladder structure

Route selection in outline

The route selection is important at a higher level as well. The following considerations play a role when selecting a route:

- how straight the route is;
- connection with regional destinations;
- estimated potential for use;
- feasibility of the organizational requirements (can the bicycle highway have 'universal right of way', for example?).

For further information, please see CROW publication 340 'Inspiratieboek snelle fietsroutes' [7].

4.5.4 Main requirements for a bicycle highway

The same five main requirements are set for bicycle highways as for the overall cycle network. However, the interpretation of them differs. The ambition to tempt people to cycle longer distances will, in terms of some aspects, result in a different, 'stricter' interpretation of the requirements. This section examines the application of the main requirements to bicycle highways. Further information can be found in the 'Inspiratieboek snelle fietsroutes' [7].

Cohesion

Bicycle highways form the backbone of the regional cycle network. They are embedded within the overall utilitarian and recreational network and constitute the highest level therein. Within a corridor between two cities, several bicycle highways or supplementary routes with a higher value in terms of recreation or perception can form a ladder structure of bicycle connections.

The bicycle highway can also play a role in spatial integration. Hence it can:

- contribute to the qualify of life of a town or city with surrounding area as a binding and structuring element;

- improve the accessibility of (small) hubs and facilities (at both city and town/recreational level);
- improve the accessibility of green zones between cities.

Bicycle highways thereby function at both a utilitarian and a recreational level as city-country connections. They bolster the accessibility of economic centres for all modalities (more journeys by bicycle means fewer journeys by car and less chance of a traffic jam).

Directness

The bicycle highway provides a direct connection between the primary origins and destinations at regional scale. In addition, the bicycle highway serves as many functions as possible 'en route', without losing its function as a long-distance connection.

Attractiveness

The bicycle highway has been fitted into its environment in an attractive way to ensure that both its users and residents in the surrounding areas experience the added value it presents and perceive the route to be a positive thing. Route selection, design and organization of the cycle route ensure personal safety in all circumstances.

Safety

The bicycle highway offers cyclists the option of travelling more or less unimpeded. The course and design of the route must minimize conflicts with other road users. Moreover, the route must give rise to as few single conflicts as possible (coming off the road, hitting obstacles, skidding). To this end, the cycle route must provide a sufficiently skid-resistant road surface with no bumps. In addition, the cycle route must present sufficient ride quality (i.e. in good condition)

and be shielded from poor weather conditions. Cyclists should experience as little nuisance as possible from fellow users of the route (overtaking, differences in speed, differences in width). Alongside the route an obstacle-free zone must ensure that it is sufficiently forgiving in the event of cyclists coming off the surfacing. When approaching junctions and bends there should be an adequate view of oncoming traffic. This particularly applies to intersecting traffic, which in principle must always give way to the users of the bicycle highway.

Comfort

Bicycle highways are sufficiently wide to enable safe, smooth overtaking and they satisfy the highest quality requirements in terms of evenness and skid resistance of the surfacing. There is maximum traffic flow on road sections and at junctions, ensuring that even fast cyclists do not experience any delay.

Table 4-1. Requirements for bicycle highways

		Ambition (x) scale level of the requirement	Minimum level	Compensatory measures
Cohesion	Wayfinding / recognizability	Recognizable as a cycle route (B): at least two continuously recognizable elements	Recognizable as a cycle route (or bicycle highway) (B)	Add route signs, signposting, route symbols
		Route is self-explanatory (B) Provided with nationwide F numbering (B)	Destination findable (B)	
	Consistency in terms of quality	Clarity in terms of materials (B) and dimensions (B)		Extra spatial quality: greenery, lighting, street furniture, etc.
	Freedom to choose route	Minimum of two different fully fledged routes due to different surroundings (B)	A good, quick route	Indicate slower alternative route
Directness	Traffic flow speed	Design speed 30 km/h (A)	Route speed: minimum 25 km/h 'from gateway to gateway'	Restrict lower speed to logical places, compensate elsewhere Faster where possible, slower where necessary
	Delay	No delay (B)		Measures in VRI Crossing in stages
	Detour factor	< 1.1 (B)	< 1.2 (B)	
Attractiveness	Attractiveness, perception	Surroundings made attractive: variety in terms of landscape and urban setting, greenery and water, sight lines, landmarks, social environment, reasons to interrupt the journey, information (B) Route not presenting any nuisance to surrounding area (A)		
	Personal safety	All route alternatives pleasant in all circumstances (B): lighting distance to plants social control	A route that ensures personal safety as a minimum (B)	
Safety	Encounters with motorized traffic	Completely car-free (A) At speed > 30 km/h grade-separated (A)	< 500 PCU/24-hour period (A)	Organized as bicycle street
			At speed > 50 km/h grade-separated (A)	Speed restriction, roundabouts
	'Forgivingness' of cycle path	Separation directions of travel Joining traffic and exiting Obstacle-free	Sufficient width for overtaking and passing vehicles approaching from opposite direction Obstacle-free	Extra width at junctions
Comfort	Surfacing	Asphalt or concrete (A)	Even and skid-resistant (A)	Limit alternatives to logical places
	Inclines	S < 0.333 *) (A)	S < 0.750 *) (A)	Interruptions in long inclines
	Opportunity to stop	No stops (B)	Max 0.4 stops/km (B)	
	Wind nuisance	Measures in wind-sensitive places (A) Hideaways (A)		
	Traffic nuisance	No nuisance (noise, smell, air quality) from passing motorized traffic (A)	A low-traffic alternative as a minimum (B)	

*) The S value can be applied as follows:
$S = h^2/l$ where
l = length of the incline in metres;
h = level difference in metres.

Summary consequences of requirements
Table 4-1 summarizes what the aforementioned requirements entail in concrete terms. For each requirement the ambition level is outlined ('what would you want ideally?'); in addition to this, the minimum level is presented along with the accompanying compensatory measures. In this regard, a distinction has been introduced between road sections and junctions (A) and route (B).

4.6 Recreational cycle network

4.6.1 Cycling as a form of recreation

Recreational cycling is a collective term for a variety of forms of cycling. In this respect, a distinction can be made between touring bicycles (setting out from home on a longer ride), racing bikes (racing in a group or alone against the clock) and mountain bikes or ATBs (sports cycling over unpaved paths in particular). Where the term recreational cyclist is used in this Design Manual, this denotes those using touring bicycles, unless otherwise specified.

Research has been carried out into when touring riders cycle and for how long [8]. The figures pertain to 2013.

- Half of all people in the Netherlands went on a cycling trip for pleasure. Equating to in excess of 8 million citizens.
- Citizens of the Netherlands went on a total of 197 million recreational cycling trips of one hour or longer.
- The average cycling trip lasted 2.5 hours. 55% of the recreational cycling trips lasted more than 2 hours.
- The average distance covered on a recreational cycling trip was 20.6 kilometres. 53% of the recreational cycling trips covered less than 20 kilometres.
- Weekend days are the most popular for a recreational cycling trip, with 22% of the cycling trips being done on a Sunday and 19% on a Saturday.
- In excess of one quarter (26%) of cycling day trips use nodal routes. That makes more than 51 million cycling day trips involving the use of nodal routes.
- The longer the day trip, the more frequent cyclists' use of nodal routes is. In the case of short trips, use of nodes is relatively scant (13%). In the case of day trips of between 20 and 50 km, this percentage rises to 34% and to 41% in the case of day trips exceeding 50 km in length.

The recreational cyclist's profile has also been studied [9]:

- Around half (49%) of recreational day trip cyclists are 55 years or older. In comparison with their share in the population of the Netherlands (30%), this group is markedly overrepresented.
- 40% of the day trips are made by people cycling with their partner. In 36% of the day trips the cyclist is riding alone.
- Amongst users of nodal routes for day trips, there is a relatively high proportion of people aged 55-64 (28%) and 65+ (31%).
- What is striking is that a relatively small proportion of residents of the Netherlands from the lowest social class (CD) engage in recreational cycling day trips (45% compared to the nationwide figure of 50%), but that those who do cycle tend to do so with a greater degree of frequency that the average resident of the Netherlands. Cyclists from this lowest social class use signposted routes relatively more when on cycling day trips.

Sports cyclists

Whereas the average cyclist covers approximately 900 km a year, sports cyclists cover in excess of 3,000 km in that time. According to the Dutch Tour Cycling Union (NTFU), 6% of the population aged 18+ regularly do cycling as a sport. In 2014 the union joined forces with Bike MOTION Benelux and GfK to carry out research into the scale of the sports cycling market in the Netherlands [10].

The research reveals that there are 815,000 sports cyclists in the Netherlands. This pertains to people aged 18 years or over who state that they take part in cycling races, mountain biking or touring 12 times a year or more. Relatively speaking, the province of North Holland has the fewest sports cyclists and the province of North Brabant has the most. 41% cycle 2,500 km or more on an annual basis and, on average, sports cyclists cover 3,157 km a year. Of the sports cyclists, 77% are focused on cycling races, 43% on mountain biking and 15% on other sports cycling pursuits. The overlap (the total exceeds 100%) is due to the fact that a proportion of cyclists practise multiple forms of cycling. Thus 21% do both cycling races and mountain biking. There is some slight growth, corresponding to

the increase in the population and an increase in participating in sports. Around 60% of sports cyclists are primarily motivated by performance and exertion, whilst the other 40% are more interested in relaxation and the enjoyment factor.

4.6.2 Types of routes

There are lots of cycle routes registered in some shape or form for which signposting may or may not be possible [11]. To start with, the Netherlands has a clear cycle route structure of national cycle routes (NC routes: 4,500 km) for trips spanning several days, as well as regional cycle route networks (node networks) for cyclists on day trips. As at 2015, these networks have a combined length of over 31,000 km.

In addition to this, there are countless cycling tours of between 20 and 50 km, often based on a theme ('Heath Route', 'Sturdy Dikes Route') or on a certain activity ('Tracks & Snacks', 'Ferry-go-round'). They can be identified by their hexagonal signs, for instance. The node system is superseding a proportion of these cycling tours step by step. Many themed routes, whether or not these are based on nodes, are being promoted on the Internet or in brochures.

There is a nationwide recreational cycle route structure with the following characteristics [12]:

- in excess of 31,000 km of nodal routes;
- in excess of 4,500 km of NC routes (national cycle routes), synchronized with nodal routes;
- in excess of 50 route networks;
- in excess of 35 highway authorities;

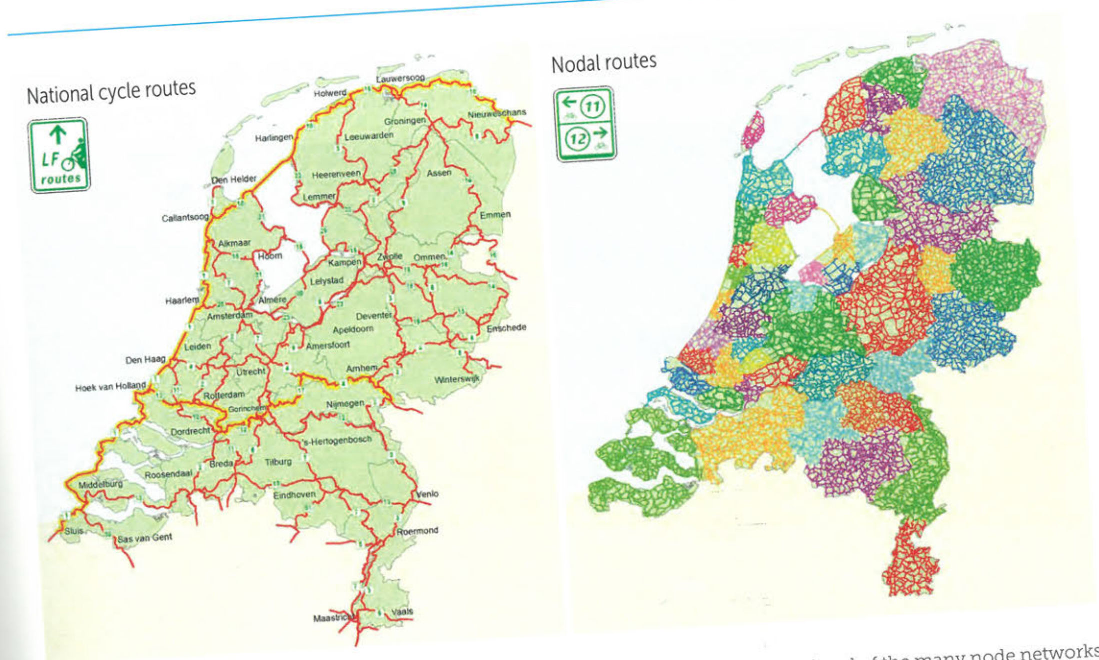

Figure 4-8. Representation of the network of national cycle routes in the Netherlands (left) and of the many node networks (2015)

- nigh on 8,000 nodes (places where a cyclist can choose where to continue his route);
- 1 nationwide responsibility for the system vested in the Fietsplatform (the Dutch organization for recreational cycling);
- 1 nationwide reporting system: www.bordjeweg.nl;
- 1 digital origin (including route planner): www.nederlandfietsland.nl.

Cyclists choose the shortest route from home (through town or city) to get to outlying areas [13]. This upholds the need to create direct cycling connections from residential areas to rural areas (shortcuts, farm paths, little bridges) and to maintain such connections that are already in existence. In that regard, the policy of ProRail (national railways authority in the Netherlands) to close small level crossings to all traffic constitutes a serious threat to recreational cyclists (as well as to the utilitarian cyclist using these connections). It would be advisable to look more often and more pointedly at whether such level crossings can be preserved for bicycle traffic.

From home to recreational route

The majority of recreational cyclists vary their outbound and inbound routes. Over three quarters of them work out their route to rural areas off the top of their heads. The most important factors determining the route through the city to rural areas are:

- the maintenance condition of the connections;
- the probability of delays on the route, with traffic lights in particular playing a role;
- the road safety: segregated cycle paths and quiet roads are preferred.

It is not always possible or appealing for residents of conurbations to get straight from their own residential area to rural areas. If rural areas cannot be reached within 5 km, then attractive

supplementary links in the cycle network will be necessary. After all, it turns out that recreational cyclists are not willing to travel more than around 5 km as a 'bridge' to rural areas [14].

Intensive use of space in the Netherlands has resulted in the outskirts of urban areas being difficult to penetrate, particularly on the periphery of cities and conurbations [15]. For example, roads/motorways, railway connections and waterways constitute an impediment to a close relationship between city and rural areas. The same goes for 'grey areas' such as industrial estates. Large-scale infrastructure and diffuse peripheral urban areas have made significant encroachments upon areas used by those engaging in walking or cycling for recreational purposes. The problem of the disintegration of recreational networks is a considerable one.

If the outskirts of urban areas are difficult to penetrate, this can give residents the sense of being trapped in the city. Thus infusing the living environment with a degree of claustrophobia, to the detriment of the city's quality of life. Nevertheless, it is rare for those who wish to take part in such recreational activities to take action that would do away with a barrier. At most, they grumble about lack of connections in places where these could have been of a better standard of quality.

In order to restore the relationship between city and rural areas and dispel city dwellers feeling of being 'trapped', opening up the outskirts of cities is necessary. Heading out from home or a place of work for a stroll or a recreational trip in rural areas must be made more appealing. At network level this means doing away with barriers by connecting low-traffic roads and paths within the city to the low-traffic network of roads and paths in rural areas.

4.6.3 Additional requirements for the recreational network

The requirements set for infrastructure for recreational cyclists do not differ significantly from those set for utilitarian cycle infrastructure. Both are used by both types of cyclist. However, what is important is that the main requirements be assessed differently. The publication 'Zicht op Nederland Fietsland' [16] presents five factors that make the Netherlands a great cycling nation. Based on these, the following conditions can be postulated for a good recreational cycle network:

- surroundings: a cycling trip should be an experience;
- accessibility: a wide range of paths and roads;
- product development: supplementary products (routes, signage and suchlike);
- supplementary facilities: catering establishments and places to stay overnight;
- marketing: information (campaigns and events) and promotion (publications, route planners, signage for cyclists, GPS).

It turns out that what cyclists take to be most important on a recreational cycling trip is a quiet (traffic) environment. Furthermore, the quality of the surroundings plays a significant role. Translated into the main requirements, therefore, attractiveness and comfort are of primary importance, along with road safety of course. In this respect, the routes for recreational use are distinct from the routes for utilitarian use; in the case of the latter, cohesion and directness constitute the most important network requirements.

Incidentally, peace and quiet, falling under the requirement attractiveness, are predominantly criteria for rural areas, away from built-up areas. Recreational routes can combine well with utilitarian routes, particularly in the vicinity of towns

and cities, even if this is purely to lead the recreational cyclist to rural areas quickly and safely. It must be stressed, incidentally, that cycling to a swimming pool or leisure centre outside of built-up areas cannot be regarded as recreational cycling. Connections to important recreational facilities must definitely satisfy the requirements in terms of directness.

Attractiveness

Recreational cyclists attach a great deal of importance to peace and quiet. For that reason, recreational networks maximize use of roads closed to motorized traffic or with limited car traffic volume (a maximum of around 1,000 PCU/24-hour period).

Furthermore, recreational cyclists enjoy riding on idyllic country roads. Hence minimum use is made of roads with lots of markings, signage and suchlike; 60 km/h roads designed in a manner that respects the landscape are the most suitable ones for recreational cyclists outside of the built environment, in addition to roads and paths closed to motorized traffic, of course.

Comfort

As with utilitarian bicycle connections, the requirement of an even road surface applies. Due to the fact that usage is usually lower than it is on utilitarian paths, the maintenance level is sometimes lower too. If the condition of the surfacing becomes unsatisfactory, then this will not be justified. It is important for the highway authority to realize that unpaved or semi-surfaced cycle paths, particularly those in farmland areas, could become overgrown within a few years' time and therefore require intensive maintenance.

In contrast to utilitarian cyclists, recreational cyclists need an interim stop with a certain degree of regularity, even if this is purely because they are covering greater distances. For that reason, resting places are incorporated into the network. A logical place for these is at the points in the network where choices are made. However, resting places are needed beyond those points as well. A distance of around 5 km should serve as a precept. Preference should be given to siting such points in places where the surrounding area is aesthetically appealing and tranquil. When developing the network, it will also be possible to take this need into account by plotting a route past the occasional catering establishment.

It is often assumed incorrectly that recreational cycle paths are allowed to be narrower than utilitarian cycle paths. Recreational cyclists more commonly ride two abreast or with family or in a group. Having infrastructure enable cyclists to ride alongside one another is something that befits cycle-friendly policy. Deviating from this requirement should only be permissible on paths where the surrounding area makes it necessary to do so. If the route runs through an area of important natural value, then this could give grounds to keep the width of the road surface as wide as possible; incidentally, a minimum of 1.50 m applies at all times.

Many recreational cyclists do their trips 'off the top of their heads'. However, their range can be increased considerably by introducing good directional signage. Moreover, unique points (such as country estates, woodland and recreational areas) can be signposted, thereby offering cyclists the most direct route too. It is also possible that introducing signposting will allow the 'discovery' of routes that users would otherwise never have cycled on without signposting.

Safety

With regard to safety, the same requirements are set for recreational cycle paths as for the other cycle paths (road sections and junctions). A particular point for attention is controlling speed in places where recreational cyclists are confronted with motorized traffic. Lighting is less important to recreational cyclists than it is to utilitarian cyclists, because recreational trips are mainly done during daylight hours.

Literature
Figures in square brackets in the text – e.g. [1] – refer to the numbers in the bibliography below.

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5 Road sections

The cycle network comprises a cohesive aggregate of bicycle connections. Bicycle connections consist of a succession of road sections and junctions. Due to the fact that the types of problem relevant on road sections differ to those at junctions, road sections and junctions will be dealt with in two separate chapters. The present chapter examines the design of road sections. Junctions will be dealt with in chapter 6. Connecting road sections to junctions is another matter that will be looked at.

The present chapter will start with the design decisions vis-à-vis the organization of road sections. In this regard, it is imperative to strike a balance between function, design and use (section 5.1). Subsequently, attention is devoted to the general requirements that may or must be set for a road section (section 5.2). Sections 5.3, 5.4, 5.5 and 5.6 examine solitary cycle paths and cycle/moped paths, combinations of bicycle traffic and motorized traffic in and outside of built-up areas and unique situations respectively.

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From the perspective of this chapter, the type of visual material presented here will refer to relevant design sheets. These sheets are included in part two of this publication. A design sheet systematically presents the most important information on a facility (function, application, implementation, dimensions and more).

5.1 Function, design and use

Thinking about facilities for cyclists on road sections is a process that starts with examining the position of the road section in the hierarchy: in the basic structure, in the main cycle network or in a bicycle highway. The road categorization for motorized traffic is also important.

A design's quality is determined by the extent to which it satisfies the five main requirements for cycle-friendly infrastructure and the requirements set by the surrounding area. The main

requirements constitute the evaluation criteria for the design. It will only be possible to achieve the right balance by working through an iterative process. The three 'dials' of function, design and use must be tweaked repeatedly to obtain an optimum design. If these three aspects are not in proper equilibrium, then there are three options for restoring equilibrium:

- adapt the design;
- influence use/behaviour;
- adjust the functional requirements (and therefore the quality).

5.2 Requirements for a road section

One basic function of a road section for bicycle traffic is to provide connection. Other functions can include opening up adjacent sections of land and enabling residential activities. If the quality of the connecting function is related to the main requirements for cycle-friendly infrastructure, then directness, safety and comfort in particular will be important at road section level. Furthermore, residential quality is important at road section level, which is why the main requirement attractiveness also plays a role.

5.2.1 Directness

A distinction is made between directness in terms of distance and directness in terms of time.

Directness in terms of distance

A road section running from A to B should offer cyclists as direct a connection as possible, ideally forming a straight line between two interchange points. This is not always what is seen in practice, but deviations from the ideal line are usually limited. Hence at road section level there is not much point in talking about detour distances. Incidentally, the more important the connecting function of a road section is, the more detrimental the effects of bendiness in the

road become. For that reason the fundamental principle must be that important, utilitarian bicycle connections are not diverted around each and every obstruction (such as a fuel station), but run straight on to the fullest extent possible.

One particular point for attention in this regard is the barriers that are difficult for cyclists to cross. Where the options for crossing are limited, this can have an adverse effect on the directness of a connection. This can lead to cycling against traffic and improper crossing. Permitting bidirectional traffic on cycle paths along these kinds of barrier can sometimes contribute to remedying this problem. Nonetheless, do consider that it could also result in new complications (see 5.4.5 and 5.5.5).

Directness in terms of time

Aside from directness in terms of distance, directness in terms of time is also important, particularly directness in terms of time as *perceived* by cyclists. A great many cyclists perceive a route through an attractive setting to be quicker than a shorter route through an unattractive setting.

When designing, it is desirable for consideration to be given at road function level to the function of the road section for bicycle (and moped) traffic and the accompanying design speed. One of the implications of this is that the road section facility must satisfy requirements in terms of width, sight distance in motion and traffic flow speed. The latter aspect will particularly have consequences for the curve radii to be used. Sufficient width is important on busier cycle paths to enable comfortable, safe overtaking. Poor surfacing or block paving will result in considerably lower crossing speeds and therefore in loss of time.

5.2.2 Safety

Road safety is extremely important on road sections because the vast majority of single-vehicle bicycle accidents occur here [1]. In addition, a limited proportion of accidents involving a bicycle and a motor vehicle occur on road sections. Consequently, requirements are set to prevent both single-vehicle bicycle accidents and conflicts with other road users.

Preventing single-vehicle bicycle accidents

Hospital records show that 60% of all cyclists seriously injured in a road accident are victims of a single-vehicle bicycle accident. Beyond this, a large number of cyclists are treated in accident and emergency departments and then sent home; these accidents are *not* recorded. Children and parents are involved in such accidents more than average.

Half of single-vehicle bicycle accidents have one or more factors related to infrastructure as their cause [2]. The road designer can implement the following measures to minimize the probability of single-vehicle bicycle accidents on road sections.

Preventing coming off the road

Cyclists coming off the road is something that must be prevented. To this end, requirements are set in terms of width, road surface, sight distance in motion, curve radii and visibility. The horizontal and vertical route should be sufficiently straight that they satisfy the sight distance in motion requirements appropriate to the function as well as to the road section's design speed. The curve radii to be used must also dovetail with the design speed. Verge accidents are particularly prominent outside of built-up areas. Making edge lines necessary on utilitarian cycle paths.

Creating 'forgiving', obstacle-free verges
Bumping into kerbs or armadillos (cycle lane delineators) and falling onto verges must be prevented. Hitting kerbs and wheel stops is dangerous and it would be best to leave these out of the design. Low, sloping edging is often a good alternative. In locations with increased risk, e.g. due to the presence of kerbs, the situation can be improved by using a row of white paving bricks or different types of surfacing on either side. It is also important for the verges to be forgiving; they should not feature any obstacles and should dovetail with the surfacing without any level difference. This will enable cyclists straying from the path to correct their course.

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Within the compass of the 'forgiving cycle path' project [3] experiments were done with verge surfacing strips made of concrete and artificial turf with widths from 0.40-0.50 m. The results were positive in the main. It is important for it to be possible for cyclists to ride onto and over these strips. The results for the concrete variant were slightly better, though the artificial turf variants are more attractive from the perspective of landscape integration. Verge surfacing strips are universally worthwhile, though particularly in locations where the cycle path is a little on the narrow side and widening it is not a viable option. They offer cyclists a safe swerving zone.

Preventing slips and falls
Cyclists can slip due to snow and ice and due to slippery materials on the road surface.
On average, one week of wintry conditions in the Netherlands produces 1,000 extra patients in accident and emergency departments. Good measures combating slipperiness in winter are spreading grit or salt and brushing and/or ploughing snow. It is also advisable to sweep leaves and suchlike throughout the rest of the year. Sand and grit should be cleaned up after work.

Manhole covers, drain covers and markings can also cause falls, especially in bends when the road surface is wet. The use of prefab concrete slabs in places where cyclists are riding is strongly discouraged. The metal edges can be slippery, besides which the plates often subside, creating differences in height. Cyclists crossing tram rails is something that must be avoided to the fullest extent possible. If this is unavoidable, then the rails must intersect cycle paths/lanes at right angles as far as possible.

Bumps and potholes in the surface can cause cyclists to veer and lose balance. This problem can be prevented by such measures as using asphalt or concrete surfacing and by fine-tuning the dimensions of the surfacing and the foundation (the sub-base) to expected peak loads. The chances of adverse effects by tree roots and moles' burrows can be minimized by harmonizing road surface and plants and by choosing the right foundations or introducing protective structures such as root barriers. Further information on the combination of road surface and trees can be found in CROW publication 280, 'Combineren van onder- en bovengrondse infrastructuur en bomen' [4].

Plants and civil engineering design of the road structure are often responsibilities vested in other parties/departments. In order to be able to ensure a good-quality road surface, it is important for these parties to join forces to harmonize the design (see also chapter 7, particularly 7.1 and 7.2).

Preventing collisions with obstacles
Obstacles and narrowing of the road often result in single-vehicle bicycle accidents, particularly among older cyclists. Many of these collisions are preventable by only using obstacles (including bollards - see below) where this is strictly necessary. For the purposes of slowing motorized traffic, solutions that do not entail obstacles can be chosen, e.g. installing a speed bump rather than narrowing the road. Another important factor is the degree to which obstacles are predictable and conspicuous. Consequently, aside from the correct finish, introductory ribline and adequate illumination are necessary.

V7

Bollards are being used on and around road sections for bicycle traffic on a large scale, particularly to prevent unwanted use of the bicycle connections by motorized traffic.
A significant disadvantage of bollards is that they cause a considerable number of serious and sometimes even fatal single-vehicle bicycle accidents. Each year, hundreds of cyclists are admitted to hospital due to collisions with bollards. Often these are elderly cyclists. Hence the costs to society of a simple bollard can mount up considerably. Incidentally, it is not just bollards in the middle of the cycle path that can cause collisions - bollards at the edge of cycle paths or on verges are just as culpable. Collisions with bollards are a relatively common occurrence in the dark.

Other gripes about bollards are that they are a permanent source of discomfort to cyclists and that they potentially impede maintenance vehicles, winter service vehicles and emergency services vehicles (unless they are easy to remove). In turn, this can indirectly result in more discomfort and more falls due to insufficient cleaning or winter maintenance.

In view of the many disadvantages, a designer should make a point of asking himself whether bollards are truly necessary; from a safety perspective, alternative solutions are always preferable. If bollards are used anyway, then they must be sited in such a way that the risk of accidents is minimized, i.e. not in cyclists' trajectory, clearly visible, well lit, and introduced by the appropriate ribline [5]. Flexible (self-righting) bollards are preferred due to how forgiving they are.

If bollards need to be easily removable, then retractable (telescopic) and removable varieties can be considered. The use of hinged (folding) bollards is greatly discouraged (these are unsafe in their folded state).

Ensuring a safe succession of elements in the lateral profile
It is important for road section elements to be combined correctly in the lateral profile and that they follow on from one another safely. Balance problems may arise if upward inclines and bends are combined. On downward inclines bends could be too tight for the speed at which cyclists are travelling. If bends appear unexpectedly at the end of a descent, and cyclists are not able to anticipate these as a result, then their speed may be too high to corner safely.

Preventing conflicts with other road users
Cyclists are a vulnerable group of road users in a traffic system dominated by motorized traffic. The majority of those cyclists involved in accidents are involved in accidents with a motorized vehicle. The following measures are possible on road sections to foster cyclists' road safety.

Avoiding conflicts with oncoming traffic
In the case of conflict with oncoming traffic (head-on collisions), there is a high probability of serious consequences. When designing road sections on which bidirectional traffic is permitted, therefore, sufficient attention to width, sight distance in motion, guidance and any carriageway separation. This is important on road sections with mixed traffic, as well as on cycle paths in particular. An overly narrow cycle/moped path with (ample) bidirectional traffic is unsafe, especially when also used by fast cyclists, such as those engaged in racing and those with pedal-assist functionality, and/or mopeds and light mopeds. (Tight) bends with poor sight distance on (narrow) cycle paths can also lead to head-on collisions.

Avoiding conflicts with traffic approaching from the rear
Fortunately, conflict between cyclists and motorized traffic approaching from the rear is rare in the Netherlands. The probability of this can be minimized by making clear choices at road section level for either a tight profile (no overtaking) or a wide profile (allowing overtaking); the interjacent critical profile should be avoided (see also 5.4.4). For cycle/moped paths it holds that conflict arising as a result of overtaking can be prevented by ensuring sufficient width. The higher the volumes, the more width is required.

Segregating vehicle types
The lower the number of encounters between cyclists and other road users, the lower the probability of an accident occurring. By combining car traffic on a diffuse main road network on the one hand and creating large residential areas on the other, the probability of encounters is reduced. Moreover, a dense cycle network ensures journey times that are competitive with those for cars. New, logical and disentwined routes can also be created by tackling missing links. If these run alongside busy roads for motorized traffic less, then cyclists will be less exposed to emissions and noise pollution.

Where there is a significant difference in speed, it is preferable to avoid having cyclists and motor vehicles use the same traffic space, with the motto in such cases being: segregate. If segregation in the cross section is not possible or desirable, then speed differences must be minimized.

Segregating traffic types is also advisable in the case of significant differences in mass. Segregation of cyclists and other types of traffic (e.g. buses or agricultural vehicles) has the potential to result in more objective and subjective safety and a higher level of comfort.

Ensuring recognizability and lack of ambiguity
Recognizability and lack of ambiguity in whatever form are important requirements in a sustainably safe traffic system. The more important the function of a road and/or cycle path and the greater the speed of the traffic, the more important these requirements are (after all, higher speed means less time to react and therefore a higher probability of errors being made).

Recognizability at road section level is primarily germane to the design of the cycle facility. Each and every specific facility should be recognizable as such to all road users, making it predictable for everyone how the road section is to be used and what behaviour is expected of the various groups of road user.

Lack of ambiguity in traffic situations is another factor ensuring that road users know what is expected of them. Lack of ambiguity is more important when it comes to the application of rules, signage, markings and design principles than it is when it comes to an actual design; after all, local conditions mean that it is virtually never the case that designs are identical. Nevertheless, the underlying principles and facilities used can be identical.

5.2.3 Comfort
The following requirements are set for road sections with a view to fostering comfort.

Preventing loss of time
Depending on the function that a road section is fulfilling within the cycle network, requirements are set in terms of the design speed. A good design will ensure that under normal conditions cyclists are not forced to ride more slowly than the design speed. This sets requirements in terms of the radius and width of facilities. A cycle facility or carriageway must be sufficiently wide that it does not cause any delay, or only causes occasional delays. There will also be as few obstacles (such as bollards) on the carriageway as possible. Not only are these dangerous, they also considerably limit capacity.

Avoiding bendiness
Bendiness is avoided as much as possible on road sections forming part of the main cycle network. Cyclists must be able to ride on these kinds of route without being hampered by tight bends, having to swerve awkwardly or move at

Table 5-1. Summary of the main requirements for road sections

Main requirement	Important here	Explanation
Directness	Directness in terms of distance	Avoiding unnecessary bends and twists in road sections.
	Directness in terms of time	This is due to the average speed and the rate of flow. Indicators for this are the average speed on a road section and the delay (forced slow driving). For road sections in the main cycle network, the design speed is 30 km/h in built-up areas and 40 km/h outside of built-up areas; for road sections in the basic structure it is 20 km/h.
Safety	Probability of accidents and severity of accidents/injury	Avoiding conflicts with oncoming traffic. Avoiding conflicts with traffic approaching from the rear. Segregating types of traffic. Reducing speed at points of conflict. Ensuring recognizable road categories. Ensuring uniform traffic situations. Preventing coming off the road. Use 'forgiving', obstacle-free verges and kerbs. Preventing slips and falls. Preventing collisions with obstacles. Ensuring a safe succession of elements in the lateral profile.
Comfort	Preventing loss of time	Under normal circumstances cyclists can ride at the intended design speed on road sections.
	Flow	Road sections are sufficiently wide. Curve radii take the design speed appropriate to the function into account. Extreme bendiness is prevented.
	Evenness	Road sections satisfy the requirements in terms of evenness.
	Discomfort due to gradients	Maximum gradients are not exceeded.
	Traffic nuisance	Cyclists do not experience any nuisance from other traffic. In busy situations with a large amount of emissions and noise, efforts are made to create a separate route for bicycles.
	Weather nuisance	Nuisance caused by wind and rain is minimized.
Attractiveness	Personal safety	Road sections satisfy requirements in terms of personal safety: there is lighting present, local residents can monitor things, road users have a good view of the surroundings and the public space is well maintained. For further information see section 7.5.
	Traffic nuisance	A route's attractiveness can necessitate separation of cyclists and other traffic.

right angles. At the same time it holds that, from the perspective of attractiveness, dead straight connections are not ideal. Gentle bends can have a positive effect on perception of a route. Where tight bends cannot be prevented due to cyclists leaning into the turn, then the bend must be widened by up to 0.50 m.

Ensuring an even road surface
The surfacing on the road section should satisfy the requirements in terms of evenness. This applies to both the surfacing itself and the transitions between different surfaces.

Minimizing discomfort due to gradients
Maximum gradients are not exceeded (see section 3.5). In addition, the number of inclines per unit of length are limited; from the perspective of comfort, having a variety of successive slopes is undesirable (even where these satisfy the desired gradients individually).

Minimizing traffic nuisance
When designing a road section for cyclists, the probability of nuisance caused by motorized traffic is minimized. If volumes of car traffic are high, then preference is given to a segregated route for bicycle traffic, not just from the perspective of road safety but also due to comfort. This will also limit nuisance due to noise and exhaust fumes.

Minimizing weather nuisance
It is possible to protect cyclists from wind and rain to a limited extent. To this end, road sections can be sheltered by means of plants, buildings or specific screen structures (wind screens). Combating katabatic winds where high buildings are present is increasingly a point for attention.

5.2.4 Attractiveness

The main requirement attractiveness is about cyclists' perception. Hence assessing the attractiveness of a road section for cyclists is by definition a highly subjective affair. Moreover, far more than is the case for a road section itself, the quality of the surroundings determine how a specific connection is perceived; an ostensibly ideal route (low-traffic, amply wide, even asphalt, right of way) can be unattractive if it passes through a dodgy area.

At road section level, the designer will have little influence on the setting. Personal safety can be improved, however, by ensuring a clear situation, e.g. by only using low plants and sufficient sight distance onto and off of the route. Good lighting is also important. Furthermore, the designer has influence over the extent to which cyclists are able to enjoy cycling without being impeded by other traffic. If cyclists are not troubled by motorized traffic, then this contributes to the attractiveness of a connection.

5.3 Solitary cycle paths and cycle/moped paths

V1

Cycle paths are identifiable by the sign 'Verplicht fietspad' ('Mandatory cycle path') (G11, Appendix 1, RVV 1990) or the sign 'Onverplicht fietspad' ('Advisory cycle path') (G13). These signs are repeated after each junction. Cycle/moped paths are identifiable by the sign 'Fiets-/bromfietspad' ('Cycle/moped path') (G12a). Road sections that resemble cycle paths but are not furnished with the aforementioned signs are, in the eyes of the law, not a cycle path or a cycle/moped path.

V2, 3, 16

Solitary or segregated cycle paths follow their own route and are intended solely for cyclists (cycle path) or cyclists and moped riders (cycle/moped path). This could pertain to connections through a park, a bicycle highway between districts or a recreational route (for example). Solitary paths are occasionally confused with segregated paths. One significant difference is that the latter are related to an adjacent road, whereas this is not the case with solitary cycle paths. Whether or not a cycle path belongs to the road in a legal sense is something that will depend on 'how the streetscape appears to the road users'. A rule of thumb is that a cycle path is no longer part of a carriageway if the distance between it and the carriageway exceeds 10 m.

In principle, solitary cycle facilities are intended for bidirectional traffic. This places demands on the width. The minimum width for recreational cycle paths with an exceedingly low volume of traffic is 1.50 m. A precondition in this regard is that the verges be 'forgiving': that they be free of obstacles, that they can be ridden on and that they have a minimal level difference between verge/pavement and path surface. If mopeds and/or light mopeds will be using the path, then a minimum width of 2.0 m applies, even with 'forgiving' verges/pavements.

V5

In order to make clear that traffic can be expected from the opposite direction, it is preferable to use a centre line on solitary paths.

Joint use on the part of pedestrians

If there is no pavement, then pedestrians are also entitled to use a cycle path. This is common in the case of solitary bicycle connections through a park and outside of built-up areas. When volumes are higher, such shared usage can cause irritation. For reasons of comfort, segregating cyclists and pedestrians is recommended in such situations (e.g. by means of markings and/or different-coloured surfacing), but only if there is sufficient space available for this. If segregation would result in two lanes that are both too narrow for their target group, then it would be better to avoid this.

Lighting desirable

One important point for attention in the case of solitary paths is personal safety. Due to the fact that the paths follow their own route which is often beyond the sphere of influence of the built environment, situations of diminished personal safety can be relatively quick to arise. This can be improved by means of lighting. The recommendation to provide lighting particularly applies to solitary paths in built-up areas that form part of a network of (main) cycle routes. New forms of lighting could be used outside of built-up areas, e.g. lighting that automatically

comes on when a cyclist is passing and then automatically switches off, or animal-friendly lighting.

V5, 6

In addition to lighting, lining and marking are often necessary to enable cyclists to distinguish verge and surfacing when it is dark.

Unlawful use on the part of other traffic

Solitary connections for bicycle traffic or for bicycle and moped traffic (and perhaps pedestrians as well) could prove appealing to other road users. Unlawful use of these paths must be prevented, however. The most common means of achieving this is to install one or more bollards at the start of a road section for cyclists/moped riders. This simple, inexpensive and effective measure not only combats undesirable use of bicycle connections, but can also effect a change in traffic circulation to the benefit of the safety and quality of life of a residential area.

V7

Due to the benefits specified, bollards have been in extremely widespread use on cycle paths in the Netherlands in recent decades. Siting bollards at the ends of a cycle path now seems to be second nature, without consideration being given to utility, necessity and design. This misses the point of the bollard, as a surfeit of bollards also entails significant disadvantages. On this, see section 5.2.2 under 'Preventing collisions with obstacles'.

5.4 Bicycle traffic and motorized traffic within built-up areas

5.4.1 Fundamental principles

Where both cyclists and motor vehicles are using a road section, one crucial question centres on the most appropriate layout and maximum/safe speed for such a road section. The functions of the road section for both cyclists and motorized traffic are paramount.

If the road for motorized traffic is a distributor road, then this will set different requirements for the road design than if it is a residential road. The same goes for the function of the road for bicycle traffic:
different requirements are set for the cycle facilities on a road section forming part of the main cycle network than are set on a road section forming part of the basic cycle structure. Hence it is not just the function of the road section for motorized traffic that is of decisive importance within the compass of road section design considerations.

General point of departure

The general point of departure is that specific cycle facilities are required on road sections with a flow function (or partial flow function) for motorized traffic (distributor roads). In principle, no cycle facilities are necessary on road sections with a residential function (exclusively or otherwise) for motorized traffic, for road safety reasons; in such cases mixed traffic is acceptable.

Nonetheless, nuances are possible and often desirable within the compass of this general point of departure. For instance, a road section forming part of the main cycle network must provide a greater degree of quality and comfort than a road section only being used by a single cyclist. For that reason, the designer will always have to look at what will constitute the best solution in a given situation, taking the actual circumstances into consideration.

V3, 8, 12, 13, 14, 15

For each road section the question is what traffic facilities are required to ensure that the situation cyclists find themselves in is safe and pleasant. Table 5-2 presents a selection plan for cycle facilities on road sections in built-up areas. This plan provides initial guidance for the decisions to be made for each road section. The plan (table 5-2) enables both functional road categories and traffic planning factors (speed, volume of traffic) to be selected as a starting point. Although a connection may be assumed between the two, in practice it emerges that this is not always the case. The speed of motorized traffic in particular is frequently an unreliable factor; it is common for limits to be exceeded en masse [6]. Consequently, highway authorities should either ensure that actual speed is in line with the speed limit or take actual speed as their point of departure, separately from the road's function. It is important for the designer to always focus on the actual or expected situation and not just on the functional category for motorized traffic.

Table 5-2. Selection plan for cycle facilities in the case of road sections in built-up areas

Road category	Speed limit motorized traffic (km/h)		Volume of motorized traffic (PCU/24-hour period)	Cycle network category: Basic structure ($I_{bicycle}$ < 750/ 24-hour period)	Cycle network category: Main cycle network ($I_{bicycle}$ 500-2,500/ 24-hour period)	Cycle network category: Bicycle highway ($I_{bicycle}$ > 2,000/ 24-hour period)
Residential road	walking pace or 30		< 2,500	mixed traffic	mixed traffic or bicycle street	bicycle street (with right of way)
			2,000-5,000	mixed traffic	mixed traffic or cycle lane	cycle path or cycle lane (with right of way)
			> 4,000	cycle lane or cycle path	cycle lane or cycle path	cycle path or cycle lane (with right of way)
Distributor road	50	2x1 lane	not relevant	cycle lane or cycle path	cycle path	cycle path
		2x2 traffic lanes		cycle path	cycle path	cycle path
	70			cycle/moped path	cycle/moped path	cycle/moped path

The selection plan presented in table 5-2 is based on three fundamental principles:

1. The most desirable situation for cyclists occupies centre stage.
2. It is not just the specific cycle facility that is important for a cycle-friendly infrastructure, but also the entire traffic situation. For that reason, the scope of the plan goes beyond the cycle facility in itself.
3. It is often the case that various solutions, with various characteristics, are possible in a given situation. This fact finds expression in threshold values that overlap one another.

The three fundamental principles just mentioned are explained below.

Fundamental principle 1: The most desirable situation for cyclists occupies centre stage.
The selection plan shows what situations are favourable for cyclists; in practice this boils down to 'as safe and comfortable as possible'. The recommendations from the plan will not always be feasible, however, even if it is often the case that various solutions are possible. The upshot of this is that in such cases the designer will prepare a design that is less desirable from the perspective of cyclists' interests. Here, the designer will endeavour to identify a better solution by searching for alternative routes or speeds, as a result of which there will be 'room for manoeuvre' within the plan. After all, the plan incorporates three variables that can be influenced: bicycle traffic volume, motorized traffic volume and motorized traffic speed. If one of these factors is changed, then it may be possible to continue working 'from the perspective of a cell' where the relevant facility is feasible in a cycle-friendly way.

If both a cycle path and a cycle lane are feasible options, then creating a cycle path will always be preferable. After all, from the perspective of road safety, exposure to exhaust fumes and comfort, a cycle path has clear advantages over a cycle lane.

Fundamental principle 2: The entire traffic situation is important
Cycle policy is not synonymous with creating specific cycle facilities. Whether or not traffic situations are safe and pleasant for cyclists is not something that depends solely on the presence and quality of facilities made for cyclists; to this end, the *entire* traffic situation is important. Furthermore, it is not always possible to fall back on general points of departure. It is too easy to state that mixing bicycle traffic with motorized traffic is always possible where the speed of the latter is low. Perhaps from a safety perspective it is, but cyclists' comfort might necessitate more. Which is why in the selection plan the general points of departure of segregation and mixing are nuanced in terms of components.

Fundamental principle 3: More solutions, overlapping boundaries
Various good solutions are possible for a given situation; hard and fast limits for such things as volumes of traffic cannot be offered. Hence the overlap between various solution options in the selection plan (table 5-2). As a result, various forms of solution are possible for various areas of application. Incidentally, the plan is merely a tool; the designer will have to produce a customized solution based on the actual situation.

Road categorization and influencing factors
Two types of criteria are used in the selection plan to distinguish traffic situations. First of all, these are the influencing factors for which it is known that they determine the bicycle-friendliness of a traffic situation to a significant extent: the speed and the volume of motorized traffic. Secondly, there are the functional categories. Fundamental to the plan is the distinction between residential road and distributor road for motorized traffic and basic structure, main cycle network and bicycle highway for bicycles.

According to publication Basiskenmerken Wegontwerp ('Dutch Guidelines for Basic Road Design') [7] mixing traffic types is the starting point on residential roads (in the case of minor differences in speed, direction and mass) and segregating traffic types is the starting point on distributor roads (in the case of major differences in speed and mass). As already touched on, this is somewhat nuanced, and also chimes with the observation that in the Netherlands there are provisionally a lot of intermediate forms in practice. These so-called *grey roads* have characteristics of distributor roads when it comes to their function in the network and use by motorized traffic, and yet at the same time they also have characteristics of residential roads due to the adjacent buildings and facilities.

In the case of these types of road with mixed traffic or light forms of segregation, a lower, safer speed is suggested [8].

V12, 13, 14

On residential roads with low car traffic volumes and high bicycle traffic volumes, bicycle streets are suggested on the main cycle network and on bicycle highways. Bicycle streets have right of way at junctions with residential streets. To this end, a decision has been made to safeguard traffic flow and comfort on the main cycle route, thereby serving the flow function for bicycle traffic.

5.4.2 Mixed traffic

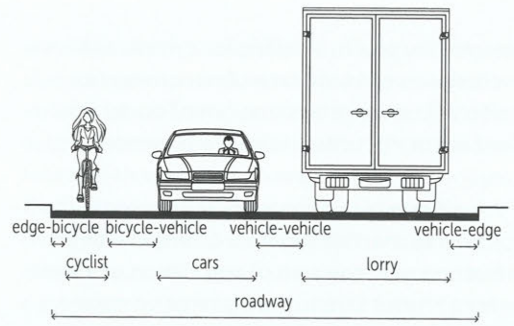
V8

A residential road, which often takes the form of a traditional residential street or a road with a limited collection function in a residential area, has a speed limit of 30 km/h. In the case of a limited number of cyclists, motorized traffic volumes of up to around 5,000 PCU/24-hour period, block paving, and in particular also a speed pattern appropriate to the road's function, specific cycle facilities are not required. In the case of low volumes of motorized traffic and bicycle traffic, a tight profile is the starting point. This contributes to the intended low speed, but is not sufficient by definition; even in the case of a tight profile additional speed-reducing measures can be necessary.

A tight profile means that a car has to stay behind a bicycle when faced with oncoming traffic (see also the text box 'Dimensional segments and indicative use'). The higher the volumes, the more irritation will be caused by motorists on such a tight profile, ultimately resulting in irresponsible overtaking manoeu-

Dimensional segments and indicative use
In order to put together a suitable profile, the designer can use dimensional segments and data on indicative use. Indicative use refers to the indicative combination on a road section, e.g. the combination of one car and two cyclists. Dimensional segments provide the dimensions required in the lateral profile for a specific user. The accompanying table shows the dimensional segments and the corresponding width for residential roads.

The value of the dimensional segment edge-bicycle represents the minimum distance that a cyclist will want to keep from a kerb. If a cyclists is passing parked cars on his right-hand side, then the value for this dimensional segment will be around double this figure. Virtually all motorized traffic will overtake the bicycle traffic when the value of the dimensional segment bicycle-vehicle is 0.85 m or more [and also when the space of the width of the vehicle remains - check this]. If the dimensional segment bicycle-vehicle reduces, then drivers will hesitate: some will overtake, some will hang back behind the cyclist. This is then a critical profile, creating a dangerous and undesirable situation. Consequently, the remaining width next to the cyclist must be restricted in such a way that motorists continue to hang back behind the cyclist.
The dimensional segment bicycle-vehicle is larger than the dimensional segment vehicle-vehicle. The reasons for this are that cyclists are more vulnerable than motorists and that bicycle traffic behaviour is less predictable than motorized traffic behaviour. Motorists take the weaving motion of cyclists into account when overtaking. Incidentally, it turns out in practice that cyclists steer to the right (towards the pavement) when being overtaken. If they were to refrain from doing so, then the passing distance would be 0.30 m smaller on average.



Example of a lateral profile with dimensional segments

Dimensional segments and the corresponding width profile, for residential roads (30 km/h)

Dimensional segment	Requisite width profile (m)
cyclist 2)	0.75
moped/light moped 6)	1.00
passenger car 2)	1.83
lorry 2+3)	2.60
cyclist – edge (kerb higher than 0.05 m) 2+5)	0.125
cyclist – edge (kerb lower than 0.05 m) 2+5)	0.00
cyclist – parked vehicle 1+4+5)	0.50
cyclist – cyclist (both in motion)	0.50
cyclist – vehicle in motion 1+4)	0.80
cyclist – vehicle in motion at 50 km/h 1+4)	1.00
vehicle – vehicle (both in motion) 2+4)	0.30
vehicle in motion – kerb 2+4)	0.25

1) value established on the basis of research
2) value in line with ASVV
3) in this regard, buses are counted as lorries
4) vehicle is taken to mean: all motorized vehicles with a minimum of three wheels
5) measured from the outside of the cyclist
6) including mirrors

vres. A wide profile allowing for cyclists to be overtaken even in the face of oncoming car traffic will ensure that situations of doubt (to overtake or not to overtake) are prevented.

If the volume of bicycle traffic is involved in the considerations, then figure 5-1 can provide an indication as to the area of application of a wide or tight profile. Due to the fact that no clear boundaries can be set between the various solutions, the graph features a transition area; within the compass of this, the designer will have to ask himself which profile is most suitable. If a wide profile is chosen, then the designer will need to be prepared for the fact that this will tempt motorized traffic to travel at higher speeds. This will be more likely to necessitate additional speed-reducing measures than would be the case with a tight profile to safeguard cyclists' comfort and safety.

Parking
In the case of mixed traffic, parking is a point for attention. Parking is discouraged on the main cycle network and alongside bicycle highways. Parked vehicles are not only a hindrance to cyclists, but they also present a hazard due to opening doors and swerving manoeuvres as a result of these. Moreover, parking manoeuvres present further hazard and hindrance.

V10, 11

If parking is permitted, then this must be facilitated by means of a parking lane or lay-bys. This will create a straight trajectory for bicycle traffic, limiting the width of the vehicle path for moving traffic and reducing the probability of cyclists hitting a parked vehicle. In order to prevent cyclists riding into an opening car door, a critical reaction strip of at least 0.50 m is always recommended for a parking lane.

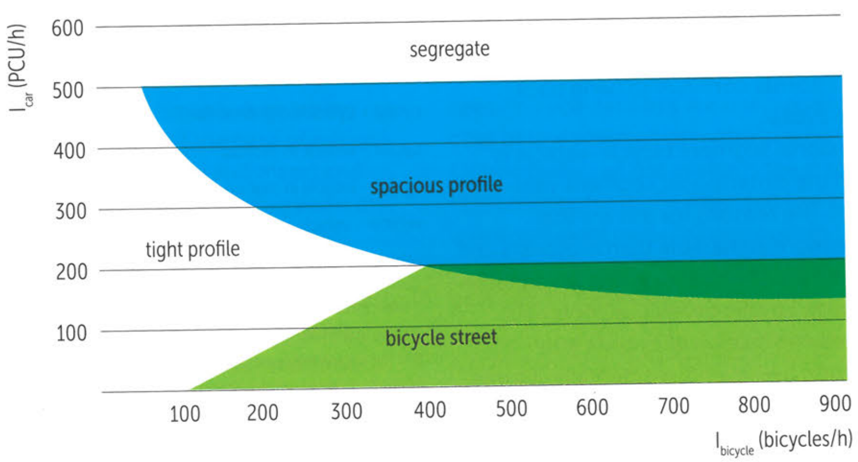


Figure 5-1. Suggested solutions (indicative) for profile choice when mixing motorized traffic and bicycle traffic

The occasional car sat on the carriageway on road sections forming part of the basic structure for bicycles is not too big a deal. If, however, more than around 20% of the stretch of road is used for parking, then the appropriate recommendation would be to create a parking lane or longitudinal lay-bys with a critical reaction strip.

5.4.3 Bicycle streets

V12, 13, 14

The main cycle network often coincides with main routes for motorized traffic. Primarily in old cities, it is frequently the case that these are the radial connections fulfilling an important function for both bicycle traffic and car traffic. However, it is also common for main cycle routes and distributor roads for motorized traffic not to coincide, or to be deliberately segregated, because cycling on busy roads is neither safe nor appealing for cyclists and can cause extra delays. If this is the case, the main cycle route will need to be segregated or plotted along residential roads through the residential area. In such cases, a specific type of main cycle route enters the picture: the bicycle street.

Bicycle street is a functional concept. It is a residential road for motorized traffic that forms part of the main cycle network or of a bicycle highway, and which is identifiable as a bicycle street due to its design and layout, but has a limited volume of car traffic on it and that car traffic is subordinate to the bicycle traffic [9]. Due to the fact that this pertains to important cycle routes, the numerical dominance of bicycle traffic is more or less self-evident. As a minimum, the extra quality afforded to the cycle route encompasses cyclists being given right of way. To be sure, generally speaking introducing right of way rules in residential areas is not permitted, but legislators have made an exception for (what are recognizable as) main cycle routes in the implementation regulations of the Administrative Provisions (Road Traffic) Decree (Besluit administratieve bepalingen inzake het wegverkeer, or BABW).

A bicycle street can be organized in a variety of ways. At any rate, the following is recommended:

- minimizing hindrance due to parked vehicles;
- using smooth surfacing (preferably asphalt);
- where need be, creating some kind of traffic island at points where choices need to be made;
- suppressing through motorized traffic, e.g. by arranging alternating one-way traffic for motor vehicles.

Benefits of bicycle street
Bicycle streets present a variety of important benefits:

- Less space
  A bicycle street is accessible to car traffic and takes up less space than a solitary cycle path or a segregated cycle path alongside the main carriageway. This makes it easier to integrate a cycle route and makes it more cost-effective.
- Lower probability of single-vehicle bicycle accidents
  The combination with motorized traffic will

mean that no (or fewer) car-suppressing obstacles such as bollards will be needed and it could be easier to create and maintain the desired width and evenness for the surfacing. This will reduce the probability of single-vehicle bicycle accidents.

- Better accessibility
  In contrast to full closure of a street or route to motorized traffic, functions adjacent to or behind a bicycle street can remain accessible to motor vehicles. Moreover, parking spaces, which are often in short supply, can be retained.
- Better personal safety
  A route *through* a residential area, with combined use on the part of bicycles and cars, provides a greater degree of personal safety than a solitary path or a segregated cycle path alongside an urban main road.

Volume of bicycle traffic
One important precondition to be able to designate a road section as a bicycle street is that the bicycle traffic be genuinely dominant in the street scene. Such a dominant position for bicycle traffic is amply in evidence if there are more cyclists on a road section than motor vehicles. If this requirement is not satisfied, even though from a policy perspective there is a wish for extra quality to be produced for cyclists' sake, then the highway authority can endeavour to reduce the volume of car traffic so that the requisite volume ratios are nevertheless fulfilled.

Aside from a *relatively* high proportion of cyclists, a high number of cyclists in *absolute* terms must also be using the road section in order for it to be eligible to be designated a bicycle street. Although local ratios play a role, a road section can only be deemed a bicycle street if at least 1,000 cyclists pass over it in each 24-hour period [10].

Volume of car traffic
Practical research [11] reveals that the dominance of bicycle traffic can easily be achieved without modifying the profile in the case of car traffic volumes of up to 500 PCU/24-hour period. In other words, main cycle routes in residential streets pretty much exclusively used by local traffic are naturally dominated by bicycle traffic, irrespective of the volume of that bicycle traffic. At volumes in excess of 500 PCU/24-hour period, it is paramount that the volume of bicycle traffic exceeds that of motorized traffic. Based on experience with functioning bicycle streets, it would appear accurate to assume as limited a number of cars as possible, with a maximum of 2,500 PCU/24-hour period.

If the volume of motorized traffic exceeds 2,500 PCU/24-hour period and there are no possibilities of reducing this number, then another solution will have to be sought for the cycle route. Consider in this regard a cycle path or an entirely new route. That route will have to be just as direct as the route initially intended.

5.4.4 Cycle lanes

V15, 16, 19, 54

Although it is preferable for segregated cycle paths to be used alongside distributor roads, cycle lanes are also an option on sections of distributor roads with a speed limit of 50 km/h and relatively low volumes of bicycle traffic. Cycle lanes are also frequently used on residential roads and particularly on what are referred to as 'grey roads' within the compass of Sustainable Traffic Safety ('Duurzaam Veilig') [7] which form part of the main cycle network and have a relatively high volume of car traffic on them. Furthermore, cycle lanes can be used for the purposes of marking main cycle routes through quiet residential areas and on residential roads outside of built-up areas with a speed limit of 30 or 60 km/h. This will accentuate the position of bicycle traffic.

A good cycle lane is characterized by:
- sufficient width;
- a red colour;
- the bicycle symbol.

Cycle lane or cycle path?
Important aspects when deciding between cycle lane and cycle path include:
- safety;
- exposure to emissions;
- available space.

Each of these aspects will be explained below.

Safety
Research from the 1980s [12] shows that cycle paths alongside urban arterial roads are safer for cyclists than cycle lanes. For every kilometre covered by bicycle, 50% fewer accidents involving injury occurred on cycle paths alongside sections of road than occurred on cycle lanes. This pertains to collisions with motorized traffic. Incidentally, the group cycle lanes was somewhat variform in this study: narrow and wide lanes, as well as advisory cycle lanes, with and without parking at the roadside, were conflated.

Furthermore, attention must be paid to the risk of unilateral accidents. A striking number of unilateral accidents are caused by cyclists hitting kerbs and transitions between different types of surface [1]. The edge of the surface or the transition between cycle path and carriageway present an additional risk of unilateral accidents. This applies all the more as the space for cyclists gets tighter and the volume of cyclists increases. For that reason, a good solution involving a cycle path will take up more space than a good solution involving a cycle lane.

Exposure to emissions
Exposure to air pollution is another reason to give cycle paths preference over cycle lanes. Particularly if the cycle path is several metres away from the carriageway, cyclists will be further from the source of, and breathe in less of, harmful exhaust fumes, which contain such substances as nitrogen dioxide (NO_2) and ultrafine particulate matter, including soot [13].

Available space
It has already been stated that on average a solution involving cycle paths takes up more space than a solution involving cycle lanes. If less than 11.80 m is available for cyclists and motor vehicles on a distributor road (without parking), then it will not be possible to create bilateral one-way cycle paths properly. This can constitute a reason for choosing cycle lanes.

Parking

V10, 11

Parking cars in spaces next to a cycle lane increases the probability of accidents involving serious or fatal injuries. These occur if cyclists are forced to swerve to avoid a car or an opening door and end up hitting a car on the vehicle path for motor vehicles. For that reason, the combination of cycle lane and parking spaces is strongly discouraged on distributor roads. The individual elements are already at odds with the ideal distributor road and it is therefore imperative that they are not used in combination. Incidentally, this is a regular occurrence in practice. In such cases, it will be necessary to always create a critical reaction strip 0.50 m wide between parking space and cycle lane in order to minimize the risks. Furthermore, reverse parking at an angle is preferred, because this entails less risk than parallel parking.

Limiting speed
Cyclists are vulnerable road users who are not protected in the event of a collision with a motor vehicle. For that reason, one functional requirement for cycle facilities is that speeds are reduced in conflict situations. The presence of cyclists on the carriageway, even where cycle lanes are available, results in potential conflict. Consequently, the recommendation is to reduce the speed limit from 50 km/h to 30 km/h if cyclists are allowed on the carriageway. This recommendation is even more pressing if parking is permitted on or alongside the carriageway.

Cycle lane width

V15

The recommended widths for cycle lanes are based on the fundamental premise that a cycle lane should always be sufficiently wide to allow a minimum of two cyclists riding abreast. This can pertain to cyclists riding alongside one another for companionship, an adult wishing to ride alongside a child for safety, or a faster cyclist wishing to overtake a slower cyclist. Cyclists must be able to use the lane safely and comfortably, without having the feeling of being pursued by motor vehicles. The width of the cycle lane must encourage passing motorists to keep their distance from cyclists.

Research from CROW-Fietsberaad [22] reveals that the width of the cycle lane exerts a great deal of influence on the way in which motorists pass cyclists (and thus on objective and subjective safety). Wider cycle lanes result in passing distances that are greater on average. The number of instances of (excessively) tight passing also declines significantly if the cycle lane is wider: in the case of cycle lanes measuring 1.80 m and wider, these are nigh on non-existent, even on busy (or very busy) road sections. On such cycle lanes it turns out that the majority of cycling pairs ride with their wheels on the lane. Unsurprisingly, surveys show that cyclists appreciate wider lanes more than narrow ones, particularly when cycling two or more abreast.

What the aforementioned fundamental premise means in concrete terms is that a cycle lane should preferably be 1.70 to 2.25 m wide, depending on the available surface width. These dimensions do not include markings. In other words, this pertains to effective width. If obstacles are located close to the cycle lane (e.g. bollards within 0.50 m), then corrections must be made for these by means of a wider cycle lane.

In built-up areas, cycle lanes can be used on roads with a wide central vehicle path, suitable for two passenger cars, or on roads with a narrow central vehicle path, suitable for a single passenger car. Central vehicle paths where there is doubt or two passenger cars can pass one another must be avoided. For the purposes of using cycle lanes, a minimum effective surface width of 5.80 m is necessary. The remainder of this section presents detailed recommendations for the layout of the cross section.

Advisory cycle lanes
It used to be common to see cycle lanes without a bicycle symbol. These so-called *advisory cycle lanes* do not have any legal status. Occasionally less stringent recommendations are applied to advisory cycle lanes than to cycle lanes (including in terms of factors like width and colour). Clear decisions are advised: either go for a fully fledged cycle lane (with sufficient width and markings), or create a fully mixed profile.

Cycle lanes on distributor roads
On a distributor road with a speed limit of 50 km/h, cars and cyclists must be separated from one another in line with Sustainable Traffic Safety. Ideally, a segregated cycle path will be used to this end, though cycle lanes are also permissible. In such cases, the cycle lane will have to genuinely delineate a discrete domain for the cyclist. To this end, a continuous stripe between the cycle lane and the main carriageway can be introduced.

The lanes for motorized traffic must be sufficiently wide that cars and lorries do not have to use the cycle lane (recommended lane width 2.90 m). The cycle lane should be sufficiently wide to allow safe and comfortable flow of bicycle traffic (including cyclists overtaking). The recommended width for a cycle lane is 2.25 m; the minimum dimension is 1.70 m (not including markings). Where bicycle traffic volumes are higher, more width will be required and a cycle path must be considered.

In order to encourage passing car and lorry traffic to keep sufficient distance from cyclists, the recommendation is to always maintain a space of 0.50 m between cycle lane and driving lane. If space is lacking, then 'savings' can be made (if need be) on the widths of cycle lanes and driving lanes, but the intermediate space of 0.50 m should continue to be fundamental.

On distributor roads (50 km/h), cycle lanes and parking spaces should not be combined.

'Grey roads'
Some distributor roads in built-up areas are too narrow for cycle paths and accommodate too much through traffic to be organized as residential roads. Sustainable Traffic Safety regards such a combination of functions undesirable. In practice, however, it turns out that it is not always possible to organize such *grey roads* in line with Sustainable Traffic Safety in the short term. In such situations, cycle lanes may be considered.

This does mean that motorists will occasionally have to veer onto the cycle lane due to an oncoming bus or lorry. And fast cyclists will sometimes have to use the driving lane for such things as overtaking a cargo bike. Then it is no longer an exclusive domain. Hence these roads will not be satisfying the essential requirement of separating slow and fast traffic that applies to distributor roads.

In order to emphasize the function for bicycle traffic and to ensure that cars are not impelled to drive too far over to the side of the road, lanes for cyclists are still recommended. Although their function differs, such lanes are also just referred to as 'cycle lanes'. Nonetheless, the recommended width for cycle lanes in these kinds of situation is 2.00 m, with a minimum of 1.70 m and a maximum of 2.25 m.

A centre line is not desirable on grey roads. After all, drivers of cars and lorries adhering to the centre line would be keeping insufficient distance from cyclists on the cycle lane. In these situations, therefore, a single, undivided driving lane is available for motorists travelling in two

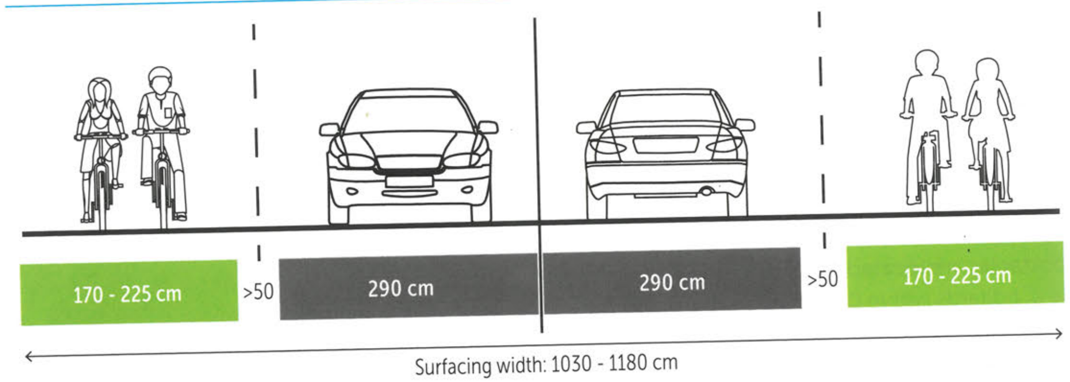


Figure 5-2. Profile A. Wide cycle lanes with sufficient gap between them and the lanes for car traffic

directions. For the purposes of this lane's width, the designer must make a clear choice: the lane must be sufficiently wide either for a single car or for two passenger cars alongside one another. Driving lane widths of between 3.80 m and 4.80 m, where it is unclear whether the space is intended for one car or two, are not permitted.

There are two ways in which the road layout can show the intention where a motorist encounters oncoming traffic.

1. Vehicle path for bidirectional traffic
Using profile B1 (figure 5-3) will enable most oncoming vehicles to pass one another (at moderate speeds), without having to resort to use of the cycle lanes. The recommended lane width is 5.50 m, with a minimum of 4.80 m. The minimum width of the cycle lanes (not including markings) is 1.70 m. The passing distance of 0.50 m from cyclists must be safeguarded at all times.

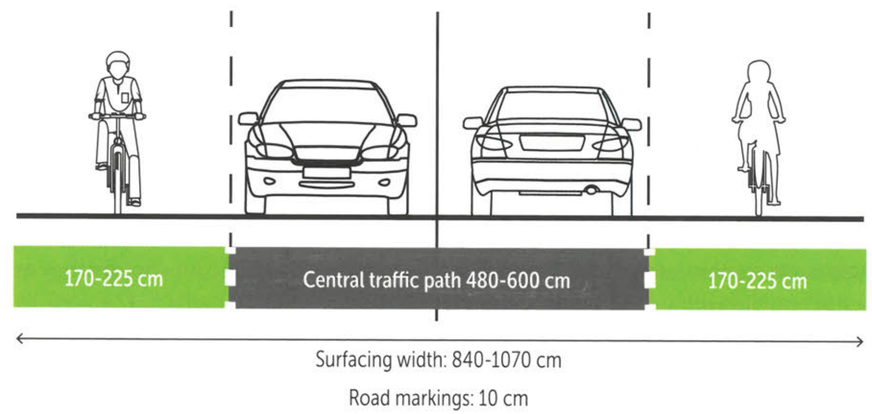


Figure 5-3. Profile B1. Cycle lanes and a central vehicle path suitable for two passenger cars

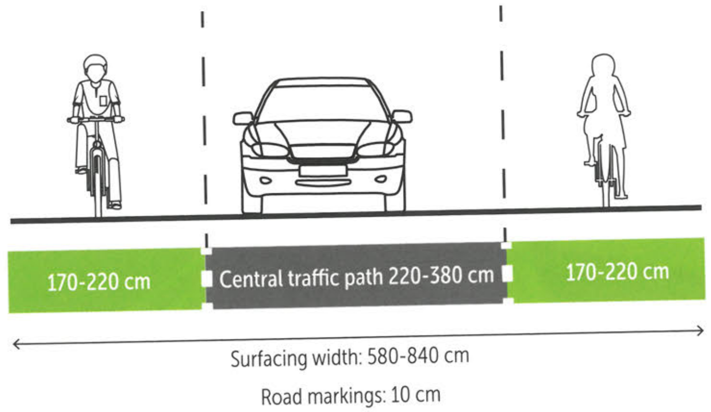


Figure 5-4. Profile B2. Cycle lanes and a central vehicle path suitable for a single passenger car

2. Vehicle path for one-way traffic
Using profile B2 (figure 5-4) will impel motorists to deliberately veer onto the cycle lane when encountering oncoming traffic. In this regard, they must not impede the bicycle traffic. The central vehicle path for car traffic may be no more than 3.80 m wide. The speed limit is 30 km/h.

Residential roads
For reasons of safety, cycle lanes are unnecessary on a well-organized residential road in the built environment. Which is why most residential roads do not have cycle lanes. Nevertheless, there could be other reasons to still have (or retain) cycle lanes. For example, designing a main cycle route through a residential area; this could be important for the purposes of creating disentwined cycle routes. Such a use of cycle lanes is not in conflict with the 'Basiskenmerken Wegontwerp' ('Dutch Guidelines for Basic Road Design') [7].

For the purposes of width profiles, please see the previous discussion of cycle lanes on distributor roads.
Cycle lanes are not created on residential roads in built-up areas with an effective surface width less than 5.80 m.

5.4.5 Cycle paths and cycle/moped paths

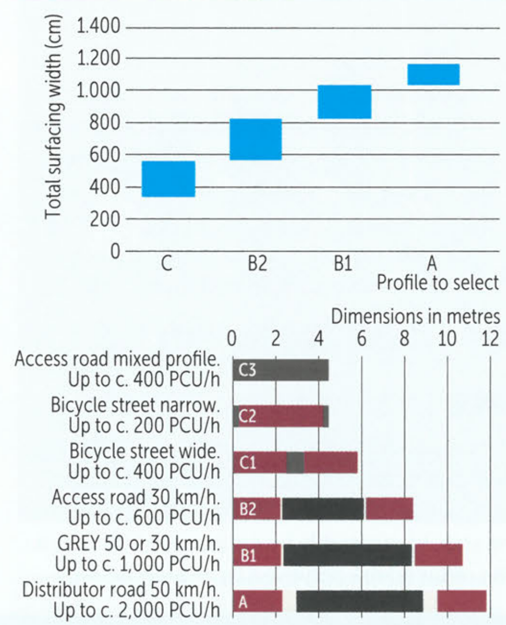
V1, 16, 17, 18, 19

Cycle paths are the safest solution on distributor road sections. Due to the fact that cyclists are separated from motorized traffic, the probability of (lateral) conflict between both groups is minimal and cyclists are less exposed to exhaust fumes. The design of cycle paths will depend on the function (design speed) and the use (width). Mopeds are not allowed on cycle paths (indicated with a G11 sign), though they are allowed on cycle/moped paths (G12a sign). In built-up areas the use of cycle/moped paths is discouraged. Only on paths alongside main carriageways with a speed limit of 70 km/h is also permitting moped riders recommended.

Profile to be chosen and the accompanying widths of traffic lane and cycle lanes

If it is decided that cycle lanes are to be used, then the following guidelines for lateral profile layout and the corresponding widths shall apply. First and foremost, the type of lateral profile is chosen, depending on the effective surface width: A, B1, B2 or C (the latter pertains to the bicycle street - see 5.4.3). The accompanying plans will produce an unequivocal choice. Please note that on roads with a surface narrower than 5.80 m, cycle lanes that facilitate two cyclists riding abreast are not a possibility. For that reason, cycle lanes are discouraged on such narrow roads in built-up areas.

It is assumed that the widths specified are actually available for traffic (including bicycle traffic). If there are any obstacles on the verge near the edge of the surfacing and/or parked cars and there is no critical reaction strip (or the critical reaction strip is not sufficiently wide), then an extra distance will have to be added to the width specified.



Two plans to determine choice of lateral profiles (maximum dimensions for each road category)

An alternative to a cycle path or a cycle/moped path is the parallel residential road. One disadvantage of this solution compared to a cycle path is that motorized traffic is also allowed on a service road, both in motion and stationary (parked). This is unfavourable for bicycle (or moped) traffic, in terms of safety, comfort and air pollution.

Service roads in built-up areas must always have a speed limit of 30 km/h, and if need be have cycle lanes, or be organized as a bicycle street.

Bidirectional cycle paths
In principle, cycle paths are organized for one-way bicycle traffic in built-up areas. Bidirectional cycle paths present a higher degree of risk where there are side roads. As a rule, side road density is high in built-up areas.

Nevertheless, there could be grounds for allowing a bidirectional cycle path, namely if:
- a bidirectional cycle path shortens the route for cyclists and/or forms a logical rapid connection in a route (this always pertaining to [extremely] short sections);

- a bidirectional cycle path prevents crossing manoeuvres;
  The effect of this is at its most significant on busy arterial roads that are tricky to cross. Incidentally, only in exceptional cases will a *unilateral* bidirectional cycle path lead to restriction of the number of crossing manoeuvres. Where the latter is desirable, using a *bilateral* bidirectional cycle path is usually best.
- there is insufficient space to create a one-way cycle path on both sides of the road, but on one side there is sufficient width for a bidirectional cycle path.

V9

The precondition for a bidirectional cycle path, particularly at junctions, is that a great deal of attention be paid to the design. The cycle crossing should preferably be created slightly raised. The reduced risk achieved by implementing a speed limit turns out to be unfeasible with markings on the road [17]. If the cycle path is given right of way, then surfacing, signage and markings must support this. Preferably, a speed bump will be created in the side road to support the cyclists' right of way. These measures will serve to reduce the probability of road users failing to spot cyclists coming from an unexpected direction (see also chapter 6, 'Junctions').

The use of bidirectional cycle/moped paths in built-up areas is strongly discouraged. The speed of the moped traffic is too high for safe usage.

5.4.6 Service roads

V15, 54, 65, 66

In principle, service roads in built-up areas are open to one-way motorized traffic. Due to the adjacent main carriageway, they only have a local function for this traffic. However, within built-up areas they do commonly form part of a main cycle route. In addition to their residential function, service roads in built-up areas often provide parking space (particularly for local residents' cars). That said, the parking function is at odds with the function of the main cycle network. Parked vehicles may not adversely affect the interests of through bicycle traffic.

Where service roads change into cycle paths or cycle/moped paths, one point for attention will be the continuity of the main cycle route. Where the cycle paths in both directions have been opened up, bicycle traffic on the service road must also be facilitated in both directions. To this end, a cycle lane or a cycle path in the opposite direction can be considered.

From a functional perspective, a service road alongside a distributor road can be deemed to be a residential road; this is described above. Service roads on the main cycle network are often eligible to be organized as a bicycle street (see 5.4.3). It is also possible to furnish service roads with cycle lanes, though this is not preferable (see 5.4.4).

5.5 Bicycle traffic and motorized traffic outside of built-up areas

5.5.1 Fundamental principles

For distributor roads outside of built-up areas with a speed limit of 80 km/h it holds as a hard and fast fundamental principle that bicycle traffic flow be kept *off* the carriageway for car traffic, i.e. on a segregated cycle path or a parallel residential road. For residential roads (mostly 60 km/h) traffic types are mixed. From the perspective of safety and comfort, however, a (motorized traffic) speed of 60 km/h is far from ideal for cyclists. Only where the volume of car traffic is low, where the speed of motorized traffic corresponds to the speed limit, and where the volume of cyclists is low can mixing be done. The 'Basiskenmerken Wegontwerp' ('Dutch Guidelines for Basic Road Design') [7] refers to this type of road as residential road type 2. (Segregated) cycle facilities are particularly desirable in situations involving a high volume of cars, agricultural traffic or a lot of cyclists (residential road type 1).

Incidentally, residential roads can also be organized outside of built-up areas with a speed limit of 30 km/h. The statutory requirements for this are no different to those for situations in built-up areas. The uses are much more limited, however, pertaining in particular to cul-de-sacs, roads only open to local traffic, roads in markedly recreational areas and service roads (for example).

Table 5-3. Selection plan for cycle facilities in the case of road sections outside of built-up areas

Road category	Speed limit motorized traffic (km/h)	Volume of motorized traffic (PCU/ 24-hour period)	Cycle network category: Basic structure	Cycle network category: Main cycle network or bicycle highway ($I_{bicycle} > 500$/ 24-hour period)
Residential road	60 (or 30)	< 2,500	mixed traffic	bicycle street if $I_{car} < I_{bicycle}$ 1); cycle path or mixed if $I_{car} > I_{bicycle}$
		2,000-3,000	cycle path, possibly cycle lanes	cycle path, possibly cycle lanes
		> 3,000	cycle path	cycle path
Distributor road	80	not relevant	cycle/moped path	cycle/moped path

1) plus any additional requirements in terms of speed

Table 5-3 constitutes a tool to help choose the correct facility outside of built-up areas. When using this table, the same considerations apply as with the table for road sections in built-up areas (table 5-2).

5.5.2 Mixed traffic

V8, 9

Outside of built-up areas the differences in speed between motorists and cyclists are considerable, even if the speed limit is 'only' 60 km/h. What this means is that the fundamental principle of mixing will only be possible if the volumes of motorized traffic and bicycle traffic are low and the speed genuinely stays limited to 60 km/h.

If a road section on a residential road outside of built-up areas is not part of the main cycle network, then mixing will be possible where the volume and speed of motorized traffic is low.

From a volume of around 2,000 PCU/24-hour period, consideration must be given to cycle facilities, preferably in the form of a segregated cycle path, though sufficiently wide cycle lanes are also acceptable in certain situations.

Agricultural traffic

One point for attention with road sections on residential roads outside of built-up areas is the presence of agricultural traffic. Where there is a relatively high volume of agricultural traffic, a wider road profile could be desirable than is necessary from a traffic engineering perspective, so as to satisfy the main requirement safety.

Even prevention of the edges of the surfacing being worn down is a safety aspect in that regard. The requisite extra width could partly be found in verge surfacing, thereby keeping the vehicle path for car traffic narrow. Verge surfacing must be properly underpinned and 'forgiving' (at least for cyclists). This means that the verge surfacing must dovetail neatly with the surface of the carriageway. In this respect, it is imperative to prevent the verge surfacing being conceived of as 'genuine' surfacing; ribbed asphalt is therefore discouraged. Even gravel is not a good choice; in the unfortunate event of cyclists straying off the road, things are unlikely to end well for them. Consequently, the most suitable option for verge surfacing is grasscrete, on the proviso that this is laid flat side up.

5.5.3 Bicycle streets

V12, 13, 14

Links in the main cycle network or bicycle highways can run through residential areas even outside of built-up areas. Service roads alongside distributor roads are an example of this. The same functional requirements can be set for these residential roads as are set for bicycle streets in built-up areas (see section 5.4.3). One difference from the situation in built-up areas pertains to the speed of motorized traffic. As a rule, this is 60 km/h outside of built-up areas. This is high for a safe and comfortable cycle environment. Despite common assumptions, it is also possible to set a speed limit of 30 km/h outside of built-up areas, as the statutory provisions – the Administrative Provisions (Road Traffic) Decree (Besluit administratieve bepalingen inzake het wegverkeer, or BABW) – are the same for situations in and outside of built-up areas. For the purposes of a bicycle street outside of built-up areas, the option of a 30 km/h speed limit certainly has to be considered.

5.5.4 Cycle lanes

V15

Outside of built-up areas, cycle lanes can only be considered on residential roads (see the plan in table 5-3). Due to the fact that cycle lanes always have to be sufficiently wide, the recommendation is to only use them on residential roads with a carriageway width of between 5.80 and 7.90 m. This is comparable to type B2 for roads in built-up areas: a lane wide enough for a single car (see section 5.4.4, figure 5-4). Because the speed of cars is higher outside of built-up areas, overly narrow cycle lanes here are even more unsafe and even less comfortable. For that reason, cycle lanes must be a minimum of 1.70 m wide even outside of built-up areas. Any function for bicycle traffic can be emphasized by means of a bicycle street set-up (see 5.5.3).

No cycle lanes are used if the carriageway is narrower than 5.80 m. Roads with a wider vehicle path for motorized traffic (type B1) are not used outside of built-up areas due to the higher driving speeds.

Hard strips and visual narrowing

It is often the case that residential roads outside of built-up areas are given hard strips, the aim of which is to make the carriageway look narrower than it actually is. The edge markings can comprise a broken or continuous stripe and are located a few decimetres from the edge surfacing. If the distance between marking and edge surfacing becomes more than 0.30 to 0.40 m, then this can give both cyclists and motorists the impression that the relevant cycle lane is intended for cyclists. Cyclists will then feel obliged to ride on that narrow lane, where they will feel even less safe. Aside from the fact that cycling on such a narrow lane requires a great deal of (mental) effort and can cause unintended traffic behaviour, it can also lead to single-vehicle bicycle accidents. For that reason, edge markings should be applied no more than 0.25 m from the edge of the surface.

5.5.5 Cycle paths and cycle/moped paths

V5, 6, 16, 17

In the case of distributor roads, segregated cycle facilities are always necessary outside of built-up areas, in the form of cycle/moped paths. The fact that moped riders use the path entails consequences in terms of its width. Moped riders are not usually allowed to use segregated paths along residential roads (60 km/h); they have to ride on the carriageway.

Public lighting along cycle paths is often inadequate outside of built-up areas. In such cases, guideline markings are necessary. Edge markings should preferably be used on both sides of the cycle path to prevent accidents on verges. A centre line will suffice in the case of a quiet bidirectional cycle path of sufficient width.

One alternative to a cycle/moped path is the service road (see 5.5.6). The disadvantage of this for cyclists is that motor vehicles are also allowed on service roads, both in motion and stationary (parked). This is detrimental to cyclists' safety and comfort. On distributor roads outside of built-up areas, service roads are often intended for agricultural vehicles and lorries as well. Where this is the case, it is desirable to create a segregated cycle path alongside the service road.

Segregation verge

V8

It is pleasant for cyclists to be able to ride at some distance from car traffic. Nonetheless, the distance between cycle path and main carriageway must not be so considerable that the cycle path ends up being beyond the main carriageway's sphere of influence; for reasons of social control, it is desirable for the cycle path to continue to be visible to motorists. The space between the cycle path and the main carriageway is referred to as a segregation verge. This serves as a 'margin of error' for vehicles straying from the main carriageway and for cyclists (or moped riders) veering off of the cycle/moped path. In addition, the segregation verge serves as a 'buffer' for preventing accidents between cyclists and motorized traffic.

Table 5-4 recommends a number of widths for a properly functioning segregation verge. These widths will help in the case of bidirectional cycle paths as well as to prevent cyclists on the left-hand side of the road (facing oncoming traffic in the Netherlands) from being blinded by the headlights of oncoming motor vehicles. If it will not be possible to satisfy the segregation verge width requirements, then some kind of segregation structure will be desirable.

Table 5-4. Recommended widths for segregation verges (between carriageway and cycle path) outside of built-up areas

	Width of segregation verge (m)	
Road category	**Recommended**	**Minimum**
Road with high traffic volume	10.00	8.00
Distributor road	6.00	4.50
Residential road	> 1.50	1.50

Bidirectional traffic

V5

On bidirectional cycle/moped paths, oncoming cyclists and moped (or light moped) riders present each other with a risky potential conflict. The problem is aggravated by the increase in how busy these kinds of cycle path are and the speeds on them. In order to make clear to all

road users that traffic from the opposite direction must be anticipated, and in order to reduce the probability of head-on collisions, centre lines are always recommended for bidirectional paths. Even better is to have a narrow, 'forgiving' segregation verge between the two directions.

It goes without saying that the path must be sufficiently wide and that cyclists and moped (or light moped) riders must be able to swerve onto the verge if need be. 'Forgiving' verges are essential. Furthermore, attention to side roads and other connections is also necessary. In terms of all these points, it would be advisable to make explicitly clear to road users that bicycle traffic (including mopeds and light mopeds) is to be expected from two directions (see also chapter 6, 'Junctions').

5.5.6 Service roads

V8, 9

From a functional perspective, a service road alongside a distributor road is a residential road. When deciding on the road section solution for this, the plan from table 5-3 can provide some assistance.
One point for attention in the case of service roads outside of built-up areas pertains to the speed of motorized traffic. Occasionally, a service road carriageway for motor vehicles will constitute a faster route than the functional main carriageway; in such cases, function, design and use will not be in equilibrium. All options in terms of limiting the speed and volume of car traffic on the service road must be used. Consider in this regard extra connections on the main carriageway, brief closures for motorized traffic (traffic bollards), and speed humps and raised junctions on the service road.

The use of service roads by agricultural traffic will also require special attention on the part of the designer. In line with the fundamental principles from Sustainable Traffic Safety, slow-moving agricultural vehicles have no place on the main carriageway of a distributor road. That said, the difference in mass between cyclist and agricultural vehicle on a service road is considerable. The impressive size and width of agricultural vehicles not only present objective risks in terms of safety, they also (and particularly) kindle a marked sense of danger. An additional problem pertains to verges that have been worn down by tyres.

Possible measures include limiting the volume of agricultural traffic, wide surfaces or adding a segregated cycle path (perhaps in combination with an unpaved service road). Particularly where the number of residential connections is limited, using passing bays for agricultural traffic on the main carriageway in combination with a segregated cycle/moped path could be a solution [18].

If the agricultural traffic nevertheless has to use the service road, then it is imperative to prevent the edges being worn down by tyres. The requisite extra width could partly be found by surfacing verges, thereby keeping the vehicle path narrow. Another option is to 'split' the service road in two by creating a central verge/axis, thereby creating two tracks. In such cases, the separate strips of asphalt will have to be sufficiently wide to serve as a cycle path. The width of the central verge/axis may not exceed the width of a passenger car's axle.

Verge surfacing must be properly underpinned and 'forgiving'. This means that the verge surfacing must dovetail neatly with the surface. In this respect, it is imperative to prevent the verge surfacing being conceived of as 'genuine' surfacing; ribbed asphalt is therefore discouraged. Even gravel is not a good choice; in the unfortunate event of cyclists straying off the road, things are unlikely to end well for them. Consequently, the most suitable option for verge surfacing is grasscrete, on the proviso that this is laid flat side up.

5.6 Special situations

5.6.1 Bus stops

Two components are highly significant for bicycle traffic at bus stops: stopping buses and crossing pedestrians.

Stopping buses

In principle, buses stop on the carriageway on residential roads. The upshot of this is that cyclists will experience nuisance from buses when they are not in motion. This is undesirable in general, but it is all the more irritating on main cycle routes. Hence for reasons of safety and comfort the recommendation would be to have buses on main cycle routes stop away from the main carriageway as a minimum.

On distributor roads, the recommendation is that buses will always stop in bus bays sited away from the carriageway. If cycle lanes are present, then the bus will have to merge with passing cyclists, which can lead to conflict. One point for attention is the design of the bus bay. This must be sufficiently wide to ensure that stopping buses are not encroaching upon the cycle path. In the case of segregated cycle paths, the recommendation is to steer the cycle path around the bus bay in a flowing movement to ensure that cyclists do not experience any nuisance from stopping buses.

Crossing pedestrians

The second component relates to the fact that bus stops result in a concentration of (crossing) pedestrians. For that reason, it is important for both pedestrians and cyclists for the road layout to make manifest the fact that there is a possibility of encounters between the two groups. Where there is a segregated cycle path, a platform must be created for waiting and alighting bus passengers. To this end, a free space of at least 2.00 m is maintained. If a bus shelter is installed at a stop, then the distance between the cycle path and the bus shelter must be at least 0.65 m. Points for attention in such cases are the bendiness in the route (main requirement directness) and the sight distance in motion for the cyclist. The latter may not be impeded by the bus shelter.

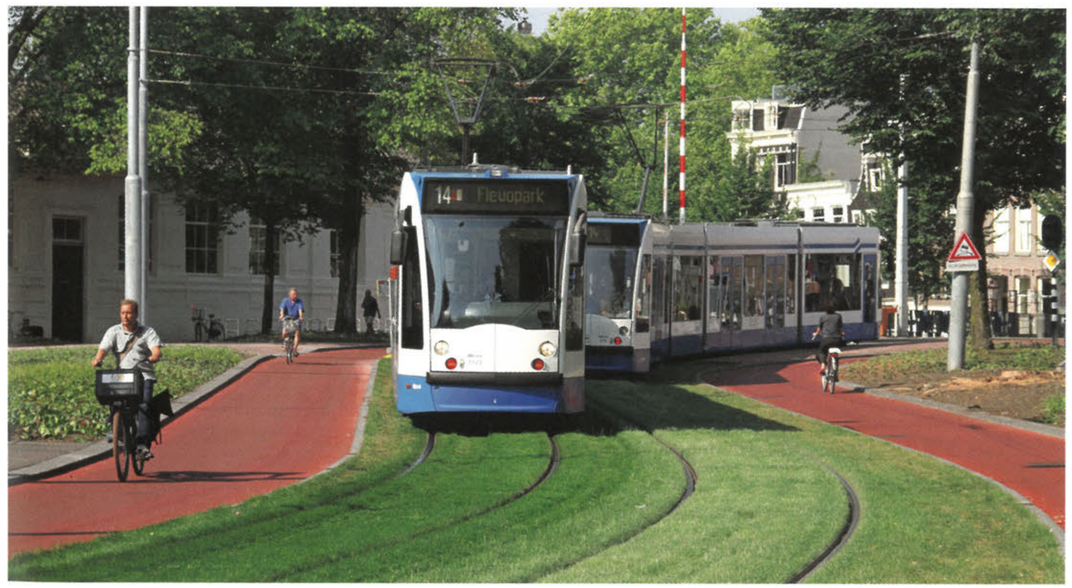
It is also possible to create a design in which the cycle path runs *in front of* the bus shelter at an elevation. This solution requires extra attention to preventing conflict between passing cyclists and passengers getting onto and off of buses.

A segregated cycle path is sometimes elevated if it runs *behind* the bus stop too. This is the case where there is a need to make the platform more accessible to disabled passengers. The elevated cycle path can be created like a plateau, making it immediately evident to cyclists that there is potential here for conflict with pedestrians.

5.6.2 Bicycle and tram/light rail

Cyclists and trams can use the same carriageway if there is sufficient space available for cyclists between the roadside and the tram rails and on the proviso that tram proceed very calmly. Nevertheless, this merging of tram traffic and bicycle traffic is not recommended. Due to the fact that cyclists are unable to respond to a vehicle approaching from the rear and trams do not have the option of swerving, a tram must be capable of coming to a complete stop very swiftly in an emergency situation. The braking distance of a tram travelling at 30 km/h is similar to that of a car travelling at 50 km/h. Consequently, a safe tram speed for conflict situations is below 30 km/h, namely around 20 km/h [19].

Merging tram/light rail and bicycle traffic calls for extra care during the design process. Tram rails on a road for mixed traffic make things more complicated for cyclists and have an adverse effect on both road safety and cyclists' comfort. Cyclists have to prevent their wheels



from getting caught up in the tram rails. They will only be able to cross the rails at an angle of at least 60 degrees. Cyclists will also need to be sufficiently alert to prevent the rails from causing a fall, to prevent themselves from missing other hazards (particularly applicable at sets of points and on bends). Furthermore, cyclists are not always capable of choosing a safe track (e.g. at a sufficient distance from parked cars) and tram rails limit cyclists' freedom of movement when it comes to emergency manoeuvres.

The above means that a combination of both types of traffic can only be considered if there is sufficient room for this in the lateral profile. Moreover, it is imperative to prevent less attentive cyclists from getting their wheels caught in the rails. Consequently, it is preferable to screen off tramlines physically, though visually as a minimum. The latter pertains to (for example) having a different surface for the tramlines or noticeable markings (0.30 m wide). In principle, elevating the tramlines is undesirable, as a cyclist can easily bump into the elevation, e.g. when overtaking or if he fails to spot it in the dark or in the snow. Only a 'forgiving' elevation may be considered.

On the main cycle network, a mixed profile with trams, cars and bicycles is avoided, opting instead for segregated cycle paths or a solitary, physically separated tram track. Where this is impossible, the following fundamental design principles will apply:

- Cyclists ride to the right of the tram. On either side of the bicycle connections (i.e. both between cyclists and trams and between cyclists and the edge surfacing or parked cars) there are critical reaction strips and two cyclists can cycle abreast without problems.
- The volume of car traffic is low in order to give cyclists the opportunity to swerve.
- There should preferably be a 'no stopping' rule on the road section.
- Where tramlines or a bicycle connection branch off, then the cyclist will need to be able to cross at an angle not less than 60 degrees.

5.6.3 Cyclist and pedestrian

Within built-up areas, cyclists do not use the same space as pedestrians on the vast majority of road sections. After all, most roads and streets have a pavement or walkway. Outside of built-up areas, pedestrians do often use the cycle path, but in view of the extremely low number of pedestrians this usually does not present much of a problem.

In built-up areas, however, it is possible to distinguish several situations in which the ratio of cyclists to pedestrians merits more detailed consideration. For example, in many municipalities there is the issue of whether or not to allow cyclists in pedestrian zones, a matter that will be examined later on in this section.

Shopping streets and pedestrian zones

Pedestrian zones are primarily found in city and town centres. Although the motive for creating these is usually the disruptive presence of *motorized* traffic, in many pedestrian zones *all* traffic (other than pedestrians, of course) is prohibited so as to create a pleasant, safe retail and residential climate. Nevertheless, the question is whether it is necessary to exclude bicycles in all such zones at all times; after all, compared to car traffic, cyclists do not cause much of a nuisance. In addition to this point, central areas and pedestrian zones not accessible to cyclists often constitute a barrier to cyclists. Furthermore, these areas are common destinations for bicycle traffic. A cycle-friendly policy will enable these destinations to be optimally reachable for cyclists.

Cyclists in a car-free area?

The question as to whether or not cyclists and pedestrians can be mixed is particularly relevant in car-free shopping areas, streets and parks. Usually, consideration of this question is limited to weighing things up between excluding cyclists and mixing cyclists and pedestrians. However, it is possible to permit both categories, albeit separating them from one another. Hence it is important to answer the following questions:

- Do cyclists need to be allowed in the car-free area and will this be a possibility?
- If so, will cyclists and pedestrians have to be mixed or separated?
- In the event of them being separated, will this separation have to be hard or soft?

Cyclists can be categorized as either 'through traffic' or 'local traffic'. Both groups have an interest in being allowed into car-free areas. For cyclists constituting 'through traffic', a car-free area often presents an attractive, safe and in certain cases also quick connection. This is particularly true in city centres. For road sections forming part of the main cycle network it holds that mixing pedestrians and bicycle traffic is often impossible as this would not be able to achieve the desired quality for cyclists. Moreover, busy through cycle routes passing through pedestrian zones can easily result in conflict with pedestrians.

For cyclists constituting 'local traffic' it holds that they need to be able to reach their destination in the car-free area quickly. This also enables them to keep their bicycle close (less chance of theft) and carry things on it. The advantages of cyclists being allowed into car-free areas must be weighed up against the disadvantages that pedestrians will experience as a result.

Joint use on the part of cyclists and pedestrians

For the question of whether or not cyclists are to be permitted in a pedestrian zone, limits are to be set on the basis of usage and profile. The layout of the street is just as decisive a factor in this regard as the number of pedestrians; obstacles such as terraces and bicycle parking racks restrict profile width. A vehicle path and a sectional profile in particular will go towards ensuring that pedestrians and cyclists keep to their own 'territory' [20].
As it turns out, the average number of pedestrians in relation to the available profile width is a good indication of the degree of mixture that is possible. Hence it is primarily the volume of

pedestrian traffic in relation to the profile width (the pedestrian density) that is the decisive factor when it comes to the question of whether it will be possible to mix. Table 5-5 shows the values at which each solution can be recommended. In this regard, it is always about joint use on the part of cyclists (constituting 'local traffic') and not about sections of the main cycle network.

Table 5-5. Possibilities for joint use of pedestrian zones on the part of cyclists

Number of pedestrians per hour per metre of profile width *)	Recommended solution **)
< 100	Full mixture
100-160	Segregation; vehicle path with non-sectional profile (no level differences)
160-200	Segregation; vehicle path with sectional profile
> 200	Combination not desirable

*) This is the number of pedestrians passing an imaginary line straight across a street in an hour, divided by the total profile width in metres.
**) The recommended solutions are based on Fietsberaad publication 8, 'Fietsers in voetgangersgebieden' ('Cyclists in Pedestrian Zones' [20].

Combining cyclists and pedestrians proves to be possible when there are fewer than 200 pedestrians per hour per metre of profile width. In the case of a higher volume of pedestrians, it will not be possible to mix the two groups well, in which case it will need to be examined what other solutions are possible. In this regard, the designer/traffic engineer must bear in mind that there can be marked fluctuations in pedestrian density. On Saturdays and evenings when shops are open late there might be a problem that is absent at other times. Although a design is based on an indicative juncture, a different traffic regime could apply at non-indicative junctures. In other words, if it is not possible to allow cyclists into a zone on Saturdays and evenings when shops are open late, that does not necessarily mean that they cannot be allowed into the zone throughout the week. The same goes for specific facilities that have certain visitor number peaks.

In the case of a pedestrian density below 100 pedestrians per hour per metre of profile width, full mixture is possible, without additional facilities; in the case of a density between 100 and 200 pedestrians per hour per metre of profile width, segregation is desirable. A visual separation will suffice (use of material, markings) up to 160 pedestrians; above 160 pedestrians it will be desirable to introduce a vehicle path for bicycle traffic.

The advantage of mixing cyclists and pedestrians is maximum freedom of movement in lateral directions for both categories of road users. The advantage of segregation is that pedestrians and cyclists will experience less nuisance from one another. Furthermore, the probability of accidents occurring between pedestrians and cyclists will be lower. Incidentally, the nuisance and the danger when mixing cyclists and pedestrians must not be overestimated. German research shows that initial public opposition to allowing cyclists into pedestrian zones significantly abates after a year. Another German study revealed that cyclists generally modify their behaviour and even dismount when pedestrian densities are high. This study also refuted the assumption that cyclists will ride faster once their presence in pedestrian zones is legalized. It also emerged that accidents between cyclists and pedestrians are scant and not serious in nature.

Design in the case of segregation

At densities of between 100 and 160 pedestrians per hour per metre of profile width it is sufficient to introduce a simple marking designating the vehicle path for cyclists. Furthermore, good spatial design of the street is desirable. This design must be geared towards making the vehicle path for cyclists clearly recognizable. Incidentally, this segregation may not be 'too hard'. Neither should it be reinforced by legal measures, lest this give rise to reciprocal intolerance due to both groups being given a 'sense of entitlement to their rights'.

Above 160 pedestrians per hour per metre of profile width the recommendation is to give cyclists their own vehicle path in the middle of the space. To ensure this is recognizable, this should be finished with a different surface and/or colour. At the same time, however, it now also holds that the separation between the cyclists' and pedestrians' domains must not be too distinct, as cyclists also have to be able to park their bicycles and therefore need to be able to leave their domain in a straightforward manner. 'Soft' segregation will also prevent cyclists and pedestrians tripping over the separation. Such segregation, entailing the boundaries between the cyclists' and the pedestrians' domains blending into one another, as it were, turns out in practice to result in flexible interaction between the two groups.

Combined path

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It is not just in pedestrian zones that mixing cyclists and pedestrians can be considered.

Time windows for allowing in cyclists

Practical experience has taught us that there is tremendous capacity for self-regulatory behaviour in pedestrian zones. Consequently, prohibiting cycling only makes sense in situations where cycling is not fully feasible or is clearly undesirable *and* there is a good alternative for the cyclists. Incidentally, in such cases the vast majority of cyclists would themselves decide to use the alternative route.
If a cycle route passes through the pedestrian zone (and if the volumes of bicycle traffic give cause to do so), then this route can be designated as a cycle path using a G11 sign. The preferred profile will then be sectional, with pavements for pedestrians. A continuous profile with a vehicle path is also a possibility.
If there are marked fluctuations in volumes of pedestrians and this makes it possible to mix cyclists and pedestrians, then time windows can be stipulated on underplates, specifying the days and times that cyclists are allowed in (or otherwise). This time window scheme must be comprehensible and unambiguous to ensure there is no confusion. There must also be room for self-regulation, with restraint being exercised when it comes to prohibiting bicycle traffic (or prohibiting it during certain time windows). Consider also the fact that bans cannot be comprehensively fine-tuned to all fluctuations. For that reason, the traffic engineer's insight and common sense will continue to be important in this respect.
In summary, cycling should only be forbidden in pedestrian zones during those periods when capacity for self-regulatory behaviour is stretched to the limit and manifest problems could arise between cyclists and pedestrians.

This also applies to other specific situations in which it is impossible to free up sufficient space within the available profile for cyclists and pedestrians alongside one another. The flush solution with pedestrian and cycle path/lane, referred to as a combined path, is only used on a limited scale in the Netherlands. They are much more common abroad (Germany, Belgium). There is also statutory signage in these countries.

The dearth of practical experience in the Netherlands means that the present Design Manual is not in a position to make any recommendations substantiated by such experience. Nevertheless, having regard to the results of research into cyclists in pedestrian zones, it would seem to be reasonable to assert that a combined cycle/pedestrian lane would at any rate be applicable in situations entailing a low volume of pedestrians (up to around 25 pedestrians per hour per metre of pavement width) and a not overly excessive volume of bicycle traffic. As stated, more precise values are not yet known.

Aside from the fact that both cyclists and pedestrians are given more physical space to use and cyclists will have less conflict with motorized traffic, combined paths also present another benefit. One significant cause of single-vehicle bicycle accidents is that cyclists hit the kerb with their pedal. Doing away with the kerb therefore means eliminating this cause of accidents. Yet another advantage is obtained if there is lengthwise parking alongside the carriageway. If cyclists are led along the right-hand side of parked vehicles, this will be more conducive to their safety than if they are riding on the left-hand side of these vehicles: after all, if they are riding on the driver's side (the left in the Netherlands) then the chances of hitting an opening car door are higher than if they are riding on the other side.

A combined cycle/pedestrian lane is discouraged in tight situations where the pavement is actually being used as a residential space (for playing and by shops and catering establishments, for instance). Residential activities would constantly conflict with bicycle through traffic, which is unpleasant for both groups. Even in tight situations where a large number of elderly people are using the pavement, this solution must be used prudently, because elderly people are quick to feel 'threatened'.

Literature

Figures between square brackets in the text – e.g. [1] – refer to the numbers in the bibliography below.

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6 Junctions

This chapter deals with intersecting (including turning onto available directions) and cyclists crossing roads. The fact that a great deal of attention must be given to cyclists' safety at junctions in designs is evident from the accident statistics. It is true that the majority of serious bicycle accidents involve only a single bicycle, but collisions between cyclists and passenger cars are also a significant cause of serious traffic accidents involving cyclists (fatalities and hospital admissions). In excess of half of the serious traffic accidents occur at junctions in built-up areas (58%), and then pretty much exclusively at junctions with 50 km/h roads (95%) [3].

Section 6.1 will examine the functional requirements for junctions, with section 6.2 going on to discuss the five main requirements. Section 6.3 is extensive. It zooms in on a total of seven junction combinations of residential roads, distributor roads, solitary cycle paths and public transport lanes. The junction of a bicycle connection with a road with high traffic volumes is not dealt with, as for these preference is always given to grade-separated solutions.

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From the perspective of this chapter, the type of visual material presented here will refer to relevant design sheets. These sheets are included in part two of this publication. A design sheet systematically presents the most important information on a facility (function, application, implementation, dimensions and more).

6.1 Function, design and use

The function of a junction is to allow interchange. At a junction, traffic is given an opportunity to turn or cross (if the only option is to cross, then it is a crossing and not a junction). For the purposes of road safety it holds that the fewer the junctions the better. However, fewer junctions means that the network will be less functional.

The design of a junction should optimally support the interchange function and must be comprehensible to road users. This goal is best accomplished by creating a clear situation with a minimal number of points of conflict. The fundamental principle of having as few points of conflict as possible can be incompatible with other wishes, e.g. in terms of traffic flow. If for that reason extra traffic lanes are created, then this could result in insufficient comprehensibility and 'aids' will be required (such as traffic lights). From the perspective of this Design Manual's design philosophy, such solutions are not pursued. They are discussed, however, as these solutions are common in practice.

Minimizing the speed of the different road users is paramount when it comes to interchange. The chances of survival when being hit by a car at low speed are considerably higher than they are if the car is travelling at high speed. Research [1] shows that the probability of serious and fatal injury among cyclists starts to rise substantially when the speeds of motorized traffic go above 30 km/h.

Figure 6-1 presents the relationship between the probability of a cyclist dying as a result of being hit by a passenger car and the applicable collision speed. It will be clear that a relatively limited increase in collision speed makes the chances of a fatality considerably higher.

Aside from the speed, other important factors for interchange safety include the directions of the various road users, the clarity of the situation and the volumes of the different traffic flows.

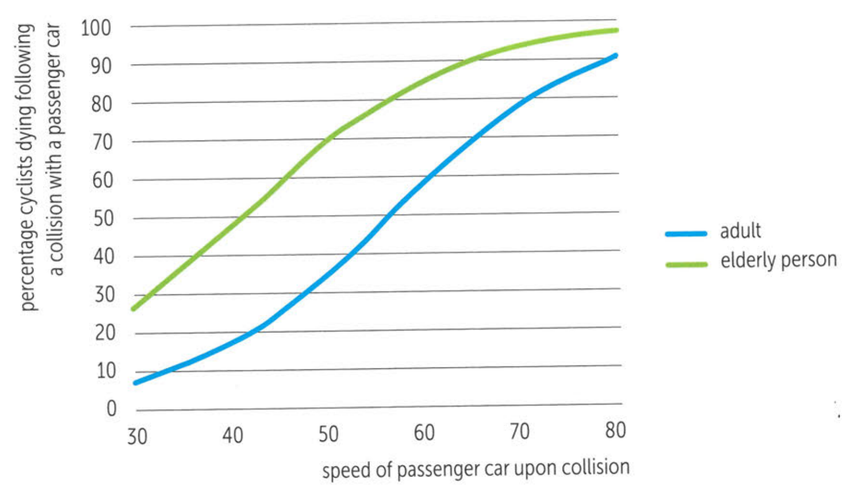

Figure 6-1. The probability of a cyclists dying as a result of a collision with a passenger car as a function of the collision speed (processed by Theo Zeegers using TNO research data [2])

6.2 Requirements for a junction

The main requirements directness, safety and comfort in particular are important at junction level. The main requirement cohesion is primarily to do with safety and for that reason it will not be discussed separately. The main requirement attractiveness is not particularly relevant to junctions. However, the requirement of personal safety does apply at all times. On this, please see section 7.5.

6.2.1 Directness

Directness contributes to a shorter journey time for each bicycle, therefore facilitating bicycle traffic and fostering the benefits that bicycle use entails. As in the case of road sections, when it comes to junctions a distinction can be made between directness in terms of time and directness in terms of distance.

Directness in terms of time

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Directness at junction level is primarily about the possibility of passing the junction smoothly. Directness (the prevention of delay) can be achieved by giving the bicycle traffic flows passing over the junction right of way as much as possible. Where this is not possible, another option is to minimize the probability of cyclists having to wait, e.g. by introducing a central traffic island of sufficient width on a road to be crossed. In the case of traffic lights, favourable settings and a good field of detection (e.g. with advance detection) contribute to improving the directness in terms of time for cyclists.

For junctions in general, and for junctions forming part of the main cycle network in particular, it holds that the probability of the cyclist having to stop ought to be minimized. As already stated in section 3.2, each instance of stopping uses up around the same amount of energy as is required to cycle 100 metres. In the case of cycle-friendly traffic light provisions, the average and/or maximum time lost at the junction serve as the criterion for optimization. What this means is that requirements are set in terms of the crossability (see box) and, in the case of traffic lights, in terms of the cycle time of the traffic light control system, as well as in terms of the average and maximum waiting time for cyclists in particular.

Aside from adequate crossability, the directness in terms of time is also fostered by opting for a high design speed. Using sufficiently wide curve radii and passageways will enable cyclists to perform a turn manoeuvre at the desired speed.

V30

Crossability

How crossable a road is, or the quality of its 'crossability', is determined by the waiting time. At priority junctions, this waiting time is dependent on the crossing length and the volume of, or rather the gap distribution in, the traffic flow to be crossed.

The crossing time is the quotient of the crossing length (m) and the speed of the crossing cyclist (m/s). If need be, consideration will be given to the time required to accelerate. In order to be able to cross, there needs to be a gap in the traffic flow to be crossed at least as big (as long) as the requisite crossing time plus a safety margin. Shortening the crossing length and using a central traffic island (of sufficient width) could drastically improve the crossability.

In the case of an even distribution of traffic, the following shall apply for a traffic flow with Poisson distribution and 1×2 lanes:

- Up to a volume of 800 PCU/hour, crossability will be reasonable without a central traffic island.
- From 800 to around 1,600 PCU/hour, crossability will be reasonable if it is possible to cross in two stages (i.e. with a central traffic island).
- From 1,600 to around 2,000 PCU/hour, crossability will be moderate to poor.
- Over 2,000 PCU/hour, crossability will be poor to very poor.

This assumes a situation in a built-up area and a cyclist speed of 1 m/s. If a cyclist approaches and does not have to stop or brake, then this speed will be much higher (c. 5 m/s), improving the qualification somewhat. For the purposes of assessment, however, consideration must always be given to acceleration and the relatively low average speed of cyclists who have had to stop for approaching traffic.

V39

At large junctions with traffic lights, cyclist will usually have to turn left in various stages. This can result in significant waiting time if crossings for cyclists are bidirectional. At smaller junctions, turning left can be expedited by constructing an advanced stop line (for instance).

Directness in terms of distance

At junction level it is important for cyclists to be able to follow the most direct route as much as possible. In situations where cycle paths bend outwards (perhaps even considerably), for instance, or where traffic manoeuvres have to be performed in various stages at a crossing regulated by traffic lights, this will be an issue. In the case of segregated cycle paths, preference is given to cycle crossings situated 2.00 to 5.00 m from the carriageway for motorized traffic, for safety reasons [3].

6.2.2 Safety

Due to the fact that most collisions involving cyclists occur at junctions (and not on road sections), safety at junctions merits special attention. Lateral collisions are the most common form of collision between passenger cars and bicycles at junctions. In the majority of cases the driver of the passenger car is held to be at fault from a legal point of view. In over half of lateral collisions the driver of the passenger car fails to brake at all [4], with the speed of motorized traffic being the dominant factor when it comes to risk of accident and severity of injury. In the case of fatal collisions at junctions, lorries are largely responsible, including blind spot-related accidents.

Avoiding conflicts with intersecting and crossing traffic

Conflict with intersecting traffic is unavoidable at junctions due to their interchange function. Nevertheless, the design of a junction has a great deal of influence over the number and nature of those conflicts. Grade-separated facilities completely eliminate conflict with motorized traffic, but such a solution is often unfeasible. If the interchange of traffic flows occurs all on one level, then it will be necessary for all road users to be able to perceive the junction on time (sight distance in motion). Furthermore, the intersecting traffic will have to have an adequate view of the traffic flow to be intersected (crossing sight distance).

It is also important to minimize partial conflict. Lateral conflicts can partly be converted into (usually less serious) longitudinal conflicts by turning a junction into a roundabout. Cycle paths along priority roads should preferably be situated 2.00 to 5.00 m away from the carriageway. This will create a waiting space for a turning car and cyclists will be kept out of the blind spot of turning traffic. In side streets, using a speed bump or exit construction can be recommended, which will reduce the speed of approaching traffic, thereby resulting in a lower risk to cyclists.

Blind spot-related accidents

A relatively high number of blind spot-related accidents occur at junctions, particularly with lorries. Hence measures to prevent these can have a relatively significant effect. Consider in this regard conflict-free control of car and bicycle traffic flows, or a head start and an advanced stop line for cyclists. In addition, an ample distance (5.00 m) between carriageway and cycle path is favourable. A no right turn for lorries can also be considered.

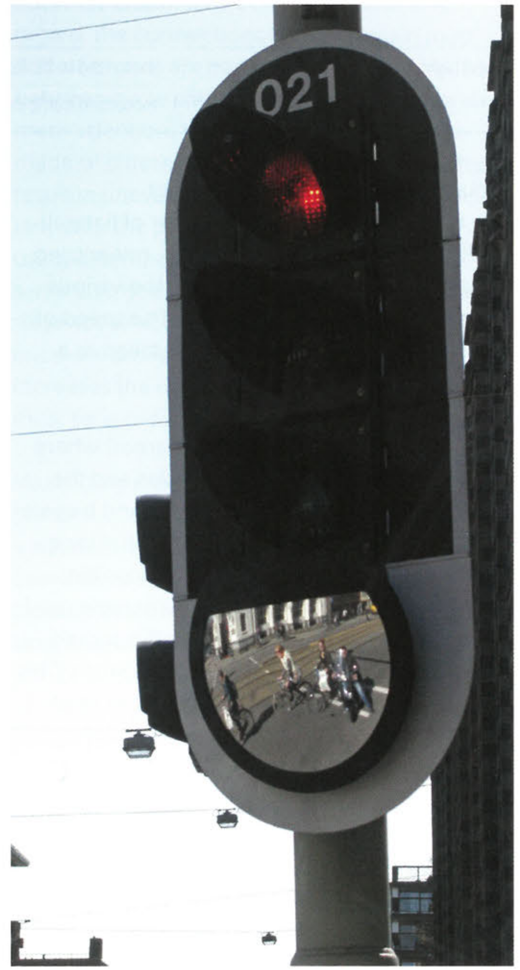

Table 6-1. 'Safe' conflicts between types of traffic according to speed [5]

'Safe' speed motorized traffic (km/h)	... conflicting (in road section, at crossing point or at junction) with ...	... with it holding that
30	pedestrians (lateral)	–
	cyclists/moped riders (lateral)	–
	cyclists/moped riders (longitudinal)	cyclists/moped riders on carriageway
	motorized traffic (lateral)	–
	motorized traffic (head-on)	–
50	cyclists/moped riders (longitudinal)	cyclists are physically separated, mopeds on carriageway
	motorized traffic (lateral)	right of way regulated
	motorized traffic (head-on)	marked carriageway separation present as a minimum
70 and higher	motorized traffic (longitudinal)	–
	motorized traffic (head-on)	physical carriageway separation present

Reducing speed at points of conflict
Due to the fact that a large number of (lateral) conflicts are possible at a junction, minimizing the differences in speed between the various types of traffic is recommended. The speed of cyclists (20 to 30 km/h) should be taken as a point of departure in this regard.

On roads (particularly in built-up areas) where the flow function for motor vehicles and the residential function for pedestrians and bicycle traffic converge, it is often the case that longitudinal and/or lateral conflicts are possible between motorized traffic and vulnerable road users. The speed of motorized traffic should then be adjusted to a safe level of 30 km/h. This is accomplished both by modifying the road layout and by setting a speed limit. These measures will reduce the probability of an accident and, if one does occur, the probability of serious injury. At points where serious conflicts have the potential to occur, the speed of motorized traffic is adjusted to the speed of cyclists and the speed of bicycle traffic (including fast bicycle traffic) is also reduced. Minimizing the differences in speed will reduce the chances of an accident and the chances of serious injury.

Reducing risk of single-vehicle bicycle accidents
In order to minimize the probability of single-vehicle bicycle accidents, requirements are set in terms of the serviceability of the road surface, the implementation of curve radii, and the use and implementation of obstacles.

Evenness is paramount for the road surface's serviceability. As in the case of road sections, an uneven surface with potholes and bumps can result in falls. In addition to this, cyclists need to pay particular attention to (intersecting) traffic at junctions and not have to concentrate on an inadequate road surface. When it rains, puddles will form on road surfaces that are uneven. If these freeze, then this could cause cyclists to slip and fall, especially when cornering. The road surface must be sufficiently skid-resistant, both in winter and non-winter conditions, not least because cyclists often have to brake and accelerate at junctions.

Incidentally, evenness also has a clear relationship with the main requirement comfort; cyclist enjoy riding on an even road surface most.

Curve radii must be at least 5 m; right-angled corners and staggered corners not be used. Furthermore, bends and edges must always be readily visible at junctions too. Tram rails deserve extra attention (see 6.3.7.2).

The fundamental principle is that as few obstacles and design elements as possible (e.g. armadillos and bollards) be used at junctions, preferably none at all. After all, it is particularly at junctions that obstacles can easily be missed because cyclists' attention is focused on traffic there. Where it is impossible to eliminate obstacles, they must be sited at a satisfactory distance from the junction area, be visible, not obstruct the cyclists' path and leave sufficient room to pass through. Bollards forming part of the junction should be avoided. If they are genuinely necessary, then they must be sited at least 12.50 m from the junction.

Ensuring recognizable road categories
Using a limited number of junction types for each road category will enable the junction design to contribute to the recognizability of a road category. Road users will then have a clearer idea as to what behaviour is required of them. Further information on this can be found in CROW publication 315A 'Basiskenmerken kruispunten en rotondes' [6].

Striving towards uniform traffic situations
Although each junction is different, it is possible to endeavour to adopt similar solutions for similar junctions. As also stated under road sections, the uniformity predominantly pertains to the use of (right of way) rules, signage, markings and design principles.

If these kinds of thing are used in a uniform manner, then this will result in a junction design that will be comprehensible to, and therefore safe for, road users.

6.2.3 Comfort
The following requirements are set for junctions with a view to fostering comfort.

Ensuring an even road surface
The surfacing on junctions should satisfy requirements in terms of evenness. In this regard, the connections between main road and side roads are paramount. The connections between cycle paths and the junction area also merit attention. If the different elements are made of different materials, then this will often result in unevenness at the transitions, particularly with the passage of time. Consequently, using different materials is not advised; the same also goes for lowered edges of the carriageway which run round the bend. The presence of tram rails is uncomfortable and increases the risk of accidents, which is why it must be avoided, particularly in a tight profile.

Maximizing probability of unhindered through traffic
It is comfortable for cyclists to have as clear an overview of the road (or cycle path) to be crossed that they can pass without having to stop, even if this requires a degree of acceleration or deceleration. In order to be able to carry on riding at junctions unhindered, ample curve radii are important. If need be, bends will be widened, if this does not lead to an increase in the speed of motorized traffic. Being able to continue riding unhindered will also prevent time being lost at junctions. For that reason, the chances of having to stop and, where waiting is unavoidable, waiting times are to be minimized.

Table 6-2. Summary of the main requirements for junctions

Main requirement	Important here	Explanation
Directness	Directness in terms of time	Directness in terms of time pertains to the design speed. Furthermore, it also prevents delays. Delay can be limited by minimizing the probability of having to stop (maximum right of way) and by minimizing waiting times. Directness in terms of time can be fostered by means of such measures as using central traffic islands and favourable traffic light provision settings for cyclists.
	Directness in terms of distance	It is imperative to preclude the possibility of cyclists having to make illogical manoeuvres at junctions or being led off the junction.
Safety	Probability of (serious) conflict	The number of encounters with motorized traffic will be minimized. Where there are significant differences in terms of speed and/or mass, and at high volumes, intersecting traffic manoeuvres will be grade-separated. In the case of at-grade crossing, speed differences will be minimized. Instances of cyclists ending up in lorries' blind spots will be minimized. Design principles and fundamental principles will be applied uniformly, appropriate to the function of the intersecting roads. Junctions will be sufficiently visible, even in darkness. To this end, the lighting level will have to be adequate, though so too will the contrast between discontinuities. There will be an adequate view of approaching traffic.
	Probability of single-vehicle bicycle accidents	Requirements in terms of evenness and skid resistance will be satisfied. Obstacles such as armadillos, narrowing, edges and bollards will preferably be avoided and otherwise be sufficiently noticeable.
Comfort	Evenness of the road surface	The surfacing will be sufficiently even. As far as possible, the use of different types of surfacing will be avoided.
	Preventing time loss	The probability of having to wait will be minimized (see under 'Directness').
	Flow	Curve radii have been fine-tuned to the design speed appropriate to the function. Through bicycle traffic at junctions will not be impeded by stationary cyclists or vehicles.
	Traffic nuisance	Cyclists do not experience any nuisance from other traffic. In busy situations with a large amount of emissions and noise, efforts are made to create a separate route for cyclists.
Attractiveness	Personal safety	Junctions satisfy requirements in terms of personal safety: there is lighting present, local residents have as good a view of the cycle route as possible, road users have a good view of the surroundings and the public space is well maintained. See also section 7.5.

Minimizing traffic nuisance

Traffic nuisance at junctions is primarily about obstructions to through bicycle traffic on the part of stationary motor vehicles or other cyclists waiting to be able to cross (for example). As far as possible, such obstructions must be prevented, e.g. by creating yellow boxes (criss-cross pattern) on (parts of) the junction area. Furthermore, minimizing traffic nuisance entails limiting cyclists' exposure to noise and emissions from motorized traffic. Cyclists' exposure to emissions is at its highest at junctions where they have to wait to be able to cross (often junctions with a traffic light control system). In such cases, the recommendation is to site the stacking space for cyclists in front of the stacking space for motorized traffic.

The main requirements for junctions have been summarized in table 6-2.

6.3 Junctions according to road type

On the basis of two road categories for motorized traffic (residential roads and distributor roads), three different junction combinations can be distinguished. If junctions with a solitary cycle path are added to these, then six different situations are possible. A junction combination entailing a solitary cycle path with a public transport lane yields a seventh variant. The combinations and subsections in which they are discussed are shown in table 6-3.

6.3.1 Junction residential road – residential road

In the case of residential roads in built-up areas, two fundamental principles are that motorized traffic should not exceed 30 km/h and all drivers are considered equal. Right of way is not dictated by means of signs, symbols or traffic lights: all drivers coming from the right have right of way (as well as a tram coming from the left). On main cycle routes in residential areas, it will be desirable to deviate from the previous fundamental principle and give cyclists right of way; after all, main cycle routes have a flow function for cyclists (in residential areas as well). Legislation makes this possible, in the form of the Administrative Provisions (Road Traffic) Decree (Besluit administratieve bepalingen inzake het wegverkeer, or BABW) regarding road signs. This decree stipulates that 'sign (B6) be used within 30 km/h streets and 30 km/h zones [...] at junctions with a main cycle route that is clearly recognizable as such'. Hence it is permissible to grant right of way to these kinds of cycle route. In that regard, it is important that the right of way be optimally supported by the design, with a further recommendation being to always install speed bumps on the road to be crossed.

The design speed is usually 60 km/h on residential roads outside of built-up areas. As far as right of way in residential areas (zone 60) is con-

Table 6-3. Overview of junction combinations and corresponding sections

	Residential road	Distributor road	Solitary cycle path
Residential road	6.3.1	6.3.2	6.3.4
Distributor road	6.3.2	6.3.3	6.3.5
Solitary cycle path	6.3.4	6.3.5	6.3.6
Public transport lane	N/A	N/A	6.3.7

cerned, the same rules apply as in built-up areas. At junctions considered equal, however, a speed of 60 km/h is too high to allow safe interchange. For these roads it would be better to proceed from a design speed of 30 km/h at the junctions, not least because it is primarily at junctions where cyclists are in most danger.

Informal right of way behaviour

Although right of way on residential roads is usually regulated with signs, in practice it is possible to talk of right of way *behaviour*. Such informal right of way behaviour is a consequence of a presupposed distribution in a main road and a side road. Informal right of way behaviour is common where there is a considerable difference in spatial quality between two roads. This difference in spatial quality could be the result of:

- spatial characteristics (buildings, plants and suchlike);
- traffic characteristics (car and bicycle traffic volumes);
- road characteristics (road profile, surfacing, type of junction).

On roads where equality is the point of departure, informal right of way behaviour must be suppressed. This can be done by modifying the profile of the most important road and/or the design of the junction. In addition, speed-reducing facilities could be considered which will interrupt the passage of through traffic (with right of way). Conversely, it is possible to enhance the difference in spatial quality by regulating the right of way. This would be a desirable solution on main cycle routes in particular, even in residential areas for motorized traffic.

6.3.2 Junction distributor road – residential road

Right of way is always regulated where distributor roads intersect. The fundamental principle here is that the traffic on the distributor roads has right of way over the traffic on the residential road. Markings, signage and design support this regulation.

Four types of junctions/crossings can be distinguished for the combination of these road types:

- priority junction (not grade-separated);
- roundabout;
- junction with traffic lights;
- grade-separated crossing.

When choosing a solution, the following factors play a role (for example):

- the functions of the roads;
- the road safety;
- the traffic flow;
- the volumes on both roads;
- the extent to which crossing is possible;
- the costs (in terms of implementation, management and maintenance);
- the desired priorities (e.g. for public transport or emergency services);
- the amount of space taken up and available;
- the connection to other junctions in a route;
- environmental aspects;
- the effect on the surrounding road network.

The type of junction that best suits a specific situation will depend on the characteristics of the location. The junction type assessment process, described in CROW publication 315A 'Basiskenmerken kruispunten en rotondes' ('Basic Features Junctions and Roundabouts') [6], can assist the designer in making the right decision.

Junctions with bidirectional cycle paths

In the case of right-of-way accidents, it is relatively common for these to involve a cyclist who came out in front of traffic from the right, from the so-called unexpected direction [3]. These are either cyclists on bidirectional cycle paths or cyclists on one-way cycle paths illegally riding the wrong way. In the case of side roads, cyclists going the wrong way have double the probability of a serious accidents that cyclists going the right way. In many of the accidents involving a cyclist coming from an unexpected direction, the motorist had an inadequate view out of the side road. The most significant cause of these accidents, however, is how observant motorists are when it comes to bicycle traffic. Research on this [7] reveals that they are very much focused on the *motorized* traffic flow that they have to cross on the priority road. More than one quarter of motorists wishing to turn right out of a side road only look left and not right when intersecting a bidirectional cycle path.

In situations where the decision to create a bidirectional cycle path is still being deliberated, the highway authority will have to contemplate whether the intended advantages of such a path outweigh the disadvantages. Bidirectional cycle paths are significantly less safe than one-way cycle paths; after all, aside from the greater risks at side roads, there is a relatively high number of bicycle-bicycle and bicycle-moped (or light moped) accidents on bidirectional cycle paths too [8]. This calls for considerable restraint when it comes to adopting these kinds of cycle path.

In specific cases (e.g. in the case of buildings on one side), bidirectional cycle paths can result in less crossing and sometimes they will be able to shorten routes as well. If the number of crossing manoeuvres (including crossing side roads) is clearly reduced, then the advantages of a bidirectional path at network level could exceed the disadvantages at junction level. The highway authority will have to make a considered decision on a case-by-case basis. If it opts for a bidirectional cycle path, then it is important for the crossing facilities at side roads to be designed to be as safe as possible. The following measures are possible to this end:

- *Creating a speed bump*. In the case of bidirectional cycle paths it is important for the speed of motorized traffic to be reduced. Which is why it is strongly advised that crossings over bidirectional cycle paths always be built raised, like a raised junction/speed hump or exit construction. This will halve the risk for cyclists.
- *Creating a stacking space of around 5 m between the carriageway (priority road) and the crossing*. This will reduce the burden on motorized traffic (first they cross the bidirectional cycle path and then they can concentrate on the priority road). Without this intervening space, too many directions will need to be scanned in a short space of time.

V58

- *Ensuring adequate sight distance*. For the sake of cyclists' safety, it is extremely important for traffic emerging from side roads to have an adequate view of cyclists coming from the right. What this means is that the cycle path must be scannable at an angle of more than 45 degrees to the right around 15 m before the crossing. Within this zone, therefore, no shrubbery or objects are allowed to obstruct the view. In the absence of the requisite view, a stop sign (sign B7) will be necessary, if need be with additional warning markings on the carriageway.

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- *Introducing appropriate signage and markings*. Correct signage and markings are to draw motorists' attention to the fact that cyclists could be coming from two sides. An underplate to accompany signs B6 or B7 (give way with or without red light) is required by law! A centre line is always advisable on the cycle path for support. Even arrows indicating the direction of travel for cyclists could be desirable. Moreover, with a view to preventing blind spot-related accidents, it is important to site the shark's teeth slightly before the crossing, e.g. in front of the table on which the cycle path is sited. This will give lorry drivers a better view of the cyclists.

Priority junction without additional measures

V23, 55

Where a relatively quiet distributor road and a residential road intersect, a regular junction will be created.

From a legal point of view, cycle paths alongside a distributor road form part of this road. This means that the same right of way regulation

applies to cycle paths as applies to the main carriageway. It is always necessary to regulate right of way in favour of the distributor road. This can be done by means of signage or an exit construction. Incidentally, it is not strictly speaking the right of way that is being regulated in the latter case but rather the flow.

One advantage of the exit construction is that it reduces the speed of motorized traffic. This is beneficial for the right of way of cyclists following the distributor road. Furthermore, pedestrians' right of way is regulated when driving in and out. After all, when driving into or out of an exit *all road users* must be given way to; in the case of priority control this only applies to *motorists*. An exit construction can also fulfil a gateway function and mark the entrance to a residential area starting at the side road.

One disadvantage is that an exit also causes nuisance to cyclists riding in and out due to the level difference. Moreover, at overly narrow exit constructions cyclists have to perform some relatively tight cornering, which can result in single-vehicle bicycle accidents. Consequently, at the side of the distributor road the approach must be sufficiently wide to enable cyclists to corner safely.

It is also extremely important that exit constructions be properly designed and maintained. Stress from heavy, twisting traffic (including lorries) must not cause dropped kerbs and paving stones to become dislodged, subside or be broken through wear and tear. Where there is a risk of this happening, timely intervention will be necessary.

The surface of dropped kerbs must be sufficiently skid-resistant to prevent slips. This is particularly a risk for cyclists who are turning. The use of natural-stone dropped kerbs is strongly discouraged as this material does not retain its rough texture for the long term.

Exit constructions both in and outside of built-up areas can be used at priority junctions without additional measures. They are also used in urban areas (in 30 km/h zones) to dictate right of way on a main route for cyclists (and pedestrians).

Priority junction with additional measures

When designing junctions between a distributor road and a residential road with additional measures, a distinction is made between situation in and outside of built-up areas.

In built-up areas

At junctions with busier distributor roads in built-up areas it is possible to make them more readily crossable if a central traffic island (≥ 2.5 m wider) is created on the main carriageway. Without a central traffic island, it will be difficult to cross at traffic volumes exceeding 800 PCU/hour on the distributor road (see box crossability in 6.2.1).

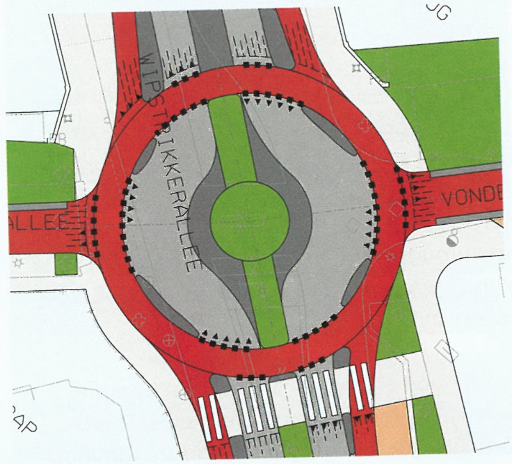
V25

Cycle paths or lanes alongside the distributor road will be continued over the junction areas to ensure that there is no interruption for cyclists on the main carriageway. At volumes of bidirectional car traffic exceeding c. 1,200 PCU/hour and where there are busy cycle routes along the distributor road, the stacking space for cyclists emerging from a side road and wishing to cross the distributor road will be a point for attention. A space of 2 to 5 m between segregated cycle path and carriageway is safest, because traffic exiting or entering the side road will then have space to wait without blocking cyclists or cars in motion.

It could be that the side road (residential road) is part of a main cycle route and that the distributor road is not. Stringent requirements are set in terms of traffic flow and cyclists' comfort when it comes to main cycle routes. In such cases, a grade-separated solution would be the safest. If this is not feasible, then a 'Zwolle bicycle roundabout' could be a solution (see the eponymous text box). Other ways of granting right of way to a cycle crossing or bicycle street when crossing a distributor road are discouraged for safety reasons.

Zwolle bicycle roundabout

In 2013, Zwolle city council was the first municipal authority in the Netherlands to construct a so-called bicycle roundabout. It is located at a site where a distributor road and a bicycle street (main cycle route) intersect. Motorized traffic is not permitted on this 'roundabout', though bicycle traffic is. Furthermore, as is customary on roundabouts in built-up areas, cyclists have right of way over the intersecting motorized traffic. Bicycle traffic flow and cyclists' road safety on the main cycle route are dramatically improved as a result. At the same time, disruptions to motorized traffic flow are kept within reasonable limits. Although the Zwolle solution is not technically a roundabout, road users do behave in line with the rules for traffic at roundabouts. Initial research results are positive, though Zwolle city council is keen not to celebrate prematurely and for that reason is monitoring the situation for the time being. It will only be over the longer terms that definitive judgements can be made as to the value of the bicycle roundabout and any possibilities in terms of improving the design.



V25

Outside of built-up areas

If the volume of traffic on a distributor road to be crossed outside of built-up areas exceeds 800 PCU/hour, then a central traffic island will be desirable. Optionally, a speed bump can be installed on the main carriageway to supplement the central traffic island. This will prevent high (or excessive) speeds on the part of motorized traffic and make differences in speed between motor vehicles less significant. The latter in particular will enable cyclists to better estimate when they will be able to cross safely.

Outside of built-up areas right of way on distributor roads is never set in favour of an intersecting main cycle route. Such a measure would not chime with road users' pattern of expectations and could therefore result in serious conflicts. What is recommended in the case of a cycle route (or main cycle route) is to always create a central traffic island of adequate width (≥ 3.50 m), both to increase drivers' attention and to enable simpler crossing with shorter waiting times.

A central traffic island will suffice up to motorized traffic volumes of c. 1,400 PCU/hour on the road to be crossed. The average waiting time will then be a maximum of 10 s with a requisite gap (taking into account the speed of 80 km/h) of around 6 s. As stated, preference is given to reducing the speed of motorized traffic by way of a supplementary speed-reducing measure. In order to give cyclists a sense of security earlier, the preferred option is to site the speed bump some distance before the junction.

In the case of a volume of car traffic exceeding c. 1,400 PCU/hour, a distributor road with just a

central traffic island will no longer be 'readily crossable'. In such cases, the average waiting time will be more than 10 s, with the following options being available:

- *Accept a higher average waiting time.*
- *Create a traffic light control system or a regulated cycle crossing.* This is a valid option up to volumes of traffic on the carriageway to be crossed of a total of c. 1,600 PCU/hour. The average waiting time will then be around 20-30 s. In itself, this is a reasonable wait at a set of traffic lights, but the question is whether this time will be any shorter at an unregulated crossing with a central traffic island. There is, however, a guarantee of there being not too long a wait until there is a gap to cross.
- *Create a roundabout.* Outside of built-up areas (where cyclists on cycle paths never have right of way), the crossing situation is similar to that of a road with a central traffic island. However, one significant advantage of the roundabout is that the speed of motorized

traffic is (much) lower, leaving the cyclist in a better position to anticipate the traffic flow to be intersected.

- *Create a grade-separated cycle crossing*. This will reduce the waiting time to zero, though this solution is expensive, often difficult to integrate spatially, and depending on the design it is possible that cyclists will have to take a bit of a detour in order to use it.

6.3.3 Junction distributor road – distributor road

From a functional perspective, two intersecting distributor roads are equal. If this fact is contrasted with the general point of departure of right of way, then apart from the well-known priority junction there are three possible solutions:

- roundabout (6.3.3.1);
- traffic light control system (6.3.3.2);
- grade-separated solution (6.3.3.3).

In many situations a variety of types of junction will be possible from the perspective of adequate traffic flow capacity. The type of junction will then be selected on the basis of a combination of other criteria, including:

- the traffic flow;
- the extent to which crossing is possible;
- the road safety;
- the desired priorities (e.g. for public transport or emergency services);
- the amount of space taken up and available;
- the connection to other junctions in a route;
- the effect on the surrounding road network;
- environmental aspects;
- the costs (in terms of implementation, management and maintenance).

The junction that best suits a specific situation will depend on the characteristics of the location. The junction type assessment process, described in CROW publication 315A [6], can assist the designer in making the right decision. In practice, it will usually be a choice of either roundabout or a junction with traffic light control system. These two solutions will be discussed in detail below. Grade-separated crossings will then be touched on briefly.

The various solutions have rather different consequences in terms of safety. For example, a relatively high number of accidents happen at full (four-way) junctions. From the perspective of safety, therefore, they must be avoided. Single-lane roundabouts are (if volumes do not exceed the roundabout's capacity) always the safest type of junction. At higher volumes, turbo roundabouts constitute a relatively safe solution, provided that the bicycle traffic is grade-separated.

6.3.3.1 Roundabout

V31, 32, 33, 34

Roundabouts are now a solution being used on a large scale. Which is unsurprising, given that roundabouts present various benefits. The most important of these are:

- preventing encounters between oncoming traffic;
- simplifying conflict situations;
- reducing speed at points of conflict.

Furthermore, roundabouts are a safe solution. Due to their sizeable capacity and relatively fluent traffic flow, roundabouts are a highly suitable solution for intersecting distributor roads.

Single-lane roundabouts are the safest type of junction. Such roundabouts have a capacity of up to c. 25,000 PCU/24-hour period (sum of the incoming arms; in the case of asymmetrical traffic volume the capacity will be up to 20% lower). A turbo roundabout is capable of accommodating many more vehicles, with the larger varieties taking up to c. 50,000 PCU/24-hour period. Nevertheless, they are considerably less safe than single-lane roundabouts and for that reason they will only be considered if this is unavoidable for reasons of capacity.

From the perspective of road safety, it is desirable to have cyclists cross other traffic by means of a grade-separated solution. If this is not possible, then cyclists will have to give way at turbo roundabouts both in and outside of built-up areas. Only if there are already more roundabouts in the local area at which cyclists have right of way will it be possible to consider to give cyclists right of way at the turbo roundabout too. Additional layout requirement will apply to this end, however [10].

Facilities for bicycle traffic

In principle, specific facilities for cyclists are unnecessary on relatively quiet roundabouts up to around 6,000 PCU/24-hour period. However, they could be wanted if they would make the design of the roundabout fit in better with the connecting roads. If the latter have segregated cycle paths (for instance), then preference will be given to creating a segregated cycle path on the roundabout as well.

A segregated cycle path is at any rate recommended on busier roundabouts. Cycle lanes on roundabouts are discouraged. Due to their blind spot, drivers of turning lorries in particular have an inadequate view of cyclists and moped riders riding next to them on the right-hand side. Furthermore, the following points for attention apply [11]:

- The design of the cycle path must encourage caution on the part of cyclists.
- The point at which cyclists cross the carriageway must be sufficiently clear and noticeable.

- Cyclists must be readily visible in the vicinity of the point at which they will be crossing the carriageway.
- Turning cyclists must be able to leave the roundabout as swiftly as possible.

In built-up areas the guideline is that cyclists on a segregated cycle path going round a roundabout have right of way [12]. This is most in keeping with a cycle-friendly policy. The design of cycle paths around the roundabout must be fine-tuned to the priority control: the cycle path is circular and is ridden in a single direction. Outward bends and 'square' cycle paths are dangerous and uncomfortable, and for that reason they are discouraged.

No less important is the design of the main carriageway. This must adequately reduce the speed of motorized traffic.
This can be done by (for example) making the central traffic island sufficiently large (to stop cars being able to drive by them at relatively high speeds), by raising the central traffic island, and by using sufficiently tight curve radii for motorized traffic.

Outside of built-up areas the guideline is that cyclists on a segregated cycle path going round a roundabout have right of way [12]. The corresponding design is a cycle path bent outwards. Here, too, there is a need to adequately reduce the speed of motorized traffic. To this end, sufficiently tight curve radii are required.

As far as possible, bidirectional cycle paths around roundabouts are avoided, as motorists are not expecting any oncoming cyclists riding clockwise as well as anticlockwise. If a bidirectional cycle path is used round a roundabout anyway, then it is strongly recommended that the cycle path be raised over the approaches and exits, with the design, markings and signage optimally drawing road users' attention to the possibility of cyclists coming from more than one direction.

If the volume of traffic on the arms of a roundabout is sufficient to necessitate a turbo roundabout, then the design of cycle facilities will require extra attention. The best solution would be a grade-separated one, preferably entailing a lowered cycle path combined with a raised carriageway. If need be, a tunnel can be used, though only on the main cycle route. This will enable at-grade crossing on the part of cyclists, depending on volumes. However, this will only apply if it is a single-lane exit, in which case the cycle path should preferably be constructed on a table. At-grade crossing of two-lane exits is extremely dangerous due to the obstructed visibility. Designs in which this is necessary are strongly advised against.

6.3.3.2 Traffic lights

Traffic lights are usually installed to ensure smooth, safe motorized traffic flow. In the case of distributor roads, this will pertain to junctions accommodating between 10,000 and 30,000

PCU/24-hour period. Traffic lights are a less (sustainably) safe solution than roundabouts or grade-separated crossings, which is why from that aspect they must be considered to be second best.

Motorized traffic is usually dominant at junctions regulated by traffic lights. Consequently, attention was primarily given in the design of the traffic light control system to the flow of motorized traffic. This entails the capacity for motorized traffic being used as a benchmark and the available time for slow-moving traffic often being limited. The combination of short green times for bicycle and pedestrian traffic and the long time required to process motorized traffic creates long waiting times for slow-moving traffic. Nevertheless, an acceptable probability of having to stop and a limited waiting time are just as important for slow-moving traffic as they are for motorized traffic. There are possibilities in terms of addressing this (or addressing this better).

Various *criteria and design requirements* for traffic lights are discussed below. Afterwards attention will be devoted to *fundamental principles for policy and management* which are important within the compass of cycle-friendly traffic control. Finally, a brief look will be taken at *possibilities in terms of control technology* to improve the position of bicycle traffic in a traffic light control system.

Criteria and design requirements

Siting criteria for traffic lights, flow capacity, waiting time (average and maximum) and probability of having to stop/probability of being able to continue, cycle time and preconditions vis-à-vis partial conflicts and a combined flow are some of the important factors.

Siting criteria traffic lights
A detailed account of the siting criteria for traffic lights is beyond the scope of the present Design Manual. Only those considerations that pertain to bicycles will be treated. From the perspective of the interests of cyclists, traffic lights can be considered with safety and bicycle traffic flow in mind. Safety is particularly important at junctions and crossings: if the scale and/or speed of the traffic flow to be crossed is sufficiently considerable that this will put cyclists in jeopardy, then traffic lights can be considered. Incidentally, this is only if other measures (including creating a roundabout or a central traffic island at crossings) has proved to be infeasible.

Flow capacity
The flow capacity of cycle paths is high: around 5,200 cyclists per hour at a width of 2.00 m. Nevertheless, high volumes and/or long red times for cyclists give rise to significant time loss and discomfort as a result of questions and saturation. Options in terms of preventing this include (locally) widening the stacking space, widening the flow space and extending the green time.

Bottlenecks and solutions where bicycle traffic volumes are high

If a junction is required to accommodate large numbers of cyclists, then the following bottlenecks could occur (for example):

- Too little space for the high volume of cyclists to wait and manoeuvre at a red light. This will cause jams and will inconvenience cyclists and put them at risk.
- It will also inconvenience pedestrians and put them at risk if cyclists have to veer onto the pavement or crossing.
- A considerable amount of time will be lost by cyclists, who will be unable to proceed during the next green phase because of how busy it is.
- Time will be lost if the bicycle traffic flow is blocked by waiting cyclists.
- Motorized traffic flow will be limited, particularly where there is a large volume of motorized traffic turning and a large volume of cyclists riding straight on.

In order to remedy the bottlenecks outlined, the following measures are possible (combined, if need be):

- Increasing the size of the stacking space for cyclists by making it wider and/or longer.
- Increasing the space for bicycles by:
  - using ample curve radii for cyclists;
  - reducing the size of speed bumps or remove them;
  - making edges of speed bumps on cyclists' side flush with the road surface;
  - widening the cycle crossing;
  - not applying block markings to but rather adjacent to the vehicle path (after all, cyclists prefer not to ride over blocks in marking paint as this is bumpy).
- Situating the stacking space for cyclists as far ahead as possible, e.g. by using an advanced stop line (which can also be connected up to a segregated cycle path, past the pedestrian crossing).
- Keeping the space for cyclists in motion separate from the space for waiting cyclists by:
  - introducing box junction markings where segregated cycle paths intersect;
  - providing traffic lanes and stacking spaces with arrows for different cycle directions;
  - introducing specific markings at particular places where cyclists 'amass', such as at ferry landings (e.g. red and green boxes, like at the ferries in Amsterdam).
- Selecting a different type of junction, such as:
  - a junction with right of way for the most important cycle direction;
  - an unregulated junction with ample central reservation, preferably over 2x1 traffic lane;
  - a roundabout at which cyclists have right of way (to prevent large numbers of cyclists amassing, as they do at traffic lights);
  - a grade-separated crossing (in the case of heavy motorized traffic flows).
- Adjusting traffic light settings, with:
  - cyclists being given a green aspect as frequently as possible, thereby reducing waiting times and the number of cyclists that will amass due to a red light. More green aspects can be achieved for cyclists by (for example):
    - giving cyclists a green aspect at the same time as other modalities;
    - giving cyclists a green aspect twice per cycle.
  - extending the green phase for cyclists, with the extended green phase coming into effect when the volume of cyclists exceeds the volume that can pass through during a regular green phase;
  - ensuring a subsequent green aspect where cyclists have to turn left through two sets of lights, thereby preventing delay, as without such a link (much) more stacking space will be required at the second set of lights.

Waiting time and probability of having to stop

For the purposes of ascertaining the bicycle-friendliness of traffic light control systems, the terms probability of having to stop/probability of being able to continue and waiting time (for cyclists, of course) are extremely important. Waiting for traffic lights turns out to be a significant source of delay, particularly in major cities. Stopping means not only lost time, but also energy loss and discomfort.

The *probability of having to stop* (and by extension the probability of being able to continue) is determined by the number of times that a cyclist will have to stop at a traffic light control system. In the case of a fixed system, the probability of having to stop is easy to establish: it will be the red time divided by the cycle time. In the case of a pre-emptive (non-fixed) system, the probability of having to stop can be calculated by dividing the overall red time in a (representative) period of observation by the overall time that this period of observation comprises.

If a cyclist has to stop, the *waiting time* will be an important measure of bicycle-friendliness. Both the average and the maximum waiting time are significant. If a cyclist has to stop at a red light, then the waiting time is determined by the red time and the point during the red phase at which the cyclist arrives. The average of this (across all arrivals) is the average waiting time when stopping. In a fixed system, this will simply be half the red time. Perhaps contrary to expectations, the average waiting time will be a little higher for a pre-emptive (vehicle-dependent) system. The calculation is more complicated - see above [16].

The average waiting time is proportional to the square of the cycle time for cyclists. Shortening the cycle time will therefore make a significant contribution towards limiting the average waiting time.

The above means that the average waiting time can be improved by reducing the probability of having to stop and/or by lowering the average waiting time when stopping (the red time). An average waiting time of less than 15 s can be deemed good, and one exceeding 20 s can be deemed bad. Between these times can be considered moderate. The corresponding values for probability of having to stop and waiting time are given in figure 6-2.

In pretty much all cases the aforementioned waiting times at traffic light control systems are higher than the waiting times when crossing priority roads without traffic light control systems. Hence from the perspective of the cyclist (or directness for the cyclist), introducing a traffic light control system is seldom a good idea. However, one advantage of such a system is that the maximum waiting time is limited. This is not so when crossing priority roads without traffic light control systems, where there is a chance that those wishing to cross will have to wait four times longer than the average waiting time when it is particularly busy. For that reason, cyclists accept slightly longer (average) waiting times at traffic lights.

There is, however, a limit to that acceptance: maximum waiting times exceeding 90 to 100 s are not credible. This limit can be lower if junctions with traffic lights are close to one another, or if a large number of cyclists are turning left and this requires them to stop twice. For that reason, the following limits are recommended for the maximum waiting time, irrespective of the type of control system (such as those pre-empted by traffic or public transport):

- outside of built-up areas: maximum waiting time < 90 s;
- in built-up areas: maximum waiting time < 100 s.

Cycle time

The waiting time for cyclists is also dependent on the cycle time of a traffic light control system. A short cycle time will not only improve bicycle traffic flow but will usually also improve flow for other types of vehicle as well. For a cycle-friendly control system it holds that the shorter the cycle time the better, though preferably not longer than 90 s. Having the green aspect for cyclists feature twice during the cycle can considerably improve waiting time for cyclists.

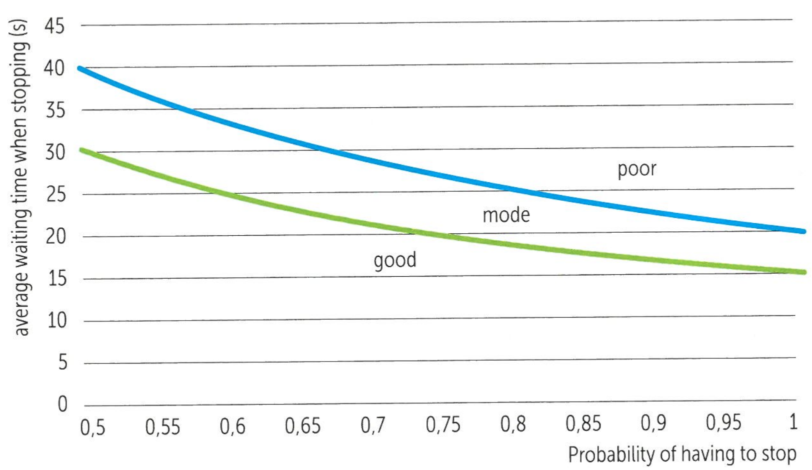


Figure 6-2. Relationship between probability of having to stop and average waiting time when stopping for traffic lights

Partial conflicts between car and bicycle

A large number of highway authorities do not allow any partial conflicts in their systems from the point of view of road safety. However, for various reasons it could be desirable to permit partial conflicts between car and bicycle in a system, e.g. to shorten waiting times or due to lack of space. Such partial conflicts may only be permitted between cyclists travelling straight on and cars from the parallel traffic flow turning (or vice versa). In this regard, having a proper view of the cyclists is crucial. Furthermore, giving cyclists a head start in this case is recommended to ensure that the presence of this flow is emphasized.

Partial conflicts between car and bicycle are strongly discouraged if:

- the volume of the motorized traffic turning exceeds 150 PCU/hour;
- a bidirectional cycle path is involved, because a proportion of the cyclists will be coming from an unexpected direction;
- it pertains to a situation outside of built-up areas in which the speeds are higher and cyclists are a less dominant force in the streetscape (as a result of which they are more likely to be missed);
- a large number of lorries are turning right (due to the probability of a blind spot-related accident);
- motorized traffic turning left has to cross a large junction (because motorists are no longer expecting any cyclists after the significant distance).

Combined flow of cyclists and other traffic or not?

Three manoeuvres can be distinguished for cyclists at a junction: turning right, riding

straight on or turning left. The choice of type of cycle facility at a regulated junction will depend on the cycle facilities present on the approach roads, the presence of partial conflicts and the volumes of car traffic.

- *Cyclists turning right*

At a junction with traffic lights, delay for cyclists turning right can be limited by leading these cyclists around the provision ('free right turn through red') or if need be permitting 'right turn for cyclists free'. Points for attention in such a case include the fact that the cyclists turning right must not experience any nuisance from cyclists riding straight on (and vice versa) and from pedestrians walking straight on. Attention must also be given to cyclists joining traffic (use cover behind them, if need be).

V35, 36

If neither 'right turn through red' nor 'right turn for cyclists free' are possible, then the stacking space will be important for cyclists. In order to enhance the flexibility of the provision, it could be desirable for cyclists turning right to be allocated their own signal group. In that case it will be desirable for them to have their own dedicated turning lane.

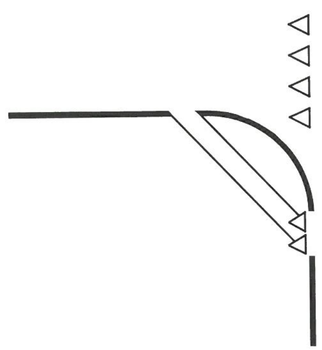


Figure 6-3. Basic principle of 'right turn through red'

- *Cyclists riding straight on*

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In the case of a mixed profile and in the presence of cycle lanes on the approach road, cyclists riding straight on will be flowing in parallel with motorized traffic. It could be desirable to create a streamed cycle path or streamed cycle lane to enable cyclists to pass waiting cars. Another possibility is to give cyclists riding straight on their own green phase. In such cases, the recommendation for a mixed profile would be to create a streamed cycle path for cyclists or give them their own dedicated turning lane. In this regard, it is important for cyclists to remain in motorists' field of vision. For that reason, it is *imperative* that the stop line for cyclists is a few metres ahead of the stop line for motorized traffic in the case of a mixed profile, this being due to lorries' blind spots. If bicycle traffic flow is on a cycle path, there are options in terms of cyclists riding straight on being merged with other, non-conflicting signal groups. This will present more opportunities in terms of the bicycle-friendliness of a provision.

- *Cyclists turning left*

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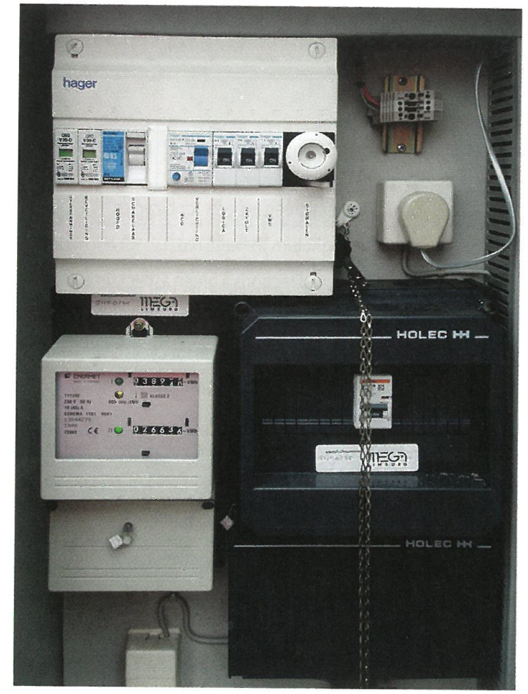
Cyclists turning left often have a raw deal at a traffic light control system. Particularly in the case of segregated cycle paths, turning left is conceived of as two different manoeuvres. Waiting time can be shortened considerably if this manoeuvre is considered a straight-on manoeuvre and the two green phases follow one another in quick succession. If there is a mixed profile (at relatively low volumes of traffic on an approach road), then an advanced stop line can be created. If there are a lot of cyclists turning left, it could also be a good solution to have cyclists travelling in all directions given a green signal at the same time. In situations involving a dominant flow of cyclists turning left, this flow can easily be facilitated by adjusting the order of the green aspect in the so-called block diagram of the traffic light control system. This could have markedly positive effects.

Fundamental principles for policy and management

One of the most important options when it comes to improving the position of bicycle traffic at traffic light control systems is at the level of policy development. Or, to put it in more concrete terms, it consists in formulating clear, cycle-friendly policy principles. Practical experience has shown that a large number of traffic light control systems are made by traffic control engineers with a high degree of independence. Taking into consideration the interests of all road users and on the basis of the engineer's own knowledge and expertise, a traffic light control system is created that to all intents and purposes constitutes a 'compromise' [13]. Such a way of working leads to the control engineer making a significant mark on the highway authority's traffic policy.

In order to prevent this, though also to avoid being overly reliant on the engineer when it comes to resolving dilemmas during the design process, highway authorities responsible for a wide array of traffic light control systems should develop a traffic light provision policy to this end. This will set out what priorities are being assigned to the various categories of road user in the different road situations. For example, one fundamental principle can be that at junctions in built-up areas right of way be given to (sections with) main cycle routes. However, it is also possible to specify maximum values for average waiting times or cycle times, for



instance. If such fundamental principles are recorded in administrative regulations, then the control engineer will have clear objectives, which will also be readily testable.

Another important measure is carrying out periodic maintenance on the provision. Once a traffic light control system is 'up and running', it often receives little in the way of attention. Performing regular maintenance work and checking in situ whether specifications are still satisfactory will prevent a provision from no longer being optimally fine-tuned to the traffic situation as time goes by.

Control engineering options

Various design sheets accompanying this Design Manual include measures to improve the situation for cyclists at junctions with traffic lights. A large number of these centre on shortening waiting time for cyclists. After all, minimizing waiting time is essential for a cycle-friendly provision. The various measures can be

Table 6-4. Possibilities for combining cycle-friendly measures at traffic lights

Number	Measure	Design sheet	Can perhaps be combined with number(s)
1	reducing cycle time	V40	2 to 16
2	including extra green aspects for bicycles	V47	1, 3, 4, 7 to 9, 11 to 16
3	permitting right turn through red		1, 2, 4 to 11, 14 to 16
4	giving all cycle directions a green aspect simultaneously	V48	1 to 3, 10 to 13, 15
5	accepting partial car-bicycle conflicts	V46	1, 3, 7 to 9, 11 to 13
6	setting a favourable idle mode for cyclists	V49	1, 3, 4, 9, 11 to 13, 15, 16
7	increasing cycle directions with right of way for public transport	V41	1 to 3, 5, 8, 9, 11 to 16
8	increasing cycle directions with other directions	V42	1 to 3, 5, 7, 9, 11 to 16
9	setting favourable phase order for cyclists turning left	V43	1 to 3, 5, 7, 8, 10 to 13, 15, 16
10	setting green wave for bicycle traffic	V44	1, 3 to 5, 9, 11 to 16
11	keeping reciprocal conflicts between slow-moving traffic outside of the regulation		all measures
12	implementing right turn through red		all measures, with the exception of 3
13	introducing advance detection/pre-request for bicycle traffic	V45	all measures
14	introducing advanced stop line	V39	all measures, with the exception of 6, 7 and 8
15	increasing flow capacity motorized traffic (to enable cyclists to be given a green aspect sooner)		all measures, with the exception of 5
16	introduce bidirectional crossings		all measures, with the exception of 4, 5 and 14
17	increase size of stacking spaces and exit lanes for cyclists		all measures, at high volumes of bicycle traffic

adopted separately, though often in combination as well (see table 6-4). The effects of the measures could vary for each situation. For that reason, a thorough analysis must be performed for each situation to ascertain the most suitable measures in situ.

6.3.3.3 Grade-separated solution

Grade-separated facilities will be desirable or necessary if other junction solutions do not satisfy the design requirements vis-à-vis directness and safety. This applies not only to main cycle routes but also to the basic network – particularly for those components that intersect busy

Table 6-5. Bridge versus tunnel

Aspect	Bridge	Tunnel	Explanation
Spanning level difference		+	There is a descent on an approach to a tunnel. This produces a build-up in speed which helps the cyclist to ascend the exit slip.
		+	At a tunnel, the level difference to be spanned is less than that at a bridge, because the requisite headroom for cyclists is less than it is for cars (and lorries), trains or ships.
Personal safety	+		A tunnel often provides users with an uneasy feeling, as it is not possible to see what is happening in the tunnel from the surrounding area. A bridge is in the open and therefore provides more possibilities in terms of monitoring and view.
		+	People are far more likely to throw stones off bridges than they are to throw stones in tunnels.
	+		A tunnel can kindle a sense of claustrophobia, particularly when the tunnel is long, curved and/or narrow. This is not the case with a bridge.
	+		Tunnels are more likely to attract graffiti and loitering youths than bridges.
Spatial integration		+	From an urban planning or landscaping perspective, a tunnel can provide more benefits than a bridge can. For example, a tunnel has a less drastic impact on the visual aspect of the surroundings: the incline can be shorter than that of a bridge (due to the smaller level difference), and furthermore, the tunnel is below ground level.
	+		A bridge enables the creation of architecturally beautiful solutions. Far more than a tunnel does, a bridge present possibilities in terms of developing a unique and recognizable object.
Comfort		+	In a tunnel, a cyclist experiences less wind nuisance than on a bridge, and cyclists can take shelter in a tunnel.
		+	A narrow, high and long (cycle) bridge can produce a fear of heights in cyclists. This phenomenon is aggravated by excessively low guard rails and views through these. The level difference at a tunnel is usually limited (particularly in the case of a half-buried tunnel).
Costs	+		A bridge is usually cheaper to construct than a tunnel, particularly if when building a tunnel facilities are needed because of the groundwater.

distributor roads or distributor roads with a speed limit of 70 km/h or higher.

Nonetheless, it will often be the case that there is not enough space and/or budget for a grade-separated solution. In such situations, it will only be possible to create a safe crossing if the differences in speed are reduced by means of speed bumps. Another possibility, which can be combined with speed bumps if need be, is to separate the differences in mass and direction in time by means of a traffic light control system.

Bridge or tunnel?
If a decision is made to create a grade-separated crossing for bicycle traffic, then the two options are a tunnel or a bridge. The potential advantages and disadvantages of both alternatives are shown in table 6-5.

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The weighting that must be ascribed to the advantages and disadvantages of a tunnel or bridge primarily depends on the characteristics of the surroundings and the exact design of the grade-separated crossing. Thus the argument

of personal safety will be less important in an environment where there is a lot going on than it would be in an isolated setting.

The ideal situation for cyclists would be if cars rather than bicycles are required to span the level difference. If bicycle traffic can stay at ground level and motorized traffic is led over a bridge or through a tunnel, then cyclists are completely spared the burden of the crossing. Where such a solution is not a possibility, the designer can nevertheless adhere to the spirit of this idea: in the case of a bridge, the road can be constructed slightly below ground level, and in the case of a tunnel the road can be 'raised' slightly. In both cases cyclists will be required to overcome a slightly less pronounced level difference.

Fauna tunnels
Cycle and pedestrian tunnels in rural areas can also fulfil a function for (smaller) animals. A landscape policy that causes fragmentation of forested areas and nature reserves generates a need for fauna tunnels. It will sometimes be possible to combine these with tunnels for (recreational) bicycle traffic. In such cases, however, it could be desirable to introduce an unpaved lane with a width of around 2 m.

Bicycle lifts, escalators and ramps
Bridges or tunnels often mean that cyclists will have to overcome a level difference. The fundamental principle is that it must be possible for this level difference to be spanned *whilst cycling*. As an 'emergency intervention', bicycle lifts, escalators or stairs can sometimes be used where there are significant level differences (e.g. at a bridge over an important waterway). However, these may only function as a supplementary measure (not least because not everyone is keen on using a lift or escalator). One alternative is an inclined travelator (escalator). The spiral ramp could be an alternative in situations where a 'normal' incline is unsuitable. See section 3.5 for requirements set in terms of gradient.

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Tunnel solutions that ensure personal safety
The following fundamental principles are used when designing a cycle-friendly tunnel conducive to personal safety (see also chapter 7):
- The view of the tunnel route from the surrounding area is optimal (inclines at a gentle angle).
- The design guarantees that the amount of time cyclists spend in the tunnel is minimal (as short a 'span' as possible).
- The design will minimize any sense of claustrophobia.
- Design, lighting and colour scheme ensure an 'open aspect'.

Special solutions
The use of grade-separated crossings for bicycle traffic often remains limited to a cycle tunnel or cycle bridge for crossing a main road, this being in the vicinity (or otherwise) of an at-grade crossing on which motorized traffic is travelling. Refraining from constructing a cycle bridge or cycle tunnel is common if a range of cycling manoeuvres need to be possible at the junction. The fact that it is perfectly possible to create a grade-separated crossing at those junctions is evident from such projects as the *De Berekuil* roundabout interchange in the municipality of Utrecht. This solution, which was completed as far back as 1944, comprises a half-raised roundabout interchange with traffic lights accommodating motorized traffic flows. The bicycle traffic passes through short half-buried tunnels under the roundabout lanes to the open space in the middle of the roundabout.

In Eindhoven, pedestrians and cyclists can use *De Hovenring*, a 'floating' bicycle roundabout over the busy Heerbaan/Meerenakkerweg junction [14]. With its slender bridge deck, imposing pylon and a diameter of 72 m, this striking steel structure constitutes a new landmark. The structure is suspended like a flying saucer hovering over Eindhoven, Veldhoven and Eindhoven's new-build district of Meerhoven. The bridge is lit up in the evenings in a unique way.

Table 6-6. Recommendations for the design of cycle tunnels

Surroundings and integration	
1.	Assuming there is a need to cross, a tunnel will preferably be created in an area where there is a great deal of social activity and more people can therefore be expected. In addition, the cycle tunnel will – if possible and advisable – be combined with a function for pedestrians. Pedestrians and cyclists will each be given their own space.
2.	In connection with monitoring, openness and cyclists' comfort, preference is given to a half-buried tunnel, with the road connection to be cross being 'raised' by about 2 m. This will enable the structure to be designed like a viaduct in the road. Furthermore, if the road to be crossed is designed using segregated carriageways, this will create an open structure, enabling daylight ingression as well.
3.	The route of the cycle route will be as straight as possible, in order to increase the view. This will ensure that the tunnel's exit is visible when entering it (i.e. no bends in the tunnel).
4.	The slopes on either side of the tunnel entrances will not be too steep (maximum 1:1). This will reduce any feeling of claustrophobia.
5.	There should be no tall plants at the entrance to the tunnel, to prevent assailants from concealing themselves there.
Design	
6.	Tunnels should preferably be as short as possible. Not only because this makes them easier to take in, but also because this will enhance the effects of daylight in them. It goes without saying that cyclists will then be in the tunnels for less time.
7.	Tunnels should not present people with opportunities to hide. Hence there should not be any niches or blind spots.
8.	The walls of a tunnel recede to the top.
9.	The minimum height of a cycle tunnel is 2.50 m.
10.	A balanced relationship between width and height is desirable. As a guideline, the width should be at least 1.5 times the height. A tunnel entrance where the height dimension clearly exceeds the width dimension gives the observer the impression of narrowness and can therefore be found oppressive. On the other hand, a tunnel that is very wide in proportion to its height will give users a feeling that they might bump their heads.
11.	In order to drain rainwater swiftly, the tunnel floor should have a cross slope of 1 to 2%.
Set-up	
12.	Tunnels must be well lit. Principles of both road safety and personal safety require that it is not appreciably darker in tunnels than it is outside of them.
13.	In the evening, the transition from outside to inside the tunnel (and vice versa) must be smooth. What this means is that there should be lighting outside the tunnel too, enabling the cyclist to adjust to the changed light intensity.
14.	In addition to the light intensity, the colour of the tunnel's walls is also important: light, friendly colours give a nicer, safer impression than drab, cold colours. A colour gradient from dark at the ends to light in the middle will boost the sense of safety.
15.	It is recommended that light fittings be sunk into walls or ceilings wherever possible so as to prevent vandalism. It is also important to ensure that damaged light fittings can be repaired or replaced quickly and easily.
16.	A careful design is required for the drainage. It is often the case that debris, such as leaves and paper, accumulates at the transition between approach and tunnel floor. A tunnel must therefore be quick and easy to sweep clean.

These fundamental principles give rise to the design guidelines as presented in table 6-6.

6.3.4 Junction solitary cycle path – residential road

V21, 22

The same priority rules apply at intersections between solitary cycle paths and residential roads as apply at intersections between residential roads (motorists coming from the right have right of way). Hence both types of junction can be treated in the same way. That said, at intersections with solitary cycle paths particular attention must be given to the design, as the view of solitary cycle paths is sometimes obstructed by vegetation and this can sometimes give rise to informal right of way behaviour (see text box section 6.3.1). In more concrete terms, what the above means is that if traffic on the residential road 'overlooks' the solitary cycle path, then it would not be advisable to grant crossing cyclists right of way. Where the chances of such behaviour are appreciable, measures should be taken to safeguard visibility and equality.

If the solitary cycle path is a main cycle route, then it holds that the path can have right of way over the residential road to be crossed. For the measures to be taken in such cases, please see section 6.3.1. Granting right of way to the residential road in built-up areas is proscribed by law.

6.3.5 Junction solitary cycle path – distributor road

Intersections between solitary cycle paths and distributor roads can be dealt with the same way as intersections between residential roads and distributor roads. In principle, the traffic on the distributor road has right of way.

If the solitary cycle path forms part of the main cycle network, the stringent requirements are set in terms of bicycle traffic flow and cyclists' comfort. In such cases, a grade-separated solution would be the safest. If this is not possible, then a 'Zwolle bicycle roundabout' could be a solution in built-up areas (see eponymous text box in 6.3.2). From the perspective of road safety, altering the right of way of a solitary cycle path when it comes to intersecting a distributor road is discouraged.

6.3.6 Junction solitary cycle path – solitary cycle path

A junction involving two solitary cycle paths can be regarded as a junction between two residential roads. One difference compared to 'normal' residential roads is that there are no significant differences in mass between the road users. Consequently, there is little reason to reduce speed and a normal T-junction or a full junction will suffice. If there is a junction with one or two cycle/moped paths, the presence of mopeds could make it desirable to reduce speed.

As with residential roads, equality of the intersecting roads is the fundamental principle. In principle, this means that no priority regulation is required. Only if one of the routes is a main cycle route will right of way be granted to cyclists on this connection. The design of the junction should be adapted to this, e.g. by using central traffic islands on the subordinate cycle paths.

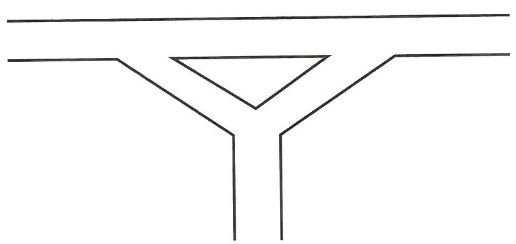

Figure 6-4. Principle of a triangular junction

At extremely busy junctions (in excess of 1,000 cyclists per peak hour in the main direction), crossability will come under pressure and a roundabout can be considered. A triangular junction could also provide a solution (see figure 6-4).

6.3.7 Junction public transport lane – solitary cycle path

In the case of a solitary cycle path and a public transport lane, a distinction can be made for the latter between a bus lane, tramlines and railway lines.

6.3.7.1 Bus lane

In terms of traffic characteristics, a segregated bus lane is most similar to a distributor road with a low (or very low) volume of traffic. What this means is that the solutions specified in subsection 6.3.2 should guide decision-making.

In the case of a junction between a solitary cycle path that is part of the main cycle network and a segregated bus lane, a priority junction is recommended, with a wide central traffic island in the bus lane and a speed bump for the bus. If the bus lane is being used intensively and by fast-moving public transport, then additional traffic lights can be used, with favourable priority regulation for bicycle traffic. Due to the low volumes of traffic on the bus lane, there will be particularly high degree of cyclists ignoring red lights. Solutions include having the green aspect show for cyclists in idle mode and/or warning sounds and lights when a bus is approaching.

6.3.7.2 Tramways

In the case of a segregated tramway, the design of the cycle crossing will be dependent on the speed of the tram. The braking distance of a tram is considerably more than that of a passenger car. Only if the tram's speed does not exceed around 20 km/h at points of conflict will the same solutions be applicable as at a junction between a solitary cycle path and a 'normal' distributor road or a bus lane (see 6.3.7.1). If the tram speed is higher, then it will not be possible to satisfy the 'low speed at conflict points' requirement, meaning that safety will not be being adequately safeguarded. In such a case, the crossing should be regulated by means of traffic lights or a grade-separated solution will be necessary.

What can make tramway situations special is that tramlines are often next to or between the carriageways for motorized traffic and sometimes trams can come from directions not permitted to other traffic. This can soon complicate the design for a crossing, leaving it out of synch with road users' expectations. Extra safeguarding of the crossing is advisable in such complex situations. In this regard, a 'standard' traffic light control system can be chosen or a warning system specially developed for the tram track (or bus lane). At crossings with a segregated tramway (or fast tramway) it is common for so-called tram lights to be used. These consist of a warning light containing the tram symbol, and the light starts flashing when a tram is approaching. Tram lights are often supported by a chiming signal.

The angle between the tram rails and the cyclists' trajectory is an important consideration where tramways and bicycle connections intersect. This angle should be as close to 90 degrees as possible to prevent cyclists getting a wheel caught in a rail or slipping on the rails when the road surface is wet. A guideline minimum value of around 60 degrees can be maintained, though it would obviously be preferable to create a larger angle. Moreover, at these kinds of crossing there must be sufficient room for manoeuvre for cyclists next to the tram rails. In the case of crossing over segregated tramways, it is desirable to have sufficiently large traffic islands between tramways and carriageways.

6.3.7.3 Railway lines

In the case of railway lines, the train's right of way is indisputable. At every level crossing, all other road users will have to give way to the train – be this an intercity or a single locomotive – once the barriers close. Where main cycle routes cross railway lines, preference should be given to grade-separated solutions. This will ensure that cyclists do not experience any delay as a result of the train traffic. In the case of railway lines with scant train traffic, barriers will suffice.

For other cycle routes it holds that if a grade-separated crossing will not be possible, then the level crossing must always feature automatic half barriers (an AHBC). Level crossings without half barriers are particularly dangerous points on school routes. In the case of bidirectional cycle paths, it goes without saying that half barriers should feature on both sides.

Unmonitored level crossings on bicycle connections are possible at quiet crossings, particularly outside of built-up areas. Motorized traffic, which causes the majority of collisions at these kinds of crossing, can be excluded by means of physical measures (gate, tree trunk). Incidentally, the latter is not intended to imply that crossings where these facilities are not present should be closed just like that. Maintaining adequate level crossings is crucial to prevent severance effect, particularly with the requirements of cohesion and directness in mind, which are extremely important for cyclists.

The national crossings policy devotes attention to the severance effect caused by railway lines and to factoring in recreational interests when it comes to crossings not being actively protected. Recreational interests when it comes to modifying or changing a crossing are assessed through the Infrastructural Severance Effect Steering Committee, of which the recreational interest groups are a member. If the Steering Committee issues negative advice on a proposal to remove a crossing, then a risk assessment will be required in order to be able to develop this

proposal in more detail. In this regard, the guidelines as set out in CROW publication 299, 'Barrièrewerking van lijninfrastructuur' ('Severance Effect of Line Infrastructure'), apply [15].

Bidirectional cycle paths constitute an additional point for attention. Central traffic islands will be introduced here at the location of the level crossing. This will inhibit cyclists trying to cross the closed half barriers on the left when the barriers have just closed or if the train has just passed. On busy (school) cycle routes the recommendation is to make the traffic island as long as the average queue of cyclists. This will help to prevent cyclists or moped riders from passing the cyclists who are waiting.

At intersections between bicycle connections and railway lines, the angle between the railway tracks and cyclists' trajectory should be as close to 90 degrees as possible to prevent cyclists getting a wheel caught between rail and surfacing or slipping on the rails when the road surface is wet. A guideline minimum angle of around 60 degrees can be maintained. In the case of railway tracks that are only used sporadically (e.g. on industrial estates) it holds that where these intersect a cycle path the nuisance and the risk that this could present to cyclists can be reduced by introducing rubber inserts.

Literature

Figures between square brackets in the text – e.g. [1] – refer to the numbers in the bibliography below.

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7 Implementation, maintenance and furnishings

Infrastructure and other facilities for bicycle traffic are pretty much exclusively determined and designed by traffic engineers. The implementation and maintenance of these designs are undertaken by the operational services of decentralized authorities and the contractors enlisted by these services.

It goes without saying that it is crucial for workers in both disciplines – design and implementation/maintenance – to know their subject. Furthermore, it is desirable for traffic engineers and designers to have some rudimentary knowledge of implementation and maintenance. And conversely, for operational services and firms to have an understanding of the hows and whys of a cycle-friendly design. After all, only then will it be possible to efficiently achieve designs that meet their objective and last for a long time without the need for radical maintenance measures.

Designing with management in mind

The above means that traffic engineers, designers, operational services, contractors and highway authorities would do well to consult with one another in a timely manner and collectively deploy their knowledge. This will enable a great many problems to be prevented and existing bottlenecks to be remedied. For that reason, integrated designing with management in mind is the starting point.

In order to ensure cyclists always have a good road surface, it is important for the implementation and maintenance to be determined on the basis of the correct prerequisites. This calls for interdisciplinary harmonization between the parties responsible. Moreover, the departments involved must be au fait with the requirements being set for the bicycle infrastructure (quality requirements, technical requirements). Meaning that a degree of technical knowledge vis-à-vis the surfacing to be used will be required of the traffic engineers. Only then will they, in conjunction with the operational services, be able to ascertain the right prerequisites for aspects such as load-bearing capacity, surfacing, foundations and verge plants.

It is important for the operational services to have a good idea as to what quality requirements apply for the purposes of the bicycle infrastructure and to design this infrastructure in accordance with the normative load, the latter being pretty much always determined by different, heavier traffic. The department charged with taking care of the surfacing must be aware of the vulnerability of cyclists and the prerequisites for the bicycle infrastructure.

In the past, local authorities would perform a lot of (maintenance) work themselves. Nowadays, the vast majority of the activities are outsourced to market parties. The upshot of this is that authorities must see to it that the work is assigned to suitably qualified firms and that the contractual requirements have been set out satisfactorily. In other words, ensuring that not only operational services but also contractors are familiar with the requirements applicable to cycle-friendly infrastructure is desirable. The present Design Manual can provide the desired knowledge for operational services and contractors.

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The image type presented as an example above refers to relevant design sheets. These sheets are included in part two of this publication. A design sheet systematically presents the most important information on a facility (function, application, implementation, dimensions and more).

7.1 Road surfacing

7.1.1 User requirements

Where the five main requirements for cycle-friendly infrastructure (cohesion, directness, attractiveness, safety and comfort) are translated to the situation of road surfacing, then this pertains in particular to:

- evenness;
- skid resistance and texture;
- drainage;
- rolling resistance.

The choice of surfacing type will have a considerable impact on cyclists' comfort. Cyclists find smooth surfacing (made of asphalt or concrete) more pleasant and comfortable than open surfacing (made of tiles or paving stones). When choosing the surfacing, however, the road designer and the highway authority will have to deal with not only user preference but also a myriad of other aspects.

The costs of construction, management and maintenance play a significant role. These are determined by such factors as the load-bearing capacity and subgrade's susceptibility to subsidence as well as by the load caused by traffic. As far as the latter is concerned, it is not so much about the (negligible) load caused by cyclists but rather the potential load caused by:

- maintenance vehicles for management of roads, plants and ditches;
- winter service vehicles;
- emergency services vehicles;
- heavy goods vehicles intersecting at entrances and crossings;
- various vehicles making improper use of the surfacing.

Other factors that could play a role in the choice of road surfacing include:

- the surfacing's susceptibility to damage arising as a result of root growth and mole burrows and the attendant unevenness;
- the presence of subterranean infrastructure, in the form of sewers, cables and ducts (for example);
- the durability of the surfacing structure, in the sense of longevity with limited maintenance;
- the durability of the surfacing structure, in the sense of the reusability of construction materials;
- the appearance of the surfacing (in an historic centre or a rural setting, for example, special aesthetic requirements might apply).

These and other requirements will apply to segregated cycle paths, though also to roads for mixed traffic (with cycle lanes or otherwise). Where such roads are fulfilling an important function for bicycle traffic, a satisfactorily cycle-friendly road surfacing will also be required.

Evenness

How even the surfacing will be is something that will determine the horizontal and vertical vibrations experienced by cyclists. Evenness is extremely important for cycling comfort and, particularly where the evenness is inadequate, for safety. Unevenness can result in accidents if it causes cyclists to lose their balance. Furthermore, evenness (or lack thereof) is one of the factors determining the energy loss experienced by cyclists when in motion (which has to be made up for using muscle power). Block paving usually exhibits a greater degree of unevenness than asphalt or concrete surfacing. The joins between the elements in particular can cause significant discontinuities. With the increase in bicycle speeds (e-bikes, racing bikes), user requirements in terms of evenness are becoming more demanding.

Skid resistance and texture

A surface's skid resistance is extremely important to users. After all, skid resistance determines braking distance and stability in bends. On an insufficiently skid-resistant road surface, vehicle users will be incapable of stopping quickly enough. They will not have enough grip in bends, increasing the likelihood of skidding, slipping and falling.

Out of all infrastructure-related causes of single-vehicle bicycle accidents, slipping on a slippery road surface is the most significant. Slipperiness in winter is only part of the problem. It is often also the combination of slippery material and a wet road surface that causes accidents, examples including edges of prefab concrete slabs, manhole covers (particularly if these are slightly higher or lower than the road surface), rails, road studs and cat's eyes, a wooden bridge deck without a coating or natural stone paving.

How skid resistant the surfacing will be is largely determined by texture. The macrotexture provides space to retain (rain)water or dirt, enabling good contact between bicycle tyre and road surface. The microtexture is determined by the coarseness of the aggregate and the binder in the surfacing.

A fine brush finish is preferred for concrete surfacing. For the purposes of the top layer of asphalt surfacing, preference is given to gradings 0/6 or 0/8 (perhaps 0/11). Both of these provide the highest degree of comfort (the designation 0/6 means that the diameter of the aggregate particles in the asphalt mix varies from 0 to 6 mm). Block paving, such as baked paving bricks, concrete paving stones and concrete tiles, generally has a texture and skid resistance that will retain their quality. The skid resistance of paving materials such as natural stone or glazed tiles – which are primarily used for aesthetic reasons – is not always adequate. Consider in this regard such things as natural-stone cobblestones (polished by traffic). Even loose, coarse crushed stone, which is sometimes used when maintaining the wearing course, is highly undesirable.

Skid resistance can be measured by means of an NEN-certified method, such as FSC-2000. Measuring skid resistance with the road surface in a wet condition is always important. Further details and limits can be found in CROW publication 247 'Stroefheid van (weg)verhardingen' [1].

The texture is also important for the skid resistance of the surfacing in winter conditions and for the options in terms of winter maintenance. As far as common surfacing types are concerned, in the case of porous asphalt problems can particularly be expected when it comes to black ice, subsidence of the road and de-icing

Table 7-1. Properties of surfacing

Asphalt surfacing	Cement concrete
Cyclists most appreciate surfacing structures with a top layer of asphalt. This is due to the fact that such road surfaces consist of a single surface, thereby optimally guaranteeing evenness. For the purposes of skid resistance and rolling resistance, the top layer is particularly important in the case of asphalt surfacing. Drainage is usually not a problem with asphalt surfacing. However, it is essential for the asphalt track to have good foundations to ensure that no holes or ruts form. Cyclists will not cause any appreciable damage to asphalt surfacing. Nevertheless, it is extremely important to take other vehicles' usage of the surfacing (legal and illegal) into account. Consider in this regard the fact that a single heavy (maintenance) vehicle can have a tremendous impact on the quality of the surfacing (see also section 7.1.3). Such use could prompt a substantially thicker surfacing layer to be chosen than is necessary for cyclists alone. Good foundations (sufficiently thick and compact) are also important for preventing damage caused by tree roots and unevenness caused by mole burrows.	Concrete surfacing provides a great deal of evenness and therefore comfort for cyclists. The precondition here is that contraction joints, expansion joints and construction joints are installed carefully. As far is skid resistance is concerned, concrete cycle paths generally present no problems. A fine brush finish is preferred for concrete surfacing. In principle, drainage is not a problem in the case of cement concrete. Due to the material's considerable durability, the chances of holes or ruts forming is minimal, meaning that cement concrete scores better than asphalt on this aspect. In addition to their relatively significant degree of bicycle-friendliness and durability, concrete cycle paths have the advantage of hardly ever needing maintenance work done on them. Compared to other types of surfacing, concrete is not particularly vulnerable to tree roots, even though the roots of some species of tree can also affect concrete cycle paths over the long term. One point for attention is to bevel the edges of the concrete surfacing. These are often created with an angle of 90 degrees. Cyclists who end up on the verge will not be able to steer back onto the cycle path safely. Constructing concrete surfacing on weak subgrade will considerably increase the probability of damage being caused by heavy vehicles. One disadvantage of concrete is the high price of construction.

salt in the pores. Problems are also likely in the case of bridge decks and other structures without a subgrade, as these cool down more rapidly at night and so condensation will more readily freeze on them [7].

Drainage
Due to the fact that cyclists are not protected from the elements by an enclosing structure, good drainage is crucial. Riding through puddles is not only uncomfortable, it is also unsafe. After all, puddles can hide the underlying road surface, meaning that cyclists will be unable to spot any (deeper) holes or ruts. Hence puddles can result in swerving manoeuvres unpredictable to other traffic and potentially in falls. Wet road surfaces are also more slippery. Good drainage can be achieved by having the road surface slope gently in one or two lateral directions and by seeing to it that the road surface remains adequately even (see also above under Evenness).

Rolling resistance
Rolling resistance is primarily determined by the nature and condition of bicycle tyres, the nature of the road surface and the interaction between these. In the case of tyres at the right pressure (properly inflated), rolling resistance is at its

Table 7-1. Properties of surfacing (cont.)

Concrete tiles	Paving stones
Tile surfacing can be used on subgrade with good load-bearing capacity. Nevertheless, due to its many joints such surfacing can be less even than asphalt or concrete surfacing. Making it less cycle-friendly. These disadvantages increase the older the tile surfacing gets, particularly if regular maintenance is not carried out in a timely fashion (which is more the rule than the exception). Tiles in bicycle connections must be a minimum of 6.0 cm thick. Tiles thinner than 6.0 cm will shift too easily and are more likely to be damaged by maintenance vehicles during maintenance work too. The recommendation is to always use kerbing, with the top of this having to be flush with the top of the tiles. The kerbing is necessary to prevent damage to the edges of the cycle path and to prevent wide longitudinal joints. Tiles should be laid transversely, in order to avoid inconvenient longitudinal joints. Tile texture is generally good, meaning that skid resistance is assured. In the case of tile surfacing in particular, special attention should be given to ensuring good drainage. If this is lacking, then rainwater will seep into the joints, rinse the sand under the tiles away and the tiles will start to become loose This will make it even easier for the water to get in under the tiles, which will rapidly diminish the quality of the tile path. Tiles can also come loose in the event of protracted dry spells, particularly on hard subgrades such as on bridges. Instead of tiles, larger elements can also be used. The use of concrete slabs the same width as the cycle path will result in fewer joints than would be the case using tiles. Cable and duct managers can take those slabs out whole and then replace them again. In addition, attention should be given to ensuring a good (even) transition into the other slabs not lifted.	The evenness (and, therefore, the comfort) of paving bricks and concrete paving stones is similar to that of tiles, but users rate it slightly less favourably. Consequently, just like tiles the aforementioned materials should only be used for cycle paths in exceptional cases. Paving bricks are common on streets for mixed traffic. When such a street forms part of a through bicycle connection, asphalt is preferred from the perspective of bicycle-friendliness. The skid resistance of concrete paving stones is usually good, but when using paving bricks in streets for mixed traffic the designer will have to take into account the fact that baked paving bricks can be slippery during wet weather and frost. This is less of an issue with concrete paving stones. Another important thing is for stones and paving bricks to be 'laid straight', so that the joints are not too wide. As with tiles, the use of kerbing is also important with paving stones to prevent damage to the edge and the surfacing starting to shift, thereby increasing joint width.

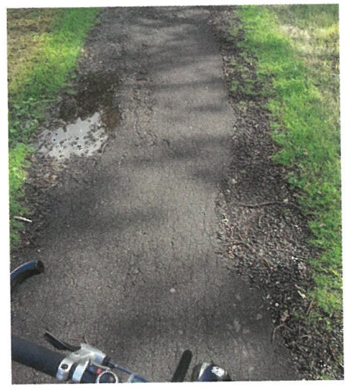
least. Furthermore, narrow tyres will experience less resistance than wide ones. On a fine-textured, even, smooth surface, rolling resistance will be minimal. Unevenness, open surfacing (paving bricks and tiles) and surfacing with a coarse texture will produce a higher degree of rolling resistance.

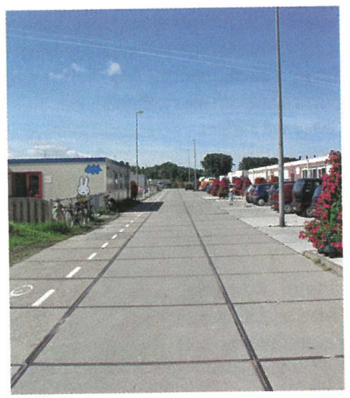
7.1.2 Types of surfacing

In most cases, a designer will be able to select from four options for the purposes of surfacing a cycle path: asphalt, cement concrete, concrete tiles and paving stones. A survey of cyclists carried out by KOAC • NPC (the research centre for surfacing) [2] reveals that they rate asphalt with an 8.5 out of 10, cement concrete with a 7.5, concrete tiles with a 6+ and paving stones with a 6−. This always pertains to the median value: the value at which 50% of the measurement values is better and 50% is worse. Table 7-1 describes the most important properties of the four types of surfacing specified.

In recreational areas, it will sometimes be the case that loose-fill road surfaces suffice too, such as well-prepared clay paths or well-maintained shell paths. Furthermore, there are myriad new surfacing materials being developed








which have the capacity to generate heat or electricity. In this respect, too, adequate skid resistance, evenness and drainage will continue to be important.

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As stated, cyclists have a clear preference for smooth surfacing types, such as asphalt and concrete; the explanation for this is that they have the greatest degree of evenness and the least resistance, thereby ensuring maximum comfort. These materials are also held in high regard by highway authorities, as they require the least maintenance (relatively speaking) and the surface stays even for a long time. Block paving, such as paving bricks, concrete paving stones and concrete tiles, generally retain a good texture and skid resistance, but they are manifestly less even than asphalt or concrete surfacing. As an aside, baked paving bricks score less well in terms of skid resistance in winter than the other types of block paving. If block paving is to be chosen anyway, then it would be advisable to combine this with good edging.

7.1.3 Choice of surfacing type

Aside from cyclists' preference for asphalt or concrete surfacing, a myriad of other aspects play a role in the choice of surfacing type [2]. The most important of these are:

a road safety;
b dimensions of surfaces;
c foundations;
d risks of damage due to plant growth;
e cables and ducts;
f rainwater drainage;
g appearance of the surface;
h materials;
i costs.

Each of these aspects will be briefly explained below.

a. Road safety

Traffic engineering considerations could provide grounds to opt for a certain type of surfacing. Block paving is generally preferred within the compass of ensuring recognizability for residential roads, for instance. 'Normal' paving materials, such as baked paving bricks, concrete paving stones and concrete tiles, generally retain their good texture and skid resistance well. The skid resistance of paving materials such as natural stone or glazed tiles – which are in common use these days – is not always adequate. Choices made in terms of spatial quality may not result in increased risks to cyclists' safety. From the perspective of road safety, preference is given to rough, even surfaces with a safe join between verge and surfacing (bevelled edge and at most a few centimetres difference in height between verge and surfacing).

b. Dimensions of surfaces

In the case of the dimensions of surfaces for cycle paths, the traffic load caused by cyclists is rarely taken as indicative. In order to prevent damage due to excessive stress, the use of the surface on the part of heavy vehicles will have to be examined. It is frequently impossible to prevent such traffic. Consider in this regard winter maintenance, maintenance of the surfacing, verges, plants and adjacent watercourses (for example). Consider that cycle path surfacing is sometimes used improperly by motorized traffic too.

As far as resistance to heavy vehicles is concerned, there is a general preference for surfacing made of asphalt and concrete. This enables the level of cycling comfort to be satisfactory for a long time. It does, however, require a thicker surfacing layer than would be necessary for cyclists only. In the case of subgrades with an extremely low load-bearing capacity, tile surfacing (even with foundations) should only be considered if it definitely does not have to support any heavy axle loads.

c. Foundations

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As stated above, it is usually other heavier traffic than cyclists that is indicative when it comes to the load exerted on cycle paths. Hence it is advisable to use a foundation under the surfacing. A foundation will reduce not only the probability of subsidence but also the risk of edge damage and damage due to tree roots and mole burrows. Furthermore, using a foundation will improve the quality of concrete and asphalt surfaces. The firm subgrade makes it possible to compact the asphalt or cement concrete better.

A foundation must be sufficiently wide. If the foundation is wider than the surfacing, then this will not just combat edge damage. It will also reduce the probability of single-vehicle bicycle accidents. After all, the firm verge will enable cyclists to correct their course when swerving or making incorrect steering manoeuvres. Moreover, it is important for the surfacing as a whole to be sufficiently wide. Then it will not be necessary for maintenance vehicles to drive with a track through the verge, which often causes damage to the edge and/or the verge.

d. Risks of damage due to plant growth
Trees alongside roads, cycle paths and pavements make the streetscape more appealing, provide guidance for road users as well as shelter for cyclists and pedestrians. Unfortunately, trees can also damage the surfacing. Root growth in and under the surfacing structure can have undesirable consequences, such as damage to the surfacing and the kerbing, loss of load-bearing capacity and subsidence of the surfacing. CROW publication 280 'Combineren van onder- en bovengrondse infrastructuur met bomen' [3] extensively examines the many problems in this area as well as possible solutions. A few main issues will suffice here.

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Undesirable root growth in the surfacing structure could be caused by the following factors (or a combination thereof):
- The tree is too close to the road structure.
- The tree has insufficient space in which to grow roots in the desired spot.
- The surfacing structure is inadequately protected against root growth.

Due to their usually delicate surfacing structure, cycle paths are particularly sensitive to root growth. Condensation on the underside of the surfacing attracts root growth. Even organic material washed in, particularly in the case of block paving, is attractive to tree roots. The consequence of root growth is that in time the surfacing is pushed up. This subsequently results in unevenness and cracks, which can have a detrimental effect on safety and comfort.

Pruning off tree roots is seldom a permanent solution. Roots usually grow back within a year and the problems of tree root damage begin again. A foundation of rubble or another coarse material will produce a better result. In general, this produces less condensation under the surfacing than when using sand. For that reason, confining efforts to use of a bed of sand is discouraged.

Other options for preventing or limiting damage caused by root growth include:
- using root-guiding or root-deflecting barriers;
- adapting the surfacing structure by means of tree sand or tree granulate in the foundation;
- using a sandwich structure;
- using a growth site structure (root cage).

The best solution will depend on many factors, including whether the matter in hand pertains to renovation or new construction work. In all circumstances it is essential to choose an integrated approach early on in the design phase, with tree experts and civil engineers working together to develop the optimum solution [3].

Mole burrows under and directly alongside a cycle path can also cause cracks. If part of the foundation has been dug away, then the surfacing will no longer be evenly supported. If a heavier vehicle subsequently uses the cycle path, then this could cause dents and cracks. A nutrient-poor, coarse foundation will help to prevent moles from digging alongside and under cycle paths.

e. Cables and ducts
In general, cables and ducts should be laid under cycle paths as little as possible. Within built-up areas, these should preferably be laid under pavements. Outside of built-up areas, they can be located in the road verge (where no trees or shrubs have been planted). Sometimes special cable and duct conduits are advisable, but they are usually not feasible.

Whenever cables and pipes are under surfacing or are planned to be there, grid operators prefer block paving without road foundations. This will render the subterranean infrastructure relatively quick, easy and inexpensive to access. Asphalt or concrete surfacing, foundations and plants increase the costs of laying and maintaining cables and ducts. They also hamper repair work, as a result of which more time is required to rectify faults. This has consequences for society. Sometimes surfacing and plants can jeopardize the (safe) functioning of cables and ducts. To be sure, this is primarily the responsibility of the grid operator, but repairing the surfacing after trench work is a concern for the highway authority. The latter must also see to it that the road surface is not subject to 'degeneration' because of that work.

The fact that both grid operators and highway authorities are serving the public interest renders optimization desirable between the costs of the (cycle path) surfacing and regular maintenance to it on the one hand and the costs of the cables and ducts and accompanying maintenance on the other, including any digging up and repair of the surfacing on top. Furthermore, during this optimization process the interests of road users (especially the comfort factor for cyclists) must be balanced with the interests of the users of cables and ducts (reliability of supply, consequential losses in the event of delays to repair work). The public space authority has a coordinating role in this consideration of interests.

In general, the landowner/highway authority is free to choose what type of surfacing to use. If a grid operator does not wish for his subterranean infrastructure to be situated underneath this, then it is usually the case that he will not be able to force a different type of surfacing to be used. He can, however, elect to relocate the cables and ducts. Whether the costs of doing so will be borne by the grid operator or by the highway authority, or otherwise be divided up according to some ratio, is a matter that will depend on agreements and regulations. These could vary considerably for each local authority and each highway authority. Hence the question for the highway authority is not so much 'may or can I create asphalt or concrete surfacing over cables and ducts?' as 'what will I be paying in relocation costs if I introduce asphalt or concrete surfacing in a location where there are currently cables and ducts?'. In this regard, it is imperative to look at the availability of alternative routes and the consequences of these for such things as plants.

Whenever a grid operator wishes to lay new cables or ducts or to reconstruct existing cables and ducts, he must inform the public space authority of this in writing. The interests of both grid operator and public space authority can be harmonized by means of timely consultation. One additional benefit is that this will enable the planning of the work to be managed better, thereby preventing overrunning. Solid agreements ensure that the inconvenience caused to cyclists by excavation work is minimized and that good repair of the cycle path is guaranteed following maintenance [4, 5].

Gas pipes constitute a special group within the compass of cables and ducts. In the case of a leak in a gas pipe under asphalt or concrete surfacing, gas could accumulate underground or escape into any crawl spaces in nearby houses.

This could lead to a risk of explosion and asphyxiation. It is therefore imperative that gas be able to escape into the open air if a gas pipe is located under asphalt or concrete surfacing. For the purposes of cycle paths, porous surfacing material will enable gas to pass through [6].

f. Rainwater drainage
Rainwater must be able to flow smoothly off the road surface everywhere. In order to achieve this, it will be necessary for the road surface to have sufficient camber (i.e. not be completely flat in the horizontal plane). Asphalt or concrete surfacing, particularly if made from cement concrete, will normally retain its camber for a long time and will not be susceptible to developing unevenness (potholes, ruts). Block paving usually has parabolic camber, with a curved slope in both lateral directions. In the case of these types of surfacing there is a chance that, under the influence of (relatively) heavy traffic, root growth or subsidence (for instance), proper drainage will be disrupted. Regular inspection and timely maintenance are required. In contrast to smooth surfacing types, with block paving a limited proportion of the rainwater will seep into the underlying structure. This must be taken into account and should therefore be capable of providing sufficient stability even in a wet condition.

g. Appearance of the surface
A road's surroundings can set special requirements in terms of the surfacing. In an historic town centre, for example, it could be desirable to use baked paving bricks or cobblestones. Thus 'sacrificing' a degree of comfort for cyclists. Such a measure will only be acceptable if it applies to *all* road users. Furthermore, a great deal of restraint is called for if it pertains to a main cycle route. In such cases, cyclists' comfort and safety may not suffer any appreciable detrimental effect. This can sometimes be ensured by devoting extra attention to making the subgrade and block paving as tight as possible. Aesthetic aspects are examined in more detail in 7.1.4.

h. Materials
Highway authorities also set requirements for the sustainability of the surfacing structure. Both in the sense that surfacing structure must function adequately for a long time with limited maintenance, and in the sense that materials should preferably be reusable or recyclable. These fundamental principles could provide grounds not to use any high-maintenance materials and structures and to select materials that can be reused.

i. Costs
Cost comparisons often unjustly consider investment costs only. An accurate cost comparison is only possible if all life cycle costs are taken into consideration. Hence the costs of minor and major maintenance work, annual management (including winter maintenance and weeding) and the residual value or demolition costs at the end of the planned life cycle will also need to be included. One of the things that will then become evident is that surfacing made of asphalt and cement concrete is cheaper than block paving (including the recommended kerbing). Incidentally, the results of the cost comparison are partly dependent on the traffic load and the subgrade, because they determine the requisite layer thicknesses of the various layers of materials.

As far as weeding is concerned, asphalt or concrete surfacing is unequivocally preferred over block paving. The probability of slipperiness is generally highest in the case of block paving [7]. When digging up surfacing, elements can often be largely reused, with little in the way of extra costs. Hence block paving can have a clear residual value. Asphalt or concrete surfacing can be processed to create granulate, which can be reused as a secondary, high-grade raw material. Nonetheless, asphalt or concrete surfacing has pretty much no residual value for the owner (the highway authority).

Weighting table
A wide array of factors influence the choice of surfacing type. As these factors differ so markedly, they cannot be measured against the same yardstick. In order to nevertheless introduce order and cohesion, the Fietsberaad combined the influencing factors in table format as part of a study of the bicycle-friendliness of surfacing types [2]. In this regard, relative ratings (++, +, 0, -, --) were assigned to the various types of surfacing for each aspect (see table 7-2). Furthermore, the highway authority can calculate a weighting factor for each aspect according to his own insight (second column in the table). In this respect it would be good to not just look at the bicycle-friendliness of the surfacing structure but also to devote attention to the life cycle costs and sustainability aspects (including the carbon footprint). The table can be used as an initial guideline for the purposes of choosing surfacing.

Table 7-2. Weighting table cycle-friendly surfacing [2]

		Type of surfacing structure											
		no foundations				unbound foundation *				bound foundation **			
Aspect	weighting factor ***	asphalt	cement concrete	concrete tiles	paving stones	asphalt	cement concrete	concrete tiles	paving stones	asphalt	cement concrete	concrete tiles	paving stones
Load-bearing capacity [1]		+	+	––	–	++	++	–	0	++	++	–	0/+
Driving/riding comfort		+	+	–	–	++	+	–	–	++ [4]	+	–	–
Accessibility of cables and ducts [1]		–	–	++	++	–	–	+	+	––	––	–	–
Aesthetic quality after repair		0	––	+	+	0	––	+	+	0	––	+	+
Probability of damage due to tree roots [2]		––	–	––	––	++	++	0	0	++	++	0	0
Probability of damage due to excessive physical stress [1,2]		0	––	––	–	++	+	–	–	++	+	–	–
Probability of damage from foundations [1,2]						0	0	0	0	+	+	+	+
Probability of consequential damage [1,2]		0	–	––	––	+	0	–	–	+	0	–	–
Probability of weed growth [2]		+ [3]	+	––	––	++ [3]	++	–	–	++ [3]	++	–	–
Ease and speed of minor maintenance work (local repairs using the same material)		–	––	+	+	––	––	0	0	––	––	0	0
Ease and speed of major maintenance work		++	0	0	0	+	–	–	–	0	––	––	––
Costs of construction [1,5,6]		+	–	0	0	0	––	–	–	0	––	–	–
Costs of management and maintenance		+	+	–	–	+	+	–	–	+	+	–	–
Demolition costs minus residual value of materials		+	+	++	++	–	–	0	0	––	––	––	
Winter maintenance	only porous asphalt less favourable												
Appearance of the surfacing	largely dependent on local integration and preferences												

1) depending on layer thickness used
2) ++ = most favourable, hence little chance of damage
3) with the exception of porous asphalt
4) if the risks of damage vis-à-vis stains and bumps have been covered effectively
5) largely dependent on the need to use kerbing
6) ++ = most favourable, hence cheapest

* The table distinguishes between bound and unbound foundations. Unbound foundation material consists of loose granules, without binding agent (e.g. crushed masonry or broken natural stone). Bound materials exhibit a high degree of cohesion, usually due to adding a few percentage points of cement, bitumen or another binding agent.

** A bound foundation directly under the asphalt is less desirable due to the risk of reflective cracking from the bound foundation. In the case of open surfacing, in the form of tiles, paving stones or paving bricks, the probability is high that these will loosen on a bound foundation, resulting in 'rattling' or becoming dislodged.

*** To be decided by highway authority.

7.1.4 Aesthetic aspects

As stated earlier on, from the perspective of safety and the comfort of cyclists, asphalt or concrete surfacing is clearly preferred. From the point of view of cultural-historic considerations, landscape integration or urban planning quality, however, other types of surfacing are occasionally chosen. Examples include baked paving bricks, block paving, glazed tiles, natural stone, shells or clay.

In particular, the evenness and skid resistance of these materials have the potential to be under par, jeopardizing safety and the comfort of cyclists. For that reason, such materials are discouraged for main cycle routes. Only in exceedingly valuable environments, such as a protected townscape/cityscape or an area of outstanding natural beauty will deviation from this principle be allowed. But even then the recommendation is to look for alternatives that are less unfriendly to cycling, such as asphalt with a pea-gravel wearing course or a colour that does not clash with the surroundings. It goes without saying that such choices will also have to be used on any other carriageways (or sections thereof).

Recreational routes often pass through nature reserves or farmland. With a view to fostering cyclists' comfort and ease of maintenance, here too preference should be given to asphalt or concrete surfacing, and given the likelihood of damage caused by tree roots, perhaps even more than in other environments. If use of asphalt or concrete has to be relinquished in extremely fragile areas, then porous loose-fill road surfaces and surfacing made of clay or shells can be considered. However, these types of surface are sensitive to joint use by motorized traffic (including agricultural vehicles) and susceptible to weed growth. Hence regular maintenance will be required. One alternative is to only surface the ruts (made by motor vehicles). If asphalt or concrete surfacing is chosen for this purpose, then the advantages of this will be that the surrounding area retains its rural character, that cyclists have an even surface and that the surfacing has considerable durability.

7.1.5 Colour of the surfacing

Colour is a tool enabling the designer to make something clear to road users. Red is now the 'national norm' for cycle paths and cycle lanes, even though there is no statutory basis for this.

In fact, any colour is permitted. Using colours (including red) will make a cycle facility more readily recognizable and support the continuity of a through route. It is supposed that this has a beneficial effect on cycling comfort (ease of use) and road safety. Nevertheless, none of this has been unequivocally corroborated by research [16, 17, 18, 19].

There are also disadvantages associated with using colours on road sections. It has already been mentioned that designating cycle lanes can increase the speed of motorized traffic. Furthermore, the colour and markings of the channelled space can give an impression of the uncoloured space being reserved for the exclusive use of cars. And that is not necessarily the case. Moreover, as opposed to edge lines, the colour red does not contribute to ensuring contrast between surfacing and verge. Neither does it foster the visibility of the course of the cycle path or road.

The colour's durability will depend on the method of application (coating, wearing course or coloured asphalt layer). The transition between the red asphalt of a cycle lane and the black asphalt of the carriageway merits special attention. It is common for the first signs of wear and tear to the asphalt to occur here. Subsequently, the asphalt can continue to crumble more and more, creating deep longitudinal potholes. The cause of this is freezing moisture in the seam between both asphalt mixtures. Consequently, this must be properly sealed.

The following recommendations apply for the purposes of using coloured surfacing:

- Make cycle paths alongside roads and cycle lanes red. Red will be less of a necessity for segregated cycle paths.
- In order to emphasize right of way, continue the red surfacing on cycle lanes and cycle paths at the point of a side road across the junction area. If cyclists do not have right of way, then continuing the colour and markings will be highly undesirable.
- Red asphalt surfacing can be continued over the entire width of the road if the car's role is a subordinate one. This could be the case on a bicycle street, for example, or in a shopping precinct where only loading and unloading are permitted.
- In places where two main cycle routes interchange, the entire junction area can be coloured red (merging platform).

In all other situations, the use of coloured asphalt surfacing will be confusing and so it is undesirable.

7.1.6 Transitions between surface and verge

Ideally, cyclists will keep to carriageways or cycle paths. Nevertheless, many (unexpected and undesirable) situations can arise in which a cyclist veers onto the verge (or nearly does so). It is important for him to be able to keep his balance in such a situation and not fall. For that reason, a good transition between surfacing for bicycles and verges is necessary.

In particular, the difference in height between the cycle path and the verge is important when it comes to preventing single-vehicle bicycle accidents. A verge can be worn down by tyres, for example, creating a(n elongated) pothole right next to the cycle path. Another option is to have the asphalt on the cycle path a little higher than the verge. The edge of the surfacing can begin to crumble or crack due to subsidence on the part of the verge, for example. It is important that the edge of the surfacing is bevelled off. Concrete in particular can sometimes have sharp edges. Even with minor differences in height, these make it tricky to get back off the verge and onto the surfacing.

There are various options for preventing or limiting the incidence of undesirable situations:

- Ensure that the verge dovetails neatly with the surfacing without any difference in height.
- Maintain an obstacle-free space of at least 0.5 m. Around one quarter of verge accidents involve the cyclist hitting an obstacle sited on the verge, particularly lamp posts and trees.
- Use surfaced or loose-fill verges. Doing so will ensure that cyclists are less likely to fall if they veer onto verges. Furthermore, the verge will be less quick to become worn down by motor vehicles and form holes.
- See to it that once new asphalt has been applied the verge and the top of the asphalt are flush, or that an unavoidable difference in height is spanned. Highway authorities would do well to include provisions on this in asphalt specifications as standard. This will prevent the new asphalt causing a shift in terms of problems: the new road surface may well be even and safe again, but the verge (or the transition onto the verge) has now been rendered more dangerous [8].
- Install a fence or railing if particular situations call for this, e.g. if there is a slope a short distance away.

7.1.7 Transitions between surfaces

Bumps and potholes can cause cyclists to lose their balance and contribute to single-vehicle bicycle accidents. In this regard, attention also needs to be given to transitions between road surfaces. These are found in such places as junctions, exits and speed bumps, as well as where bicycle connections lead onto roads for mixed traffic. Furthermore, transitions containing elements, such as manhole covers in the surfacing, will require attention.

It will be self-evident that the connection between two different types of surfacing must be as even as possible, with a practically imperceptible transition (≤ 3 mm difference in height). If a transition is not constructed properly, then this will not only be uncomfortable but also unsafe; after all, cyclists at junctions and suchlike are focused on traffic, and may therefore find themselves getting a nasty surprise if there is any unexpected unevenness.

It is desirable at junctions to ensure that the surfacing of the priority road is continued and that the surfacing of the side road is interrupted. The same goes for cycle paths: if they have right of way, then the surfacing should be continued and that of the side road interrupted. However, in situations where an intersecting main cycle route has right of way, the surface of the side road (i.e. the main cycle route) should be continued over the junction so as to support the anomalous right of way regime. This does not apply to situations in which a side road or solitary cycle path (the main cycle route) intersects a distributor road. In such cases, the main cycle route should not be given right of way [9]. See also section 6.3.

Unevenness is particularly common at exits because in such places the cycle path's foundations have not been fine-tuned to the heavy intersecting traffic. For that reason, providing proper foundations for cycle paths at exits is recommended.

Various materials can be slippery, especially once rainwater is involved. Examples include iron drive ramps and prefab concrete slabs used in roadworks, manhole covers, fluorescent cat's eyes, metal road studs, markings, wooden cycle bridges without a wearing course, cobblestones (partly due to the significant unevenness of this surfacing) and other forms of ornamental paving. Manholes, storm drains and suchlike are a common cause of unevenness: creating an even road surface is difficult around a drain or manhole and sometimes the road subsides while the drain or manhole does not.

In order to prevent significant unevenness, dangerous swerving manoeuvres and skidding, the designer should bear the following points in mind:

- Avoid having manhole covers, (thermoplastic) markings (such as at pedestrian crossings) and transitions between surfacing materials in bends.
- Do not situate drains in carriageways, cycle lanes or cycle paths but rather in pavements, gutters, parking lanes or adjacent verges.
- Preferably do not situate other drains, such as those for sewage or water pipes, in places where cyclists are riding. This applies to cycle paths, cycle lanes and the right-hand side of the carriageway. If it will prove unavoidable to situate drains in such places, then even transitions will be a prerequisite. Selecting a flat type of manhole cover will enable discomfort to be limited.
- When applying a new layer of asphalt, prevent manhole covers from 'ending up in a hole' (due to the surrounding asphalt having been raised).
- Never use prefab concrete slabs on road sections that cyclists use. Prefab concrete slabs are virtually guaranteed to subside, thereby creating differences in height. Furthermore, the metal edges are smooth (particularly in wet weather) and the temporary situation often persists for longer than was expected.
- Preferably screen off trams from bicycle traffic physically. Where it will not be possible to do so, use visual separation, e.g. different surfacing materials or clear markings. Cycle crossings and routes intersected by trams should preferably be at right angles to the rails, with a minimum angle of incidence being 60 degrees.
- Always install warning signs at temporary transitions and in temporary situations where slipperiness could occur [10, 11, 15].

7.1.8 Material for markings

Markings are intended to guide road users and to clarify traffic situations. For that reason it is essential for markings to be properly situated, recognizable and visible. This particularly applies to markings for cycle facilities: they must make clear where other road users could expect cyclists to be. In addition, there are markings that primarily have a function for the cyclists themselves: edge lines to delineate the road alignment and central markings on bidirectional cycle paths to make clear that oncoming bicycle traffic can be expected.

Markings made of thermoplastic material and two and three-component cold plastic are the most durable. They are easily visible in all conditions, retain their colour and are not particularly susceptible to wear and tear. In the case of a wet road surface, these materials are sufficiently skid-resistant on straight paths, though in bends the skid resistance of thermoplastic is critical.

One disadvantage is that thermoplastic sticks up by around 3.0 mm over the top of the surfacing. This is to the detriment of evenness. Cold plastic and sprayplastic can be applied with a thickness of around 1.5 mm. When using thermoplastic, preference is given to applying the markings in such a way that cyclists will generally be able to avoid it. To that end, thermoplastic block markings cannot be used on junctions, instead being applied next to the cycle lane.

Due to the critical skid resistance in the event of wet road surfaces in bends, lateral markings (such as pedestrian crossings) in bend should not be applied in thermoplastic. Longitudinal markings, such as central markings, can be applied in thermoplastic.

During construction work, plastic materials are more expensive than road paint, but they are cheaper to maintain. On junctions in particular, where markings are subject to a relatively high degree of wear and tear, preference is given to thermoplastic or cold plastic. When applying these to surfaces such as concrete, paving bricks and slightly older, porous asphalt, the use of an undercoat (primer) is recommended.

Profiled marking materials can be used to further emphasize the division between cycle lane and carriageway and to introduce bollards on the cycle path.

White paving stones can be laid as markings in block paving. The disadvantage of this is that they will be less visible than thermoplastic, and white paving stones look dirty more readily. Due to their lack of evenness and skid resistance, the use of road surface reflectors as permanent markings for cycle facilities is discouraged.

7.2 Verges and plants

In general, the use of plants is intended to bolster the landscape features of an area and make it more pleasant to live in. The following functions apply specifically to cyclists:

- making cycling and residential environments more pleasant;
- providing shelter by reducing wind nuisance;
- reducing dazzling from oncoming motorized traffic;
- screening off motorized traffic visually (in places where a cycle paths is situated alongside a carriageway).

In contrast to these positive effects, there are also disadvantages. These are primarily in the sphere of social control and safety. Plants alongside bicycle connections can:

- hamper the view (and monitoring) of the bicycle connection from the surrounding area and/or from the carriageway nearby;
- hamper or eclipse cyclists' view of the surrounding area;
- provide a place to hide for people with malign intentions;
- restrict cyclists' view of one another or other traffic. This is particularly the case in bends, at junctions and at exits. Consider also the backdrop effect of a row of trees alongside a road;
- damage the road surface, particularly due to root growth;
- constitute inconvenient obstacles to bicycle traffic, e.g. if trees are too close to the side of the road or cycle path;
- inhibit traffic flow due to overgrowth;
- soil the road surface due to falling leaves, flowers, fruit and suchlike.

Whether the pros will outweigh the cons is something that will depend on many factors. A few of these include the way in which the bicycle connection is used (for utilitarian purposes or recreationally) and the environment in which the bicycle connection is located. When using plants, there must always be (permanently) adequate visibility of oncoming traffic in bends. In addition, viewing angles must be safeguarded at junctions and exits.

Verges

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Verges alongside cycle paths must be 'forgiving' and may not contain any objects that hinder cyclists. To this end, an obstacle-free space of at least 0.50 m must be maintained. This also means that plants are to be cut back to at least 0.50 m from the edge of the surfacing. Naturally, sufficient unhindered height is important too.

The section of the verge right next to the cycle path must be even and firm and at the same height as the cycle path, particularly if the cycle path is narrower than 2.50 m. A reinforced verge will reduce the probability of an accident if a cyclist ends up straying from the cycle path due to a swerving manoeuvre. This is one of the reasons to make the foundations wider than the surfacing. Thus preventing an immediate fall if a cyclist strays from the surfacing and hits a soft verge.

Grasscrete tiles are sometimes used alongside the carriageway for the benefit of motorized traffic. This form of verge surfacing can also be installed alongside cycle paths, on the proviso that the tiles are laid flat side up.

Plants
Adequate sight distance prevents a feeling of claustrophobia. For that reason, maintaining a view in all directions is desirable. Dense shrubbery should be kept at a sufficient distance (> 3.00 m) from the bicycle connection. Due to the fact that in time bushes can grow up to around 2.00 m from their stems, young bushes must be planted at least 5.00 m from the bicycle connection. If there is not enough space for this, then no upright bushes should be planted, opting instead for vegetation that will not hamper the view, such as trees or ground cover. In this regard, do bear in mind (particularly at crossings) the backdrop effect; this increases the thicker the trees get. It is advisable to select species whose roots will not damage the cycle path (see also 7.1.3, under d). Always plant trees at a sufficient distance from the edge surfacing, taking into account their ultimate size.

Informal monitoring and social control from homes or from the main carriageway can scare off potential assailants and give cyclists a (greater) sense of safety. For that reason it is imperative to prevent upright bushes from obstructing the view of cyclists from the carriageway or from nearby homes.

Sight lines
Aside from personal safety, road safety also plays a role. Plants may not interrupt the requisite sight lines. This applies to (horizontal) bends and at junctions. Upright bushes are undesirable in the vicinity of junctions. They grow so rapidly that they frequently have to be cut back to maintain adequate sight distance. Ground cover and low-growing shrubs are suitable, as are solitary trees. It is advisable for the local authority to have the General Municipal By-laws (*Algemene Plaatselijke Verordening*, or APV) in order on this point so as to enable legitimate action against landowners who do not adhere to the aforementioned guidelines.

7.3 Lighting

7.3.1 Lighting according to function
The principal functions of lighting are:
- to make the setting visible;
- to enhance comfort (including for cyclists);
- to improve traffic flow;
- to improve personal safety;
- to increase people's attentiveness in unsafe situations;
- to increase the contrast between vehicle path and verge.

(Main) cycle routes
(Main) cycle routes are most intensively used within the network of connections between villages, towns, neighbourhoods and districts. Hence high requirements are set for these connections in terms of comfort and personal safety, as well as lighting. For that reason, lighting is always recommended for main cycle routes. In this regard, it holds that the higher the design speed is, the greater the requisite sight distance will be, which could in turn have an effect on the level of lighting.

Outside of built-up areas in particular it is not always effective and desirable to have the lights permanently on full power. Consequently, technologies have been developed to enable the level of lighting to be adapted to the presence or absence of cyclists. With a view to maintaining personal safety, it is important for this not to be done (overly) abruptly, so as to prevent a 'spotlight effect'.

Basic network
Regular street lighting usually sufficed for the basic network. The use of new lighting technologies, which entail the light being far more targeted, makes it possible that cycle paths will end up having less light shone on them, as a result of which they will be too dark for sufficient contrast to be visible. Sometimes a solution can be to only illuminate the cycle path (and not the main carriageway) or to introduce markings on the cycle path.

The function of the lighting is primarily to enable road users to get their bearings. With a view to maintaining personal safety, particular attention should be paid to illuminating shortcuts and (by-)paths out of sight of local residents and other traffic.

At crossings for cyclists and/or pedestrians, lighting must be selected that ensures the point of illumination is above or behind the crossing. Lamp posts on segregated cycle paths should be installed on one side of the road (ASVV 2012; [12]). Cycle references should be indicated on general signage (as well as) on illuminated road signs [10]. Bicycle fingerposts and combined bicycle signs should be in retroreflective material (class III). Where lighting is completely absent, consideration must be given to installing local lighting at hazardous points, such as junctions or obstacles (whether or not these are the result of roadworks).

Recreational network
Recreational cycling trips are usually something done during the day. For that reason it is unnecessary to light recreational cycle paths. Lighting is even undesirable in valuable nature reserves. If lighting is needed there anyway for reasons of personal safety, then ecodynamic lighting can be used. This entails the colour of the LED lighting being adapted to the setting, thereby minimizing disruption to the flora and fauna.

7.3.2 Lighting related to location and usage
If the lamp posts for the main carriageway provide adequate lighting for the route for cyclists, then no separate lamp posts will be necessary to illuminate the cycle path. Where it is technically possible, then there is no objection to lighting the carriageway and the cycle path using the same lamp posts, with two brackets if need be. Dedicated lighting will only be required in places where a cycle path diverges from the carriageway. The visibility of the road alignment can best be enhanced by using edge markings.

If the cycle path is located more than 2 m away from the main carriageway or if the lamp posts are not in the segregation verge, then it will not be permissible to simply assume that the cycle path is being adequately lit. Particularly where the segregation verge is overgrown or the cycle path is situated slightly further away from the carriageway, dedicated lighting for the cycle path could be necessary.

In the case of cycle facilities there should be an obstacle-free space of at least 0.5 m from the surfacing. No lamp posts may be installed within this space.

If consideration is being given to only installing lighting for a segregated cycle path, then the designer will have to look into whether this could mislead other road users; where a cycle path and a main carriageway are following a different route, cycle path lighting can produce a confusing streetscape for the road users. In such cases, it might be better to confine the solution to edge markings on the cycle path with no additional lighting.

Edge markings
In general, the visibility of the road alignment can be better enhanced by applying edge markings than it can by adding lighting. After all, introducing a greater degree of *contrast* will already enhance visibility at extremely low levels of light, whereas illuminating something that lacks contrast will have very little effect. Clearly visible edge markings enable cyclists to maintain their course in the dark and focus on other road users, unevenness in the road surface and bollards. These markings have been standard for cycle paths to be constructed outside of built-up areas since 2015. In built-up areas, however, they are only required in bends. The elderly and partially sighted in particular will benefit from continuous markings, even in built-up areas.

(Cycle) underpasses
Daylight must be maximized in underpasses for cyclists. This can be achieved by such measures as creating two shorter tunnels under lanes rather than one long tunnel under a full carriageway, with an open central section or a skylight. In addition, lighting is recommended to foster personal safety. The difference between the lighting level within and outside of the underpass should not be too pronounced, which is why the lighting on the approach to the underpass should be harmonized with the lighting level in the underpass itself. The Netherlands Society for Lighting Technology (Nederlandse Stiching voor Verlichtingskunde, or NSvV) has drawn up specific recommendations for tunnels [13].

Luminance
The visibility of the course of a cycle path (for example) is not so much determined by the quantity of light cast on it as by the quantity of light reflected by the road surface (luminance) and the degree of contrast produced by certain hues of LED lighting. Green light, for instance, produces greater contrast than white light.

To a significant extent, the visibility of a road surface in the dark can be determined by the clarity of that road surface. Markings always have greater luminance than surfacing. Hence the use of markings (including edge markings) will clearly add value, even in the case of lit cycle paths. For information on the recommended light intensity, please see the Richtlijn Openbare Verlichting 2011 ('Public Lighting Guidelines 2011') [14].

Colour and uniformity
It is important for personal safety that the lighting contains various colours from the spectrum. This will enable faces to be recognized at greater distances. From this perspective, white light is the colour to be recommended most.

The level of light on the road surface under a lamp post must not differ significantly from the level of light between two lamp posts. If it does, then this will result in diminished visibility of the road surface and fatigue in cyclists, whose eyes

will then be forced to constantly adjust to the fluctuations in levels of light. The differences are determined by such factors as the distance between lamp posts, the height of the lamp posts, the quality of the lamps and the optical system in the light fitting.

Sufficiently uniform lighting is possible at the customary distance of 30 m between lamp posts. The NSvV states that, from the point of view of personal safety, the lowest light intensity on the road surface must be no less than 30% of the highest light intensity.

Dazzling
If there is potential for cyclists to be dazzled by oncoming traffic, then the intensity of the lighting should be relatively high. The differences in intensity between street lighting and vehicle lights will then be less pronounced, meaning that less adjustment will be required in terms of cyclists' eyes. Incidentally, street lighting can occasionally dazzle people. This is particularly the case with spectacle wearers in the rain; water droplets on the lenses cause increase scattering of the light. This phenomenon can be prevented by selecting a good height and location for the lamp posts and good-quality fittings.

Cyclists must be able to see obstacles on the vehicle path with light from behind them. In the case of bollards, therefore, lamp posts should not be sited level with bollards but on two sides a few metres away from the bollard.

Extensively used bicycle connections
For environmental and efficiency reasons, wherever it is highly exceptional for people to cycle in the dark it will not be reasonable to provide intensive lighting for a bicycle connection. Nevertheless, it is not permissible for the lack of lighting along the connection to dissuade large groups from cycling there. Hence it is not just about actual use of the connection but also potential use.

Refraining from installing intensive lighting will only be acceptable if each of the following conditions is satisfied:

- the bicycle connection is situated outside of built-up areas and connects residential centres in excess of 5 km away from one another;
- the bicycle connection is not on a home-school route or home-work route;
- the bicycle connection is not on a route to evening destinations, such as entertainment centres and sports halls.

On routes satisfying these three requirements it will be possible to confine solutions to alternative measures that only indicate the course of the bicycle connection, such as orientation lighting and/or edge markings. This is important for cyclists' road safety. Bends, junctions and obstacles at a distance of less than 0.50 m from the road or cycle path must be illuminated. In the case of a segregated cycle path, the relationship to the main carriageway is also important: if elements of the cycle path are lit, then the road in that location should also be lit.

7.4 Signage

Since 1 January 2015, statutory responsibility for signage has been the remit of the National Signage Service (Nationale Bewegwijzeringsdienst, or NBd). It is recommended that decentralized authorities get in touch with this organization early on in the process. The NBd can advise on such matters as choice of destination, routes and design of (utilitarian) cycle signage. It will also be able to manage projects that cross (highway authorities') boundaries. For the purposes of (cycle) signage, CROW publication 322 'Richtlijn bewegwijzering 2014' ('Signage Guidelines 2014') has a leading role [10]. The contents of this publication have been fine-tuned with the NBd.

In the Netherlands, a cyclist can use the following signage:

- general signage;
- specific cycle signage;
- signage for tourist routes.

Each type of signage will be explained in the next subsections.

7.4.1 General signage

If a route is partly or wholly closed to cyclists or if a shorter or more suitable route is available for bicycle traffic then, in addition to the general signage, specific cycle signage should be used. In such situations, general signage will feature a motorway symbol or A number in brackets after the destinations. For cycle signage, please see 7.4.2.

7.4.2 Specific cycle signage

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At any rate, specific cycle signage is used if:

- the route for cyclists diverges from the general route for other traffic;
- cyclists require additional destinations;
- cycle paths have their own route;
- the general signage is not legible (or is barely legible) to cyclists due to the position of the arms of the signposts;
- the general signage provides inadequate guidance to cyclists at a junction.

Provided it is uniform and continuous, cycle signage can assist in linking existing cycle facilities. In this regard, local and long-distance cycle signage must blend seamlessly in logical fashion and as far as possible cyclists must be directed along routes that are the quickest, safest, most comfortable and most attractive. One point for attention is the fragmentation of highway authorities, which sometimes causes problems in terms of harmonization. Poor harmonization between neighbouring highway authorities will impact on the quality of cycle signage in the wider surrounding area.

Target groups

When establishing a cycle route network, the various target groups for which the cycle signage is intended must be taken into account. The network for so-called long-distance utilitarian bicycle traffic in particular is important. This is intended for cyclists who are occasionally en route from one destination to another: the social-recreational cyclists. People cycling to school or work will not use cycle signage (with the possible exception of their first journey).

Route selection

In principle, the shortest routes (in terms of distance and/or time) in the cycle route network are included signage. Nevertheless, when choosing the routes consideration must be given to aspects such as road safety, personal safety and comfort. This can mean that a slightly less short route will be specified on the signage.

Sometimes it is worthwhile offering an alternative route in addition to the shortest one, such as a 'scenic route' or another one without busy car traffic. In such cases, it goes without saying that a clear distinction must be made between these and the shortest route.

System

In principle, cycle signage consists of red text on a white background. This colour combination marks a clear deviation from the system used for car signage (white text on a blue background). If there is an alternative, scenic route, then this can be stated in a different colour combination: green italic text on a white background. The difference in colour will only be used at the point where the choice needs to be made. Further on along the alternative route this will revert to the red-white designation, as 'additional bicycle traffic' will be there.

References
In general, cyclists cover limited distances. For that reason, in principle no more than two destinations per direction are specified on cycle signage outside of built-up areas. These will be the next destination along the route in the indicated direction and the nearest major location. If there is a fork in the routes ahead, then the nearest major location for the other route will be stated.

This system is also used in built-up areas so as to ensure that local and long-distance signage tie in with one another in a logical fashion. Furthermore, important local objects can be specified, such as tourist and recreational objects that attract a great deal of traffic, railway stations and bicycle parking facilities.

The system described above has evolved historically. One consequence of this is that long-distance cyclists riding 'by signs' will nevertheless be directed to the nearest major location, because destinations located further away are not generally mentioned on the signs. This could result in the cyclist not following the most direct route. Naturally cyclists can do something about this themselves.

7.4.3 Signage for tourist routes
Touristic cycle routes can be utilized to promote tourism and recreation. In this regard, a distinction should primarily be made between local/regional circular trip routes and nationwide through cycle routes. Furthermore, an increasing number of regions have nodal networks for cyclists. These enable cyclists to put together their own route. In addition, digital route planners are available, such as *www.fietsrouteplanner.nl* and *www.routeplanner.fietsersbond.nl*.

7.5 Personal safety
Personal safety calls for extra attention to routes to destinations that are heavily frequented in the evenings. Consider in this regard such places as entertainment centres, sports halls, town or city centres or community centres. Personal safety – which, depending on the context, can be referred to in the negative (lack of personal safety, danger, etc.) – is determined by the extent to which people can move freely in an environment without being threatened or confronted with violence. The topic is often relevant in the case of bicycle connections in green, quiet or out-of-the-way places. And in the case of bridges, viaducts and underpasses.

Fundamental principles for new routes
Personal safety is undeniably linked with the organization of the space. In places and on connections where there are lots of people, and therefore plenty of monitoring, there is a greater sense of safety. Passers-by will then be able to

intervene if need be. Even more important is that potential offenders will be put off by the presence of people. In places with little or no people, the availability of escape routes is an important criterion.

Layout is also important. It turns out that whether or not people will actually intervene depends on the extent to which they feel responsible for the situation. In a well-kept, small-scale residential environment, people prove to be more willing to act than they would be in (for example) a muddled space amidst some large-scale blocks of flats. It is also the case that the more visible the victim (or potential victim) is to bystanders, the greater the chances of them actually intervening.

Due to the above, it is best to route cycle routes as much as possible through areas where social activities take place, preferably in the evenings as well. In principle, this can be effected in two ways: by leading cycle routes past 'crowd-pullers' and by bringing such 'crowd-pullers' to cycle routes. In this regard, the term 'crowd-puller' should be taken to mean not so much large buildings as small-scale facilities. Examples include a postbox, a bus shelter or bus stop, and illuminated advertising or information boards. The presence of such facilities can be extremely useful. In addition, a cycle route through a suburb which passes the front doors of homes will be more socially pleasant than one passing fenced-off back gardens.

Transparency is another contributing factor to potential danger being spotted early. Transparency entails (for example) the structure of the situation being clear and there being no objects along the connection that potential offenders could hide behind (dense bushes, for instance). Not having any hidden or unused spots is also important.

Incidentally, not all cycle routes have to meet these criteria. That said, for routes that have a lower degree of personal safety there must always be a better alternative available within a reasonable distance.

Even if all conditions have been satisfied, it is unfortunately the case that personal safety cannot be guaranteed. Even the busiest urban cycle route can sometimes be deserted and lonely at night. And somebody with malicious intent will always find somewhere to offend.

As far as personal safety is concerned, the designer can achieve most at the level of network formation. By seeing to it that there are enough connections for cyclists that do not pass through any deserted and obviously unsafe locations, the most important requirement will be satisfied: ensuring monitoring and social control.

Existing routes not ensuring personal safety

If a route is set and the spatial planning context can no longer be influenced, then the options open to the designer are different in nature. In such cases, measures to reduce or eliminate danger will have to be focused on:

a optimizing the informal monitoring of cyclists and cyclists' view;
b discouraging opportunistic offences;
c facilitating (informal) escape routes;
d providing an alternative route, if an acceptable level of personal safety will not be feasible (in the dark, for instance);
e keeping the area clean (no litter, graffiti and overdue maintenance).

sub a. Optimizing monitoring of cyclists and cyclists' view

If there are opportunities in terms of improving the monitoring of a bicycle connection, then this will be the most significant step to take. The more people there are in the area, the greater the degree of personal safety. Removing dense plants right next to a cycle path and introducing lighting for cyclists can improve their view and have an attendant positive effect on personal safety. Conversely, such a measure can also ensure that the view *of* cyclists is improved.

sub b. Discouraging opportunistic offences

People with malicious intent can be tempted into committing offences by a certain situation.

A cycle path's immediate surroundings play a significant role in this regard. If there is no dense shrubbery or high objects a short distance from the bicycle connection, then it will not be possible for people to hide there. In a well-lit environment monitored from nearby homes or from the road, people will be less inclined to offend than they might be in a poorly lit environment that is not monitored much.

sub c. Facilitating escape routes

Knowing that there are possible means of escaping will increase the sense of personal safety. This is not about (designated) escape routes but possibilities of 'getting away'. Cycle routes between fencing (e.g. along railway lines), between guide rails or ditches score poorly on this criterion.
The same goes for routes over bridges and through underpasses. In places where screened-off structures and suchlike and unavoidable, it will be especially important to adopt the measures specified under a and b.

sub d. Offering an alternative route

With some routes it will be impossible or undesirable to eliminate the lack of personal safety completely. For example, this could be the case for a quiet leafy route that is beautiful and pleasant during the day. In such cases, the highway authority should provide an alternative route that ensures personal safety. In terms of distance, the latter will presumably be longer than the route that is less conducive to personal safety, but it will enable cyclists themselves to choose depending on the circumstances.

e. Cleaning the surrounding area

Even the 'quality of the environment' plays a role. A good design and a well-maintained situation will reduce the probability of vandalism

and be less conducive to inappropriate behaviour than a poorly maintained environment.

Not every route has to ensure personal safety

Routes that may be considered unconducive to personal safety at night can be pleasant, comfortable, useful and less risky during the day and on busy evenings. Thus segregated cycle routes through parks and woods also present significant benefits: they are low on traffic, making them low on emissions and health as a result.

Personal safety versus other interests

Measures to foster personal safety can conflict with other interests. A few examples include:

- If bushes are removed to encourage a clearer view, then this could have a detrimental effect on the area's natural beauty.
- If a bicycle connection is not routed through a park for reasons of personal safety but instead is routed along a busy road parallel to the park, then this could result in detours and less comfort.
- If a cycle route intersects a busy road by way of an underpass, then this will be less conducive to personal safety and less direct than it would be if that road were to have an at-grade crossing.
- If a cycle path is lit in a vulnerable nature reserve, then this will lead to 'light pollution'.

Such conflicts necessitate thorough assessment. A general methodology is not available to this end, because personal safety is dependent on highly specific local circumstances.

7.6 Other facilities

The appeal of travelling by bicycle can be enhanced by introducing small-scale infrastructural facilities in specific locations. Examples include shelters and rest areas.

Shelters

Shelters provide protection from the elements. Places where cyclists regularly wait (or have to wait) will naturally be the first to be considered when it comes to siting these facilities. Shelters are desirable:

- on bicycle connections that include ferries, locks and movable bridges;
- in places where cyclists are used to waiting for each other (groups of schoolchildren);
- at bus stops where cyclists get on buses (these will also require good bicycle parking facilities).

Shelters must be sufficient in size to accommodate bicycles as well as their riders. When siting shelters, consideration must be given not only to the sheltering cyclists' view of the approaching ferry, closing bridge and suchlike but also to the view people on the road have of what is going on in the shelter. This being to ensure personal safety.

Rest areas

On leafy, long-distance connections in particular, which attract a great deal of recreational bicycle traffic, benches and picnic sites are desirable. It will be self-evident that quiet locations should be selected for these, in areas of natural beauty. Locations close to a railway, motorway or car park are less suitable. An overview of existing benches can be found on the Route Planner issued by the Cyclist's Union (Fietsersbond) [w6]. Incidentally, research shows that benches are much more popular than picnic tables. Moreover, they are cheaper.

Bottle banks

Bottle banks are sited at least 5.00 m from the edge of the surfacing to avoid collisions with the obstacle and to prevent shards of glass causing punctures.

Literature

Figures between square brackets in the text – e.g. [1] – refer to the numbers in the bibliography below.

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8 Evaluation and management

Properly functioning infrastructure for cyclists requires not only a well-considered design and the correct organization but certainly also effective management and maintenance as well. The latter is even more important for cycle facilities than it is for carriageways intended solely for motorized traffic. After all, an uneven or unclean road surface is more likely to produce a great deal of nuisance and danger to a cyclist, who is operating a balance vehicle, than a car driver (for instance). Comfort is not the only issue. Even more problematic is the substantial increase in the probability of single-vehicle bicycle accidents. For that reason, surfacing for bicycle traffic in permanent situations must be of at least the same standard of quality as surfacing for motorized traffic. In temporary situations, surfacing for bicycle traffic must satisfy minimum requirements (including in terms of safety).

The present chapter devotes attention to the following items in succession:

- inspecting and evaluating bicycle connections (8.1);
- inspecting surfacing for cyclists (8.2);
- measures in the case of work in progress for cyclists (8.3);
- winter maintenance for the benefit of cyclists (8.4).

8.1 Inspecting and evaluating bicycle connections

The quality of a bicycle connection is the sum of the quality of all facilities (road surfaces and junctions) and the continuity of these. The (totalled) quality can be ascertained on the basis of an inspection or evaluation. An inspection can be triggered for various reasons. Well-known examples include residents having com-

plaints about a route or accidents/near misses having occurred. An inspection of a cycle network could also be carried out whilst drafting or updating a cycle route network. This is particularly relevant in the bottleneck phase. An inspection could also be useful for the purposes of setting priorities within the compass of a maintenance programme.

Incidentally, there is a significant difference between an inspection and setting priorities. In the case of an inspection, criteria are considered which a direct bearing on the quality of the cycle facility or, more specifically to cycle infrastructure, which express the extent to which the five main requirements are being satisfied (see 4.3). When setting priorities, other criteria play a role too, such as financial resources, political dilemmas, existing procedures within the framework of zoning plans and the number of road users that will benefit from any improvement (the efficacy).

An inspection of cycle facilities can be performed on three levels, namely:
- network level;
- connection or route level;
- facility level (road sections, junctions, crossings, bicycle parking facilities).

Connections can be inspected on myriad aspects, though also on a single aspect, e.g. the bicycle-friendliness of junctions. It is also possible to carry out an inspection in terms of a single main requirement. This would constitute a thematic inspection.

8.1.1 Evaluation of a network

Five steps can be distinguished when evaluating a network. The first of these pertains to indicating the reason and objective of the inspection. The second step entails specifying the inspection method. The third step relates to implementation. The fourth step sees the results being processed. Finally, the fifth step entails the quality of the facilities or connections being expressed as a rating and weightings being assigned to the various criteria, thereby obtaining a final assessment of the facilities or connections examined.

There are various inspection methods. Specific aspects in particular can often be assessed in a variety of ways.
This subsection looks at the Bicycle Balance method. Created by the Cyclist's Union, this tool was in common use in the past and the benefit of it is that it considers bicycle use across the full spectrum.

Evaluation method in steps
The Bicycle Balance method was developed as a benchmark tool and charts how various elements affecting the cycle climate can be investigated and assessed. In line with the Bicycle Balance system, the following evaluation steps are distinguished [50]:
- Create an overview of all policy documents relevant to bicycle traffic and analyse how much attention is devoted to bicycles therein.
- Survey the public to measure cyclist satisfaction.
- Generate a picture of bicycle use and safety, e.g. based on an analysis of Statistics Netherlands (CBS) figures.
- Use a practical measurement on the street to objectively record what the (daily) cyclist experiences.

The information thus obtained will form the basis of ten criteria on which the cycle climate and cycle facilities will be assessed. Scores are established for these ten criteria (see table 8-1). These pertain to: directness, comfort (nuisance), comfort (road surface), attractiveness, competitive position, bicycle use, road safety, urban density, cyclist satisfaction and written policy. The scores (blue area in figure 8-1) are compared with the standard (grey line) as well as with the scores in a town/city or towns/cities of similar size (green line). Presenting the results in such a clear manner soon enables transparency in terms of which aspects are and are not satisfying the standard.

Threshold values
Results of measurements only have explanatory power once they are compared and contrasted with a standard or threshold value. Sometimes clear standards are available, but it is frequently the case that they are not. The present Design Manual offers a degree of guidance when it comes to setting standards, but ultimately it will fall to the highway authority to develop policy in order to set standards. A benchmark can help. The Cyclist's Union's Bicycle Balance makes it possible to compare one's own situation with a number of standard values. These values constitute a good reference for a cycle-friendly infrastructure [50].

Table 8-1. Assessment criteria from the evaluation method

Aspect	Description
Directness	Directness is an indicator of the time that a cyclist requires to reach his destination. A cycle-friendly network has plenty of short, quick cycle routes. The following subaspects are measured for the purposes of assessing directness: - Detour factor (cycling distance/distance as the crow flies); - Delay (number of seconds stationary per kilometre); - Average speed (kilometres per hour).
Comfort (nuisance)	Six subaspects are measured for the aspect comfort (nuisance) which to some degree or other can affect the fun of cycling. The frequency of stopping and traffic nuisance are the most important in this respect: - Frequency of stopping (number of stops per kilometre); - Slow-moving bicycle traffic (proportion of the time for which the speed falls below 10 km/h); - Traffic nuisance (having to cycle one behind the other due to cars, pedestrians or other cyclists); - Infrastructural nuisance (having to cycle one behind the other due to overly narrow infrastructure or bollards); - No right of way (number of times that cyclist does not have right of way per kilometre); - Turning (number of instances of turning per kilometre).
Comfort (road surface)	In order to establish the comfort (evenness) of the road surface, vibration meters are used to measure the vertical acceleration to which a bicycle is subjected.
Attractiveness	Cyclists are in direct contact with their environment. Which is why they appreciate an attractive environment. However, attractiveness is a subjective term and is difficult to measure. For the purposes of Bicycle Balance, noise pollution has been chosen as an indicator of attractiveness. Noise pollution is relatively easy to measure. Furthermore, very few cyclists would consider a noisy environment to be an attractive environment.
The indicators discussed below are of a different order to the preceding ones. Whereas directness, comfort and attractiveness pertain to the actual situation on the street, the following indicators provide more of a picture of the opportunities for bicycles and the policy attention.	
Competitive position bicycle-car	This aspect provides a picture of the advantages of bicycles over cars in a municipality. In order to be able to give an assessment in terms of competitive position, all journeys are made on the routes to be studied by both bicycle and car. The competitive position is subsequently established on the basis of the following subaspects: - average journey time ratio (cycle time/driving time); - proportion of the journeys for which the bicycle is faster; - the parking costs for the car.
Bicycle use	The percentage of people opting to use a bicycle (rather than another mode of transport) is an important measure of the quality of the cycle climate. It is an indication of both the extent to which a local authority is succeeding in eliminating barriers to bicycle use and the degree to which a local authority is succeeding in fostering bicycle use. As a unit for bicycle use the Bicycle Balance uses the ratio of bicycle use on all journeys of up to 7.5 kilometres. In the case of municipalities with over 20,000 inhabitants, this is around 34% (data circa 2000).
Road safety	Road safety is an important basic precondition for a good cycle climate. As an indication for road safety, the probability of a cyclist being involved in a serious accident if he were to cycle 100 million kilometres is calculated. The risk figure is corrected for high or low bicycle use. Moreover, it contains a correction for a disproportionate number of elderly people. Incidentally, this pertains to objective safety, which does not always correspond to cyclists' perception of safety.

Table 8-1. Assessment criteria from the evaluation method (cont.)

Aspect	Description
Urban density	Cyclists benefit if they are able to choose from a wide array of destinations within cycling distance. For that reason, the Bicycle Balance also factors urban density into the assessment. The density of surrounding addresses serves as a basis, a variable from Statistics Netherlands which is used for such purposes as a gauge for the degree of urbanization. This density of surrounding addresses is subsequently corrected for the number of inhabitants in a municipality. A good score means that the municipality has a high density compared to other municipalities of the same size, and therefore has the basis of a cycle-friendly infrastructure.
Cyclist satisfaction	It goes without saying that the opinion of the cyclists themselves is indispensable in a study of the cycle climate in a municipality. A survey will allow cyclists to rate their own municipality. They will also be able to express their opinion on: - bicycle parking facilities (monitored and unmonitored); - cycling comfort (traffic nuisance, quality of road surface); - cyclists' road safety; - cyclists' personal safety (threat of violence); - approach to bicycle theft (enforcement, detection, engraving).
Written policy	What cyclists encounter on the street is largely down to the traffic policy operated in the past. The cycle policy of today can tell us something about the cycle climate of tomorrow. The aspect 'written policy' charts how well the cycle policy has been embedded in the policy plans, the budgets and the municipal organization. To this end, a survey has been used which was filled in by the local authority. It is particularly tricky to assess policy content on the basis of a survey. For that reason, the assessment on this aspect is restricted to an inventory of the degree to which topics, objectives and aspects form part of the policy. The following points are looked at: - cycle network (substantiation, quality requirements, implementation and maintenance); - cycle policy recorded in memoranda and policy documents on bicycle parking (substantiation, quality requirements, implementation and maintenance, subsidies); - budgets; - local authority as model employer.

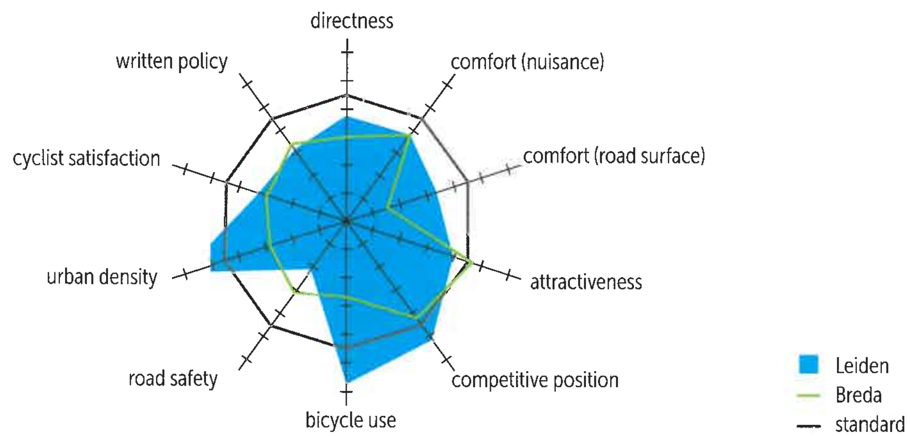


Figure 8-1. The Bicycle Balance score for Leiden compared with that for Breda

8.1.2 Route inspection

It is not always necessary or worthwhile evaluating an entire cycle network. The wish or need can also be limited to inspecting one or a few specific routes, e.g. routes to a city centre, school routes or all routes with a particular use. In such cases, it is possible to look at route characteristics in targeted fashion.

A Cyclist's Union method can also be used for the purposes of the route inspection. The Cyclist's Union Route Inspection is an investigatory method enabling a detailed opinion to be given on (the layout/organization of) a cycle route (or main cycle route), both in and outside of built-up areas.

The following aspects determine quality at route level:

- detour factor;
- delay;
- frequency of stopping;
- road surface quality;
- dimensions (width, curve radii, stacking space);
- right of way;
- turning;
- noise pollution;
- 'infrastructural finish' (bollards, evenness of verge, obstacle-free space);
- fluctuations in quality.

Moreover, the following aspects are of decisive importance when it comes to quality at road section/junction level:

- layout in relation to speed and intensity of motorized traffic;
- delay;
- frequency of stopping;
- right of way;
- road surface quality;
- dimensions (width, curve radii, stacking space) in relation to bicycle traffic volumes;
- 'infrastructural finish' (bollards, evenness of verge, obstacle-free space);
- width of critical reaction strip in the case of car parking spaces;
- personal safety;
- noise pollution;
- clarity of right of way regulations.

Furthermore, the following matters are examined in detail (in terms of both road sections and junctions where stopping is mandatory):

- the waiting time and the cause thereof (e.g. traffic lights or a priority road);
- dimensions;
- right of way;
- road surface quality;
- noise pollution;
- sight distance;
- lighting and guidance;
- signage.

8.1.3 Analysis of specific bottlenecks

The method based on the Bicycle Balance is labour-intensive and unsuitable for inspecting a specific location. If this is required (e.g. due to the volume of complaints), then it would make sense to start with an inspection using a detailed map (preferably at a scale of 1:500). Nonetheless, due to the fact that this will not allow anywhere near all of the design aspect to be assessed, an inspection 'out in the field' will always be necessary as well. Depending on the objective of the inspection and the problem, resources such as the 'measuring bicycle' or conflict observation techniques could also be used.

What is important, however, is to also formulate a clear description of the problem as well as an assessment framework beforehand so as to prevent issues of data interpretation arising subsequent to the inspection. The standards used within the compass of the Bicycle Balance method can be used as a guideline in this respect.

8.2 Inspecting surfacing for cyclists

The surfacing of bicycle connections constitutes a crucial part of the cycle infrastructure. Both a good design of the surfacing structure and effective maintenance of the road surface are essential for cyclists.

When assessing surfacing, the highway authority must bear in mind that what may be regarded as slight damage for car traffic will soon be deemed moderate or even severe damage for cyclists.

The aim of the visual inspection is to identify and assess visible instances of damage and to record these in an unambiguous manner. The road or cycle path will be examined on technical grounds and the damage will be assessed in a qualitative and quantitative sense (according to severity and scale). The results of the assessment will provide a picture of the road's condition.

The following four forms of inspection are briefly examined below:

- outline inspection;

- inspection minor maintenance;
- detailed inspection;
- safety inspection.

Further information can be found in the CROW publications 'Handboek Visuele Inpectie 2011' ('Visual Inspection Manual 2011') [1] and 'Handleiding globale visuele inspectie 2011' ('Outline Visual Inspection Manual 2011') [2].

Outline inspection

The aim of an outline inspection is to amass information at network level swiftly and efficiently vis-à-vis the condition of the entire road network's surfacing. The minimum frequency of the outline inspection is once every two years. In order to obtain results that can be compared,

Table 8-2. Relevant damage groups and damage types in the outline inspection [1]

Damage group	Damage type		
	Asphalt concrete surfacing	**Block paving**	**Cement concrete surfacing**
Texture	Wear		
Evenness	Lateral unevenness	Lateral unevenness	
	Unevenness	Unevenness	Unevenness
Cohesion	Cracking		Cracking
Impermeability			Joint filler

it is desirable to always carry out the inspection in consistent seasons. In general, it is the damage types and damage groups specified in table 8-2 in particular that are important when it comes to an outline inspection.

The table shows that the damage types 'drainage' and 'subsidence' do not form part of the standard outline inspection. Nevertheless, as these are highly important to cyclists it is recommended that these damage types also be included in the outline inspection. Moreover, it is important for damage types, particularly those related to evenness, to be assessed more strictly than they are for motorized traffic. As stated earlier, what may be regarded as slight damage for car traffic will soon be deemed moderate or severe for cyclists.

Inspection minor maintenance

The aim of the inspection minor maintenance is to detect and record in a structural way minor defects that will have to be repaired during the current budgetary year. Repairing or maintaining the weak spots in the surfacing will extend the lifespan of the surfacing over the entire road section component.

Keeping a record of minor maintenance work to be done is something that can be linked to a separate complaints log. It is recommended that the inspection minor maintenance for cycle routes, main cycle routes and solitary cycle paths be carried out three times a year, e.g. before the winter, after the winter and in the summer. On other routes the inspection will usually coincide with the inspection of the other roads (mixed traffic).

Detailed inspection

The aim of the detailed inspection is to record the visual condition of the road surfacing at project level. This is the most comprehensive and accurate form of inspection. In principle, all damage is assessed. No set frequency can be indicated for the detailed inspection. This form of inspection is performed when the highway authority deems it necessary for some reason, e.g. prior to transfer of roads, for the purposes of recording the baseline in the case of planned construction work or due to liability claims. Table 8-3 sets out the relevant damage groups along with corresponding damage.

Safety inspection

Regular safety inspections are carried out throughout the year. The focus of these is the safety of road users and preventing claims and liability. They are particularly about flagging up damage that could cause accidents. If such damage is noticed, then it must be repaired forthwith [1]. Furthermore, attention can also be given to the utility and visibility of obstacles, the connection between verge and surfacing and other factors that could contribute to single-vehicle bicycle accidents in particular [3, 4].

Table 8-3. Damage groups and damage types in the detailed inspection [1]

Damage group	Damage type		
	Asphalt concrete surfacing	**Block paving**	**Cement concrete surfacing**
Texture	Wear Greasiness		Deterioration
Evenness	Lateral unevenness Unevenness	Lateral unevenness Unevenness	Unevenness
Cohesion	Cracking	Joint width Quality of elements	Cracking
Impermeability			Joint filler
Surfacing edge	Edge damage Kerbing	Kerbing	
Miscellaneous	Drainage Verge Lateral cracks/Lateral welds Longitudinal welds Holes Subsidence	Drainage Verge Holes Subsidence	Drainage Verge Joint filler Joint damage Joint width Slab corner damage Holes Subsidence
Repairs	Repair		Repair

8.3 Measures in the case of work in progress

A wide array of types of work can be carried out alongside and on the carriageway. This section focuses on work on the road (in a lateral and/or longitudinal direction) as well as on construction activities alongside the road insofar as these could impede traffic. In many cases such work pertains to laying (or relocating) cables and ducts, often in combination with domestic connections. For that reason, chapter 7 already argued for cables and ducts not to be laid under cycle paths and cycle lanes. This is also linked to the decision to use even surfacing, which can best be achieved using asphalt or concrete.

In the case of temporary measures for cyclists, it is extremely important to minimize adverse effects on the existing quality of the cycle facilities. The basic quality of the existing bicycle connection must be maintained and as far as possible the facility for cyclists alongside the work zone must be the same as the ones before and after the work zone. Segregated facilities before and after the work zone also mean segregated facilities alongside the work zone.

The volume of motorized traffic alongside the existing bicycle connection will impel protective, temporary measures for cyclists. Extra barriers will be necessary in the case of work being carried out on and in the vicinity of tramways, segregated bus lanes and hazardous obstacles and/or trenches so as to prevent cyclists from being able to enter the work zone. In the case of long work zones, consideration must be given to ensuring sufficient shortcuts for cyclists.

A degree of obstruction is often inevitable during roadworks, but it is important to minimize any adverse effects on the main requirements of cohesion, directness, attractiveness, safety and comfort. In the case of temporary measures, workers are frequently count on the 'obligingness' of cyclists, without taking the five main requirements sufficiently into consideration.

In the case of work in progress and temporary measures, the following fundamental principles are important for cyclists:

- cyclists should not be forced to dismount and detours should be kept to a minimum;
- no unsafe (slippery and uneven) temporary surfaces should be used;
- cyclists should not be directed onto the other side of the carriageway;
- sufficient attention should be given to management of the temporary facilities.

Each of these fundamental principles will be explained below.

No dismounting, minimal detours
In the case of work in progress, it must be clear what behaviour is expected of cyclists. Furthermore, consideration must be given to the fact that cyclists are inclined towards taking the shortest route and to keep cycling (not dismounting). The recommendation is to direct cyclists alongside the work zone wherever possible. Where this is not feasible, the recommendation is to properly seal off the work zones and, if need be, the pavements as well. This will necessitate a diversion. In this regard, do bear in mind the maximum acceptance of extra journey time. 2 minutes is adhered to for this purpose. What this means for cyclists is a detour not exceeding around 600 m as a maximum.

If no better solution is possible, then under certain conditions it will be possible to direct cyclists over the pavement. This measure may only be used if the footpath has a width of a minimum of 3.50 m. If volumes of pedestrians and cyclists are significant, then the highway authority may consider a physical barrier between pedestrians and cyclists. Additional points for attention accompanying the measure 'cyclist on pavement' include:

- both cyclists and pedestrians being given ample warning vis-à-vis the anomalous traffic situation;
- any level differences between cycle path and footpath being spanned properly (minimum gradient 1:10);
- obstacles on footpaths (signs, lamp posts, bins) that cyclists will not be anticipating being removed or clearly marked.

No unsafe temporary surfacing
In the case of work in progress, temporary surfacing is regularly used to direct cyclists (and any other traffic) alongside a work zone. It is important that the temporary surfacing is of sufficient quality to enable cyclists to ride on it safely. In practice, it is common for this to be not up to scratch. The following conclusions from a study on single-vehicle bicycle accidents during works on or alongside the road are telling [5]:

- The materials used for a temporary road surface are suboptimal for cyclists' safety: metal drive ramps and concrete slabs with metal edging. Concrete slabs are virtually guaranteed to subside, thereby creating differences in height. In addition, the metal edges are smooth and the temporary situation often persists for longer than was expected. Furthermore, the road surface is not always properly finished.
- Improperly installed or missing roadblocks cause single-vehicle bicycle accidents.
- Cyclists will slip due to sand, mud and gravel on the road surface after incorrect completion of new surfacing.

Not being directed to the other side of the carriageway
Moving a bicycle connection to a cycle path on the other side of the carriageway is discouraged. This will result in extra crossing manoeuvres and to unexpected manoeuvres on the cycle path

concerned. It would be better to create a temporary cycle path, particularly if the work is to take a long time. Naturally, this will have to be sufficiently wide, even and skid-resistant.

If it is nevertheless decided that cyclists are to be directed to the other side of the carriageway, then it will be possible to minimize the danger caused by additional cyclists crossing by:

- setting a lower speed limit for motorized traffic;
- warning traffic that there are extra cyclists crossing;
- organizing the crossing point in such a way that it is safe, with an adequate view of anomalous traffic manoeuvres.

Furthermore, traffic lights can be installed in busy locations [6].

Attention to management
One important point for attention which is nevertheless commonly overlooked is the management and maintenance of temporary facilities. Particularly in the case of more major, long-term roadworks that involve regular roadworks traffic driving across the (temporary) cycle path, there is a significant probability of subsidence or ruts and sand and mud ending up on the cycle path or the road section for cyclists. It is advisable to remedy such inconveniences as quickly and as effectively as possible. Failing to do so will not only impact on the comfort and safety of bicycle traffic, it will also increase the likelihood of cyclists seeking out other, less desirable routes.

Work in Progress Guidelines
With roadworks it is important to seal off the road section properly to ensure that cyclists cannot ride into the work zone. If the pavement alongside the work zone is accessible, then a lot of cyclists will use this. In this respect, they are not inclined to dismount. What this means is that even when the work zone has been properly sealed off and all measures have been implemented in accordance with the guidelines, undesirable behaviour can occur. For that reason, extra measures must be taken for this situation (a footpath opened up to cyclists alongside a cycle path or carriageway closed to cyclists) [6].

The present Design Manual does not deal with all possible measures exhaustively, instead emphasizing the preparatory process. Within the compass of this, the key question is how the interests of bicycle traffic can best be served in the case of work in progress. For more detailed guidance, please see the CROW publication 'Maatregelen op fietspaden en voetpaden – Werk in Uitvoering' ('Measures on Cycle Paths and Footpaths – Work in Progress') [7].

In order to ascertain what measures will be necessary during work in progress on cycle paths, consideration must be given to:
- the safety of road workers in the road section;
- the road safety of cyclists and other road users;
- the flow of bicycle traffic and other traffic;
- the consequences in terms of quality of life and the environment;
- information and communication.

The preparatory work for measures comprises the following steps:
- *Preparing and commencing project*
  In this regard, the duration of the work is important. In the case of short-term work (less than a half-day), straightforward measures will suffice. If the work will take longer, then sufficient attention to diversions, roadblocks and suchlike are required.
- *Drawing up a signage and diversion plan*
  If the work is to take longer than a half-day, then a signage and diversion plan should be drawn up in advance to make it clear to the maintenance team or contractor what has to be done.

When establishing measures, a general principle to be adhered to is that cyclists should experience as little nuisance as possible due to the work. The measure 'cyclists dismount' may only be adopted as an exception. This measure should only be considered if it is absolutely clear to the cyclist why he needs to dismount. If this is not the case, then significant numbers of cyclists will be highly likely to disregard the advice to dismount and seek out their own way, around the roadblocks if need be. It is precisely this latter situation that must be prevented. Diversions will only be acceptable if narrowing or moving the cycle facility will not be possible (from a spatial or traffic engineering perspective).

Dimensions in the case of roadblocks
When determining the type of roadblock and the accompanying measure, attention must be given to the work zone, the safety zone and the free space up to the roadblock. In the case of temporary facilities, the following dimensions can be adhered to as a minimum:
- clearance for cyclists to the roadblock: 0.50 m;
- free space on roadworks side of roadblock: 0.60 m;
- safety margin between work zone and fence/mobile variable message sign: 5.00 m;
- space for a cyclist in motion: 0.75 m;
- space for a cyclist in motion + moped rider: 1.50 m;
- space for a cyclists travelling in two directions: 1.75 m;
- space for a cyclists travelling in two directions, high volume, moped riders permitted: 2.25 m.

Possible situations
In the case of segregated and solitary cycle paths, six situations can be discerned as regards the position of roadworks compared to the bicycle connection. Within these situations it is possible in a number of cases to make a further distinction between short-term and long-term work. Short-term work (less than 2 hours) entails less radical measures being taken, meaning that less intrusive roadblocks can be installed too.

The six situations are:
1. *Work a significant distance from the cycle path*
   No measures need to be taken in this situation, given that the bicycle traffic will not experience any nuisance because of the work being done.
2. *Work a short distance from the cycle path*
   Here too the cycle path can be kept open. However, a longitudinal roadblock should be installed using guide beacons or traffic cones. A free space of at least 0.60 m along the roadblock must be observed at the side of the work zone. Consideration must also be given to space to allow for anxiety regarding obstacles at the side of the cycle path. The remaining cycle path must be sufficiently wide. A safety space of at least 5.0 m must be observed between the roadworks and the mobile variable message sign or warning fence to be installed.
3. *Roadworks right next to the cycle path*
   Measures must be taken if the roadworks will be within 1.5 m of the cycle path. A straightforward stationary roadblock will suffice. No 'tidal flow' is permitted on bidirectional cycle paths. Cyclists approaching each another from the opposite direction must be able to pass one another at all times. On erecting roadblocks on cycle paths, please see the Guidelines for measures on in the case of work in progress [10].
4. *Roadworks right next to the cycle path, entailing work being carried out from the cycle path*
   In this situation it may be possible to keep the cycle path open, but it will have to be narrowed. This will only be possible if, in addition to a free space of 0.60 m on the inside of the roadblock as well as the requisite space for the roadblock itself, at least 1.00 m of the cycle path's width remains.
   If there is less than 1.00 m left, then it will first have to be examined whether a proportion of the carriageway can be closed to motorized traffic for the benefit of the cyclists (see also below). If this is not a possibility, then a diversion will have to be sought. It is also important for the longitudinal roadblock to be placed on the verge if work is not being done. This might be a hassle for the contractor, but it means added quality for cyclists.
5. *Roadworks at the edge of or on the cycle path*
   Depending on the remaining width, it may or may not be possible for the cycle path to be kept open.
   See under 4.
6. *Roadworks in the middle of or across the full width of the cycle path*
   In this situation it may sometimes be possible to keep the cycle path open by narrowing it. If this is not possible, then it will have to be examined whether a proportion of the main carriageway can be used by cyclists (with roadblocks and if need be a local speed limit for car traffic - see also below). If this is not a possibility either, then the bicycle traffic will have to be diverted. If the roadworks will be extremely short in duration (< 2 hours), then it might be permissible for them to be carried out without a signposted route; roadworks that will take longer than this will require signposting.

Segregating motorized and bicycle traffic in the event of cyclists being directed onto the carriageway
If cyclists are being directed off of the cycle path and onto a section of the carriageway for motorized traffic, then the two types of traffic will have to be separated. This can be achieved by means of a vehicle-retaining barrier, a double row of guide beacons, element markings with cordon signs or fencing. The choice will depend on the duration of the roadworks and the characteristics of the adjacent traffic lane

and traffic flow. The heavier the traffic function and the longer the duration of the roadworks, the more substantial the separation will need to be. If substantial separation will not be possible, it will be necessary to introduce speed limits for motorized traffic.

Measures on residential roads

Due to the nuisance experienced by cyclists if they are required to dismount, take a detour or go around roadworks, efforts must be made to ensure minimal hindrance to cyclists heading to or coming from destinations along a residential road. This means that the work zone on such a road must be situated and organized in such a way that the destinations along the road continue to be accessible. Outside of built-up areas the closure of a residential road will usually result in a long diversion, because the network of roads is less dense here. For that reason it is imperative to endeavour to direct cyclists along the work zone, particularly if the road forms part of an important cycle route. Further information on this topic can be found in CROW publication 517 'Maatregelen op niet-autosnelwegen' ('Measures on Non-motorways') [10].

Measures on distributor roads

On distributor roads too (both in and outside of built-up areas) efforts must be made to minimize potential hindrance to bicycle traffic heading to or coming from destinations along the road. Where necessary, cyclists can be diverted via the network of residential roads, provided that these routes are suitable for this. Outside of built-up areas the network is more diffuse and during roadworks it will be imperative to endeavour to direct cyclists alongside the work zone as much as possible, a principle that will apply all the more if the distributor road forms part of a main cycle route.
In the case of roadworks at junctions (including roundabouts as well) involving both residential roads and distributor roads it holds that motorized traffic should be diverted and that cyclists should preferably be directed alongside the work zone. This will prevent unnecessary detours and additional nuisance for bicycle traffic.

8.4 Winter maintenance for the benefit of cyclists

Winter maintenance is even more important for cyclists than it is for car traffic. After all, cyclists are vulnerable road users. This is partly due to the fact that they are not protected by a surrounding structure like motorists are. Another cause is the limited stability of a cyclist. In order to ensure a safe journey and remain on course, it will be necessary for him to be able to build up sufficient speed and have an even, skid-resistant road surface. A small slippery patch, such as a frozen puddle, could be enough to cause a fall.

It is partly because of cyclists' limited protection that the consequences of falling could be serious even at low speeds. The probability of slipping as a result of ice and snow is particularly high on sloped sections and in bends. For that reason, maximum efforts should be made to prevent ice and snow, particularly on important bicycle connections, by means of preventive spraying and gritting.

This section will discuss several topics that are important in connection with preventing and combating ice and snow for bicycle traffic. Much more comprehensive information can be found in CROW publication 334 'Gladheidsbestrijding voor fietsers en voetgangers; beleid, organisatie en uitvoering' ('Winter Maintenance for Cyclists and Pedestrians: Policy, Organization and Implementation') [9].

Harmonizing routes

The starting point for winter maintenance must be that the set network of cycle routes (including main cycle routes) remains satisfactorily passable in non-extreme winter conditions. Where cyclists and motorized traffic are sharing the carriageway, irrespective of whether or not there are designated cycle lanes, the winter maintenance will not be focused specifically on bicycles. On these routes the bicycle traffic will simply be part of the overall winter maintenance picture for motorized traffic. Specific winter maintenance work will be carried out for segregated bicycle connections belonging to the cycle network. Spraying salt brine is preferred over scattering pre-wetted salt, as spraying gives a better result, particularly for bicycle traffic. In order to prevent cyclists on their journey constantly encountering sections of a route that have and have not been treated, winter maintenance must be harmonized as optimally as possible for segregated cycle paths and for carriageways.

Planning winter maintenance routes – for both (preventive) spraying/gritting only and for ploughing and/or brushing snow in combination with spraying/gritting – is an activity requiring specialist knowledge, up-to-date data and suitable software. Points for attention for bicycle connections include obstacles (bollards, underpasses with limited headroom, raised kerbs), locations liable to become slippery (bridge decks, inclines) and the equipment to be deployed (the speed and capacity of sprayers, gritters, brushes and snowploughs for bicycle connections are limited). During winter maintenance consideration must be given to time limits; winter maintenance is, for example, undesirable during bicycle traffic rush hours.

Width of cycle paths and obstacles

The width of the equipment to be used must be fine-tuned to the width of the cycle paths to be treated. One point for attention in this regard is the axle track of the vehicles. It is imperative to prevent the wheels of vehicles from driving on the edges of the surfacing. This would result in a high probability of damage to the edges of the surfacing and verge subsidence. Obstacles can hinder maintenance and winter service vehicles. Bollards in particular will impede the progress of work on cycle paths.

Harmonization surfacing and load

Segregated cycle paths often consist of a relatively light surfacing structure with a thin layer of asphalt or concrete, or with block paving. In order to prevent unnecessary damage to these surfacing types, the weight of the winter service vehicles must be fine-tuned to them (conversely, when designing surfacing for bicycles, consideration must be given to the load presented by winter service vehicles - see 7.1.1).

Anomalous thermal behaviour
Measurements show that cycle paths cool down more swiftly than carriageways in some situations. This difference in thermal behaviour can mean that wet sections of cycle path can freeze over or become slippery due to frozen condensation, even though this is not happening on the carriageway. This has to be factored in when planning winter maintenance.

Bridge decks are special points for attention in winter maintenance for the benefit of bicycle traffic. Not only because of their sometimes markedly anomalous thermal behaviour, but also because they have not always been designed for winter service vehicles. The latter point also applies to inclines, cycle overpasses and cycle underpasses/tunnels.

Policy plan winter maintenance for cyclists
If there is sufficient support for a targeted approach to winter maintenance on bicycle connections, then a policy will have to be developed for this. The first step is to establish and record the level of ambition for winter maintenance on cycle paths. Table 8-4 features recommendations for winter maintenance work on segregated cycle paths.

Slipperiness should preferably be tackled preventively and action should be taken within a reasonable time frame. It is important for choices contained in the policy plan to be clear and logical for road users and that the latter are adequately notified of these. Once the policy plan for winter maintenance on bicycle connections has been established, it will be transformed into an implementation plan.

Table 8-4. Recommendations for winter maintenance on segregated cycle paths in and outside of built-up areas [7]

Category	Speed limit (km/h)	Slipperiness due to ice/snow	Slipperiness due to condensation	Slipperiness due to precipitation
Segregated cycle path outside of built-up area	40	preventive	preventive	preventive and curative (3.5 hours)*
Segregated cycle path in built-up area	30	preventive	preventive	preventive and curative (3.5 hours)*

* The target time of 3.5 hours for curative action pertains to the time between the point at which a decision to act is made and the treatment of the final square metres of a winter maintenance route.

The aim of the policy plan and the implementation plan collectively is to ensure that the winter maintenance work is carried out in the agreed way and that the approach followed to that end is transparent and effective. In combination with factual data on winter maintenance work carried out – such as times, routes driven and quantities of de-icer used – they can also serve to stave off claims for damages. Due to the fact that highway authorities are being held liable for damage in connection with ice and snow more often, the importance of a sound policy vision, an effective implementation plan and accurate data administration is increasing.

Evaluating the implementation on an annual basis is recommended. In this regard, the following questions can be discussed:

- Does the network of bicycle connections to be treated need to be modified?
- Are there any new developments on the market which provide grounds for modifying aspects of the implementation?
- Have other highway authorities had experiences that could prompt modification of aspects of the implementation, e.g. us of different equipment?
- Are there any organizational developments that could provide grounds for modifying aspects of the implementation (consider in this regard contracts with contractors or scaling up support centres, for instance)?

Being wary about slipperiness in the autumn too
One aspect that receives too little attention is slipperiness caused by leaves that have been shed. During the autumn, leaves on cycle paths are a potential hazard, particularly in wet conditions. Consequently, highway authorities will have to periodically clean important cycle routes situated under and alongside deciduous trees in the autumn using street sweepers.

Literature

Figures between square brackets in the text – e.g. [1] – refer to the numbers in the bibliography below.

1 Handboek visuele inspectie 2011 (CROW-publicatie 146a). Ede, CROW, 2011.

2 Handleiding globale visuele inspectie 2011 (CROW-publicatie 146b). Ede, CROW, 2011.

3 Samen werken aan een veilige fietsomgeving (Fietsberaad-publicatie 19), O. van Boggelen (Fietsberaad), P. Schepers (IenM), P. Kroeze en M. van der Voet (Ligtermoet en Partners). Ede, Fietsberaad, 2011.

4 Safe Cycling Network; Ontwikkeling van een systeem ter beoordeling van de veiligheid van fietsinfrastructuur (SWOV-rapport R-2014-14, in opdracht van ANWB), dr. G.J. Wijlhuizen, dr. ir. A. Dijkstra en ir. J.W.H. van Petegem. Den Haag, SWOV, 2014.

5 De rol van infrastructuur bij enkelvoudige fietsongevallen, P. Schepers. Rijkswaterstaat, Dienst Verkeer en Scheepvaart, Afdeling Veiligheid, 2008.

6 Verkeersonveiligheid bij werk in uitvoering, deel III en eindrapportage (SWOV-rapport R-2009-4), dr. ir. W.A.M. Weijermars. Leidschendam, SWOV, 2009.

7 Maatregelen op fietspaden en voetpaden – Werk in Uitvoering (CROW-publicatie 96b). Ede, CROW, 2005.

8 Leidraad gladheidsbestrijdingsplan (CROW-publicatie 236). Ede, CROW, 2006.

9 Gladheidsbestrijding voor fietsers en voetgangers; beleid, organisatie en uitvoering (CROW-publicatie 334). Ede, CROW, 2013.

10 Maatregelen op niet-autosnelwegen (CROW-publicatie 517). Ede, CROW, 2014.

Design sheets

Contents Design sheets

V1 Designations cycle path and cycle/moped path

Function	- designate legal status
Application	- sign G11 'Mandatory cycle path'; sign G12 'End of mandatory cycle path' - sign G12a 'Mandatory cycle/moped path'; sign G12b 'End of mandatory cycle/moped path' - sign G13 'Advisory cycle path' (forbidden to mopeds and light mopeds with a combustion engine in operation); sign G14 'End of advisory cycle path'
Implementation	- in the case of bidirectional paths with underplate 0406 - a traffic decree is required for all signs - not zonally applicable - G13 and G14 are allowed in non-standard dimensions (0.60 × 0.20 m) on solitary paths in parks and suchlike - G11 and G12a are allowed in non-standard dimensions (with cross section less than 0.40 m) on solitary paths in parks and suchlike
Considerations	- G11 to G14 are allowed to be sited both on the left and the right of the path - where desired, riders of mopeds with combustion engines in operation can be prohibited from using solitary paths


G11
Mandatory cycle path

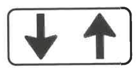

G12
End of mandatory cycle path


G12a
Cycle/moped path


G12b
End of cycle/moped path

G13
Advisory cycle path

G14
End of advisory cycle path


0406
Secondary sign for bidirectional path

V2 Solitary cycle path

Function	- providing a connection for cyclists
Application	- within and outside of built-up areas - in recreational and utilitarian cycle networks - rapid connection between neighbourhoods, districts, etc. - bidirectional traffic
Implementation	- siting sign G11 ('Mandatory cycle path') or sign G13 ('Advisory cycle path'): see V1 - design speed 30 km/h for main cycle network and 20 km/h for basic structure - centre line desirable on utilitarian paths: see V5 - edge markings if unlit: see V6 - preferably asphalt or concrete surfacing - preferably provide lighting for utilitarian paths in built-up areas - if need be, surfaced (or partially surfaced) verge strip/pavement on both sides (0.30-0.50 m wide)

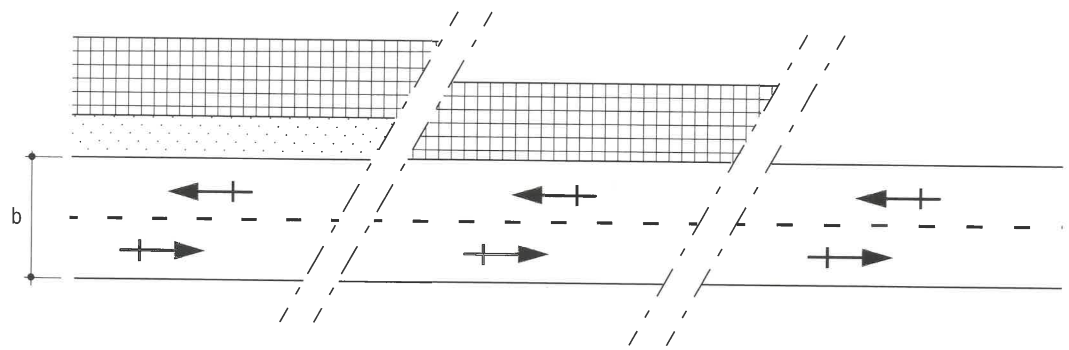
Dimensions

rush hour volume (bidirectional) (bicycles/hour)	minimum width of path (b)
0-50	1.50 m[1)]
50-150	2.50 m[1)]
150-350	3.50 m
> 350	4.50 m

1) up to 2.50 m wide a path will have a verge or pavement on both sides which can be ridden on, giving cyclists room to swerve

- centre line: 0.30-2.70 m on straight sections; 2.70-0.30 m in bends
- width of any footpath ≥ 1.00 m

Considerations	- comfortable for cyclists - safe for cyclists - nuisance between cyclists and pedestrians if there is no pavement or footpath - unconducive to personal safety in the case of remote location - nuisance due to unlawful use on the part of mopeds and motorcycles
Combination possibilities	- footpath
Alternatives	- solitary cycle/moped path: see V3



V3 Solitary cycle/moped path

Function
- providing a connection for cyclists and moped riders

Application
- in utilitarian cycle networks
- rapid (direct) connection between neighbourhoods, districts, etc.
- bidirectional traffic

Implementation
- siting sign G12a ('Mandatory cycle/moped path'): see V1
- design speed 30 km/h in built-up areas and 40 km/h outside of built-up areas
- centre line desirable on utilitarian paths: see V5
- in built-up areas: edge markings if unlit: see V6
- outside of built-up areas: edge markings: see V6
- preferably asphalt or concrete surfacing
- preferably provide lighting for utilitarian paths in built-up areas
- if need be, surfaced (or partially surfaced) verge strip/pavement on both sides (0.30-0.50 m wide)

Dimensions

rush hour volume (bidirectional) (bicycles/hour)	width of path (b)
0-50	2.00 m[1)]
50-100	3.00 m
100-300	4.00 m
> 300	5.00 m

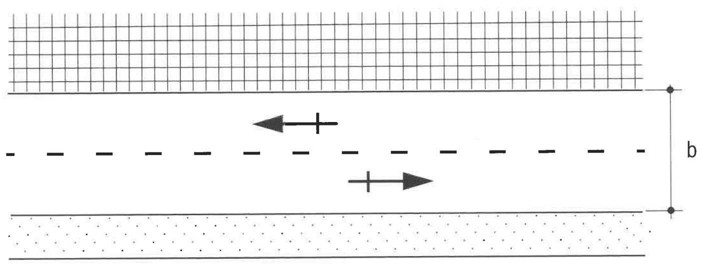
1) up to 2.50 m wide a path will have a verge on both sides which can be ridden on, giving cyclists room to swerve

- centre line: 0.30-2.70 m on straight sections; 2.70-0.30 m in bends
- width of any footpath ≥ 1.00 m

Considerations
- comfortable for cyclists and moped riders
- safe for cyclists and moped riders
- nuisance between cyclists and moped riders
- relatively significant differences in speed between cyclist and moped rider, particularly outside of built-up areas
- nuisance between cyclists/moped riders and pedestrians if there is no pavement
- unconducive to personal safety in the case of remote location
- nuisance due to unlawful joint use on the part of motorcycles

Combination possibilities
- footpath

Alternatives
- solitary cycle path: see V2



V4 Bicycle highway

Function
- providing a high-quality connection for cyclists

Application
- in utilitarian cycle networks
- over longer distances

Implementation
- design speed 30 km/h in built-up areas and 40 km/h outside of built-up areas
- separating directions of travel
- edge markings: see V6
- asphalt or concrete surfacing
- providing lighting
- surfaced (or partially surfaced) verge strip/pavement on both sides (0.30-0.50 m wide)

Dimensions
- the cross section to be aimed at is shown in the tables below; a width of 1.0 m should be adhered to for a cyclist on a bicycle highway [21]

Cross section to be aimed at for bicycle highway with separated directions of travel

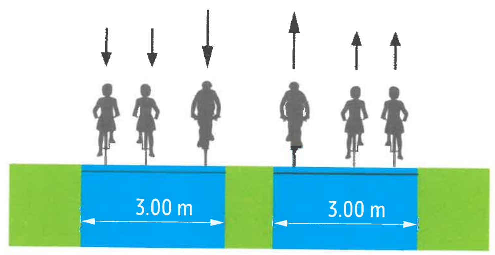
Basic width vehicle path in the case of one-way bicycle traffic	3.00 m	3 × 1.00 m
Central reservation width	> 0.5 m	
Adjustment in the case of high kerb or plants	+ 0.5 m	2 × 0.25 m
Total	> 7 m	

Cross section to be aimed at for bidirectional bicycle highway

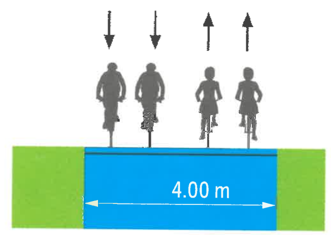
Basic width vehicle path	4.00 m	4 × 1.00 m
Adjustment high kerb or plants	+ 0.5 m	2 × 0.25 m
Adjustment high volume or significant differences in speed (mopeds)	+ 0.5 to 1.0 m	> 3,000 bicycles/ 24-hour period
Adjustment low volume, though not where there are significant differences in speed (mopeds)	− 0.5 to 1.0 m	< 1,000 bicycles/ 24-hour period

Considerations
- the cross section to be aimed at should provide sufficient space for cycling two abreast and for cyclists to overtake one another
- the cross section to be aimed at should minimize the chances of conflict with oncoming traffic and the chances of accidents on verges and/or kerbs

Combination possibilities
- footpath



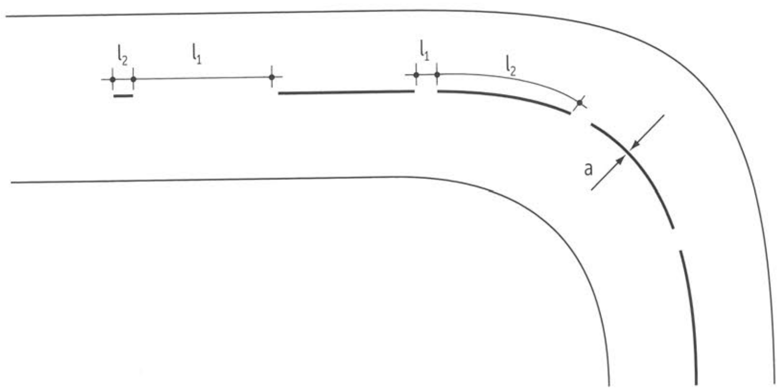
cross section profile 2 x 3 metres



cross section profile 4 metres

V5 Centre line cycle path

Function	- separating directions of travel - guiding
Application	- in the case of bidirectional cycle path - as a warning stripe in places where there is an increased probability of head-on conflict (e.g. in a bend with poor visibility)
Implementation	- thermoplastic material, agglomerate, road paint or surfacing material - preferably thermoplastic or surfacing material where there is a side road if there is a chance of wear and tear
Dimensions	- a = 0.10 m in the case of thermoplastic material, agglomerate and road paint; in the case of surfacing material, width of a will depend on the material (0.15 to 0.30 m) - normal centre line: l_1 = 0.30 m, l_2 = 2.70 m - warning stripe: l_1 = 2.70 m, l_2 = 0.30 m
Considerations	- makes it clear that traffic is bidirectional - sets up carriageway for the directions of travel - good guidance



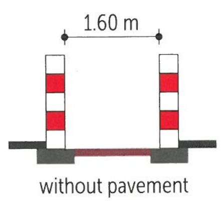
V6 Edge markings cycle path

Function	- guiding - indicating the edge of the surfacing
Application	in built-up areas: - if the cycle path veers off (e.g. for a bus shelter or at a junction) - where there are no street lights outside of built-up areas: - on utilitarian cycle paths and cycle/moped paths
Implementation	- thermoplastic material, agglomerate, road paint or surfacing material - preferably thermoplastic or surfacing material where there is a side road if there is a chance of wear and tear
Dimensions	- width of edge markings should preferably be 0.10 m and a minimum of 0.05 m - a minimum of 0.10 m from the edge of the surfacing
Considerations	- good guidance

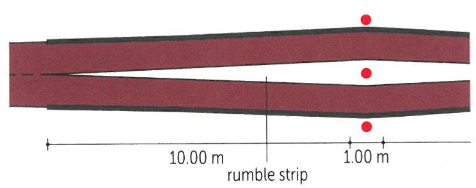
V7 Bollard

Function	- keeping out unwanted car traffic
Application	- only site if other measures have been insufficiently effective and if the problem that has to be solved is more important than the disadvantages presented by the bollard - on cycle paths within and outside of built-up areas - to support signs G11, G12a or G13: see V1
Implementation	- in a colour that contrasts with the surroundings - retractable or flexible if a wide vehicle will occasionally need to pass (fire service, maintenance) - introductory ribline required (rl) - adequate lighting required
Dimensions	- effective width alongside bollard (a) = 1.60 m - length introductory markings (L) ≥ 10.00 m
Considerations	- keeping out car traffic - a nuisance for cyclists (due to limiting width) - dangerous for cyclists (chance of collision with bollard) - a nuisance in routes when it comes to winter maintenance
Combination possibilities	- physical narrowing on both sides of the cycle path

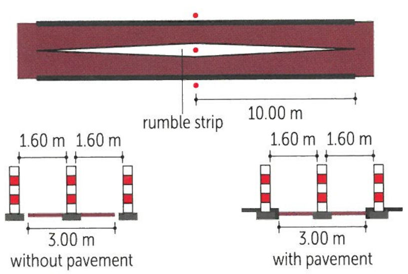
Cars can be kept off of very narrow paths using bollards on the verge:



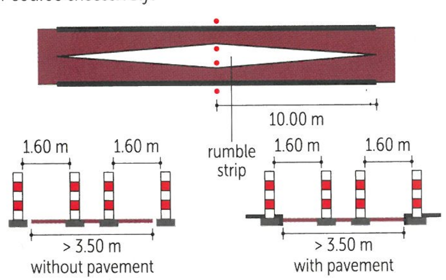
Narrow cycle paths must be expanded at the level of bollards to create sufficient width there:



In the case of a cycle path width of between 2.50 and 3.50 m, siting two bollards on the verge and one in the centre will usually suffice:



Site two (or more) bollards in the centre on wide cycle paths. This will enable cyclists to pass the bollards without having to adjust their course excessively:



V8 Carriageway for mixed traffic

Function	- providing a connection for all vehicle types
Application	- within built-up areas: see selection plan subsection 5.4.1 - outside of built-up areas: see selection plan subsection 5.5.1
Implementation	- asphalt/concrete surfacing or block paving - outside of built-up areas it might be possible to create a proportion of the requisite surface width using verge surfacing
Dimensions	- width of carriageway within built-up areas:

Normative situation	Carriageway width [m]1)	
	minimum profile2) W =	ideal profile3) W =
one-way car + bicycle	3.40	3.85
one-way car, bidirectional bicycle	3.85	4.40
bidirectional car, based on design vehicle passenger car, and bidirectional bicycle	4.80	5.80

Comments

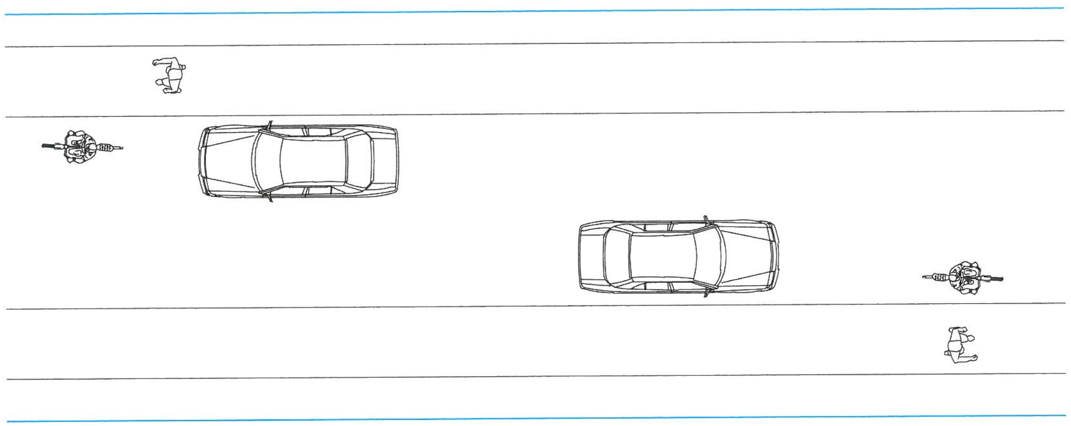
1) Fundamental principles used:
- requisite space for cyclist in motion 1.00 m to 1.45 m
- requisite space for passenger car in motion (30 km/h), including deviation from course 2.40 m
- requisite space for lorry in motion (30 km/h), including deviation from course 3.10 m
- requisite space for lorry not in motion, including mirrors 3.00 m

2) Faced with oncoming traffic (bicycle and/or car), it will not be possible to overtake cyclists

3) Situations of doubt must be prevented. These dimensions do enable cyclists to be overtaken when faced with oncoming traffic

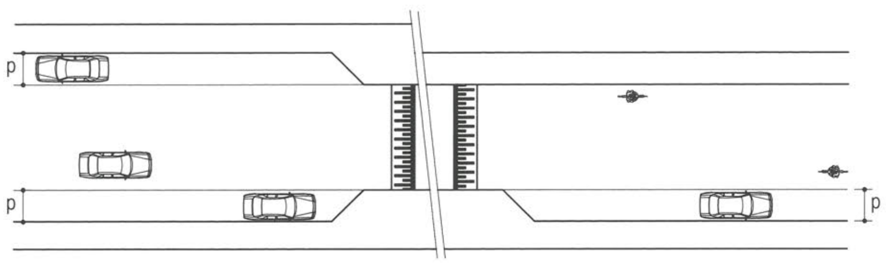
width of carriageway outside of built-up areas:
- 4.20-5.50 m
- any edge markings (1-3) a maximum of 0.25 m from side edge of surfacing

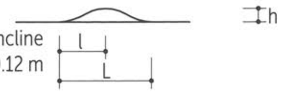
Considerations	- tight profile contributes to low speed - a tight profile is relatively generous at low volumes of bicycle traffic and motorized traffic - the situation for cyclists will be neither comfortable nor safe when mixing with motorized traffic for which a speed limit of 60 km/h applies (outside of built-up areas) - relatively unsafe for cyclists where a lot of parking manoeuvres are happening
Combination possibilities	- pavement or footpath (≥ 1.80 m) with 'forgiving' kerbs - longitudinal lay-by (with critical reaction strip for cyclists) - outside of built-up areas: guidance (reflector bollards) in bends - speed bumps (sinusoidal) - outside of built-up areas: reinforced verge, grasscrete with flat side up - outside of built-up areas: consider edge markings



V9 Cycle-friendly speed-reducing facilities

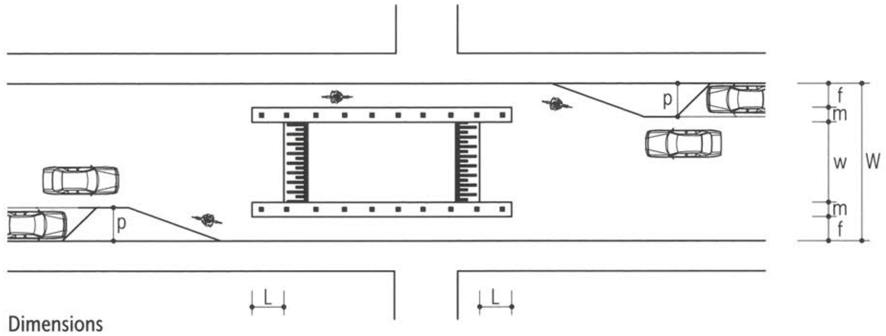
Function	- reducing differences in speed between bicycle traffic and motorized traffic - reducing speed in conflict locations
Application	- residential road within and outside of built-up areas - distributor road within built-up areas - crossing point with cycle route
Implementation	- by means of vertical or horizontal speed bump - a cycle-friendly implementation will entail the cyclist riding alongside the speed bump or the speed bump being given a sinusoidal shape longitudinally - speed bump must fit in with the function of the road - a design speed of 30 km/h is recommended at points of conflict with a lot of cyclists
Dimensions	- dependent on function of road and type of speed bump - width of any bypass for cyclists 1.60 m
Considerations	- vertical facilities are usually the most effective - sinusoidal incline presents relatively little hindrance - vertical facilities occasionally result in vibration nuisance - bypass with limited width will prove troublesome to cyclists





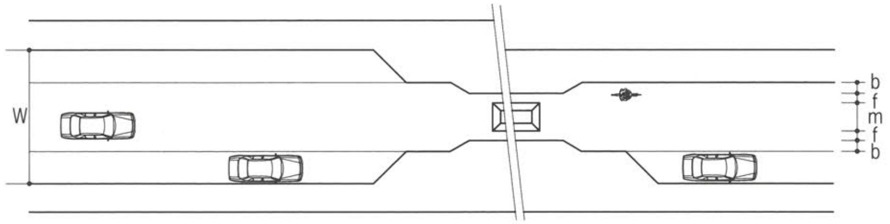
Dimensions

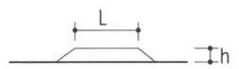
	sinusoidal incline where h = 0.08 m	sinusoidal incline where h = 0.12 m
▬ l =	1.75 m	2.40 m
▬ L =	3.50 m	4.80 m
▬ p ≥	2.00 m (width parking lane)	2.00 m (width parking lane)



Dimensions

- f = 1.50 m
- f+m ≥ p
- L = 2.00 à 4.00 m
- m ≥ 0.85 m
- p = 2.00 m
- w = 4.80 m (minimum profile) to 5.80 m (ideal profile), in the case of bidirectional traffic
  = 3.10 m, in the case of bidirectional traffic with narrowing to a single lane and in the case of partial one-way traffic
- W ≥ 7.80 m, in the case of one-way car
  ≥ 9.50 m (minimum profile) to 10.50 m (ideal profile), in the case of bidirectional traffic
- bevelling cycle paths 1:5
- (see also sections 11.2.21, 11.2.24, 11.2.28)





Dimensions

- b = variable
- f = 0.65 m
- h = 0.08 m
- L ≥ 3.00 m
- m = 1.80 m
- W ≥ 7.40 m (minimum profile) to 7.85 m (ideal profile), in the case of one-way traffic
  ≥ 8.80 m (minimum profile) to 9.80 m (ideal profile), in the case of bidirectional traffic

V10 Longitudinal lay-by with reverse parking (parking angle > 30°)

Function
- providing cycle-friendly parking for car traffic

Application
- residential road and distributor road within built-up areas
- if need be with partial one-way traffic

Implementation
- delineating lay-by by means of raised protrusions at side roads, exits and suchlike
- at start/end of lay-by, take crossing site distance emerging from side road into consideration
- lay-bys in different surfacing
- consider critical reaction strip between lay-by and bicycle facility/carriageway
- height differential or physical separation between lay-by and pavement

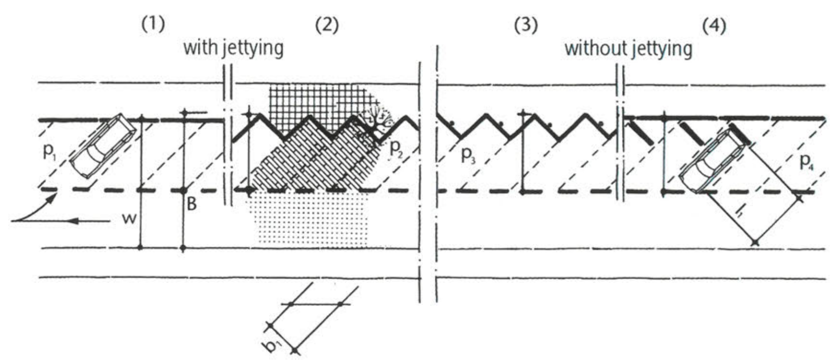
Dimensions
- width of parking space (b1) 2.30 – 2.50 m
- length of parking space (m) depending on parking angle:

	60°	45°	30°
p_1	4.75	4.45	3.90
p_2	4.80	4.65	4.15
p_3	5.30	5.05	4.45
p_4	5.15	4.85	4.20

- vehicle path car traffic (w) > 4.00 m (in connection with space for parking manoeuvre)

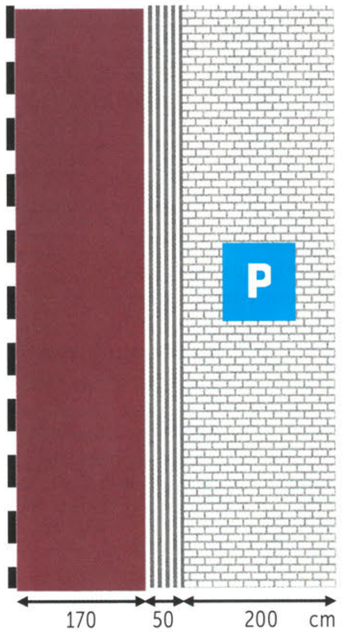
Considerations
- rear parking manoeuvre easier than parallel parking
- safe for cyclists: no trouble from doors being opened
- good visibility of cyclists when entering and leaving parking space
- no pedestrians on carriageway/cycle lane
- no unnecessarily large road profile in the absence of parked vehicles
- more parking spaces per stretch of road compared to parallel parking
- poor visibility of pedestrians crossing
- having parked/stationary cars on carriageway can make leaving parking spaces impossible
- poor access to buildings when volumes of parked vehicles are high
- in the case of residential properties: exhaust fumes closer to homes

Alternatives
- lay-by parallel with carriageway



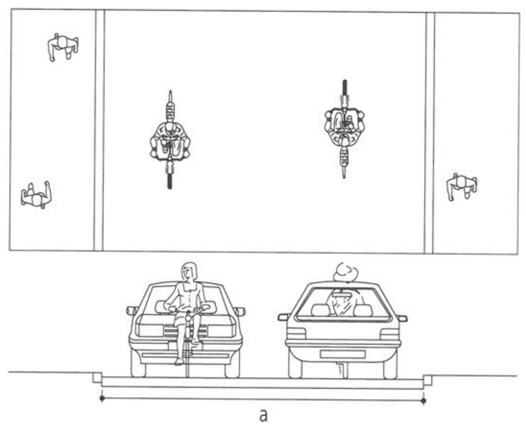
V11 Critical reaction strip

Function	- creating a buffer space to bolster cyclists' safety where cars are parked
Application	- within and outside of built-up areas - buffer space between carriageway/cycle lane and lay-by
Implementation	- different surfacing for strip than that of carriageway/cycle lane and lay-by
Dimensions	- width of critical reaction strip 0.50 m
Considerations	- safer for cyclists (lower probability of accidents as a result of doors opening and consequent swerving manoeuvres) - strip can also be used for drainage - extra use of space
Alternatives	- cycle path on the right alongside the lay-bys



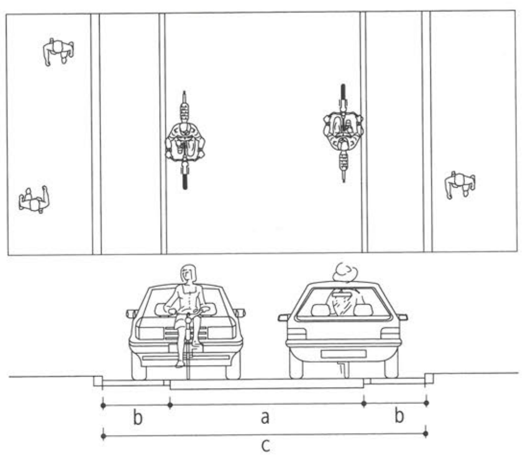
V12 Bicycle street with mixed profile

Function	- providing high-quality cycle connection, with joint use on the part of motorized traffic
Application	- residential road within and outside of built-up areas - main cycle network - v_{max} = 30 km/h (within and outside of built-up areas) - one-way or bidirectional traffic for motor vehicles - applicable if $I_{bicycle} \geq I_{car}$, if $I_{bicycle} \geq$ 1,000 cycles/24-hour period and/or if I_{car} < 2,500 PCU/24-hour period - if $I_{bicycle}$ is double I_{car}, then I_{car} < must be 2,500 PCU/24-hour period
Implementation	- asphalt or concrete surfacing - colour of surfacing red (to make cycle route recognizable) - priority regulation at junctions (bicycle street has right of way), perhaps with speed bump: see V9 - route guidance at points where choices need to be made (where necessary) - no parking on the carriageway
Dimensions	- width of vehicle path (a) 4.50 m (more than enough for 2 × 2 cyclists approaching one another)
Considerations	- safe for cyclists - comfortable for cyclists - clear to motorists that there is a cycle route - potentially too attractive for motorized traffic (right of way at all junctions) in the absence of supplementary regulatory measures for motor vehicles
Combination possibilities	- lay-by with critical reaction strip: see V11 - speed bumps: see V9 - alternating one-way traffic for motor vehicles
Alternatives	- bicycle street with cyclists in the middle of the road: see V13 - bicycle street with carriageway separation and cyclists at the sides of the road: see V14



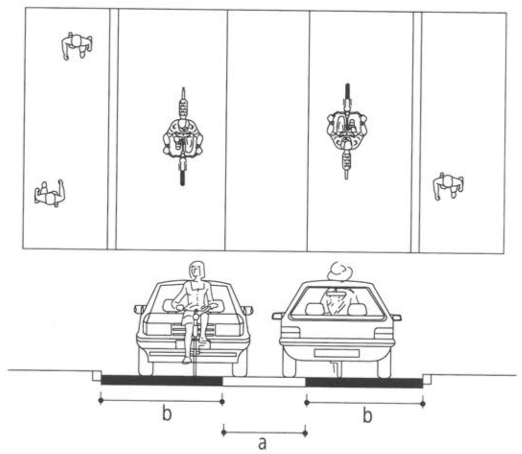
V13 Bicycle street with cyclists in the middle of the carriageway

Function	- providing high-quality cycle connection, with joint use on the part of motorized traffic
Application	- residential road within and outside of built-up areas - main cycle network - v_{max} = 30 km/h (within and outside of built-up areas) - one-way or bidirectional traffic for motor vehicles - applicable if $I_{bicycle} \geq I_{car}$, if $I_{bicycle} \geq$ 1,000 cyclists/24-hour period and/or if I_{car} < 2,500 PCU/24-hour period - if $I_{bicycle}$ is double I_{car}, then I_{car} < must be 2,500 PCU/24-hour period
Implementation	- asphalt/concrete surfacing for vehicle path - border strips in block paving - colour of carriageway surfacing red (to ensure cycle route is recognizable as such) - colour of border strips black/grey - priority regulation at junctions (bicycle street has right of way) - even transition between cycle lane and border strip - route guidance at points where choices need to be made (where necessary) - parking off the carriageway
Dimensions	- carriageway width (c) 4.50 m - width of border strip (b) 0.50-0.75 m - width of vehicle path (a) 3.00-3.50 m
Considerations	- safe for cyclists - comfortable for cyclists - clear to motorists that there is a cycle route - potentially too attractive for motorized traffic (right of way at all junctions) in the absence of supplementary regulatory measures for motor vehicles
Combination possibilities	- lay-by with critical reaction strip: see V11 - speed bumps: see V9
Alternatives	- bicycle street with carriageway separation and cyclists at the sides of the road: see V14 - bicycle street with mixed profile: see V12



V14 Bicycle street with carriageway separation and cyclists at the sides of the carriageway

Function	- providing high-quality cycle connection, with joint use on the part of motorized traffic
Application	- residential road within and outside of built-up areas - main cycle network - v_{max} = 30 km/h (within and outside of built-up areas) - one-way or bidirectional traffic for motor vehicles - applicable if $I_{bicycle} \geq I_{car}$, if $I_{bicycle} \geq$ 1,000 cyclists/24-hour period and/or if I_{car} < 2,500 PCU/24-hour period - if $I_{bicycle}$ is double I_{car}, then I_{car} < must be 2,500 PCU/24-hour period
Implementation	- preferably asphalt or concrete surfacing - colour of surfacing for cycle lanes preferably red - priority regulation at junctions (bicycle street has right of way), perhaps with speed bump: see V9 - border strip in the middle that can be ridden on - route guidance at points where choices need to be made (where necessary) - parking off the carriageway - possibly mole burrows at the sides
Dimensions	- width of cycle lanes (b) 2.00 m - width of border strip (a) 0.80-1.50 m
Considerations	- safe for cyclists - comfortable for cyclists - clear to motorists that there is a (main) cycle route - potentially too attractive for motorized traffic (right of way at all junctions) in the absence of supplementary regulatory measures for motor vehicles
Combination possibilities	- lay-by with critical reaction strip: see V11 - speed bumps: see V9 - alternating one-way traffic for motor vehicles
Alternatives	- bicycle street with cyclists in the middle of the road: see V13 - bicycle street with mixed profile: see V12



V15 Cycle lane

Function
- designating position of cyclist and keeping it safe

Application
- within built-up areas: see selection plan subsection 5.4.1
- outside of built-up areas: see selection plan subsection 5.5.1

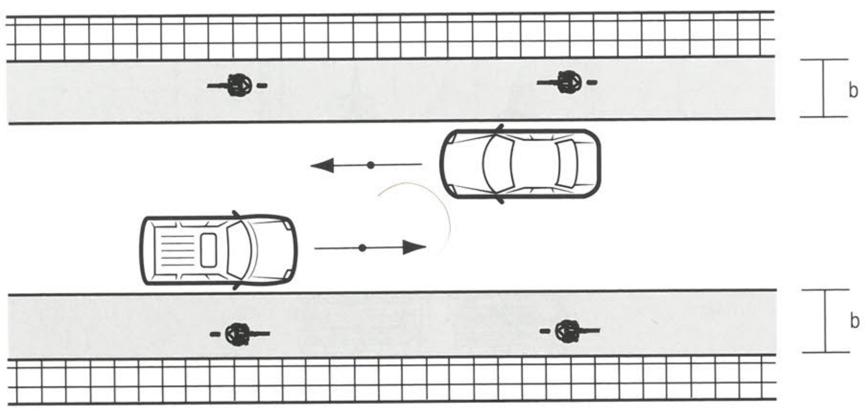
Implementation
- surfacing of cycle lane coloured red
- use bicycle symbol after each side road and possibly every 50-100 m (in built-up areas) or every 500-750 m (outside of built-up areas): see V54
- broken (1-1) or unbroken markings, with the latter being used at exits and lay-bys being broken by 1-1 stripe
- parking alongside cycle lane is advised against; if parking is nevertheless permitted, then this should only be in combination with critical reaction strip: see V11

Dimensions
- width of cycle lane (b) 2.00-2.25 m (minimum 1.70 m) excluding markings
- width of stripe 0.10 m
- dimensions in the case of various profile widths in built-up areas: see subsection 5.4.4
- dimensions in the case of various profile widths outside of built-up areas: see subsection 5.5.4

Considerations
- mixed profile is starting point on residential road in built-up area
- segregated cycle path is starting point on distributor road: see V16
- not demonstrably safer for cyclists on residential roads, though it is on distributor roads
- cyclists' safety best ensured on distributor road by segregated cycle path
- clear place in cross section (enhancing visibility) with legal status
- no vehicles are allowed to be stationary (i.e. no parking either) on cycle lane and on the carriageway
- joint use on the part of motorized traffic (in the case of broken markings)
- no physical protection

Combination possibilities
- speed bumps: see V9

Alternatives
- mixed traffic
- bicycle street: see V12-14
- segregated cycle path: see V16



V16 Segregated cycle path

Function
- separating motorized traffic and bicycle traffic for the benefit of cyclists' safety and comfort

Application
- within built-up areas: see selection plan subsection 5.4.1
- outside of built-up areas: see selection plan subsection 5.5.1

Implementation
- design speed 30 km/h for main cycle network and 20 km/h for basic network
- verge present between cycle path and main carriageway (raised or flush)
- always use centre line in the case of bidirectional traffic on cycle path: see V5
- edge markings (see V6) if the cycle path alongside a road bends away and where there is a lack of street lighting; on all utilitarian cycle paths outside of built-up areas
- preferably asphalt or concrete surfacing
- siting sign G11 ('Mandatory cycle path') or sign G13 ('Advisory cycle path'): see V1
- colour of surfacing preferably red
- the same priority regime as for adjacent carriageway; if side road has right of way, then continue cycle path surfacing over the junction surface (with exit construction in line with CROW publication 344): see V23

Dimensions
- width of cycle path

One-way path		Bidirectional path	
rush hour volume (one-way) (bicycles/hour)	**width (b)**	**rush hour volume (bidirectional) (bicycles/hour)**	**width (b)**
0-150	2.00 m	0-50	2.50 m[1]
150-750	2.50-3.00 m	50-150	2.50-3.00 m
> 750	3.50-4.00 m	150-350	3.50-4.00 m
		> 350	4.50 m

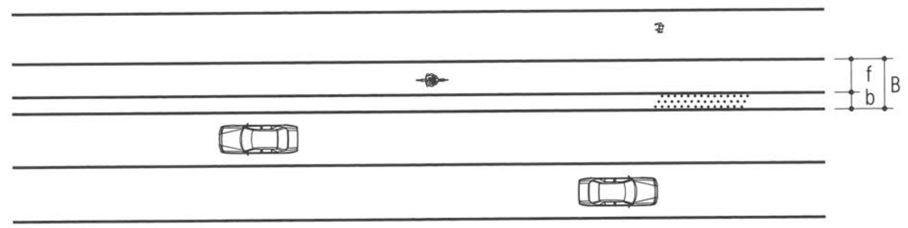
1) Up to 2.50 m wide a path will have a verge on both sides which can be ridden on, giving cyclists room to swerve

- width of segregation verge: see V18

Considerations
- comfortable for cyclists (if sufficiently wide)
- safe for cyclists on road sections (no conflict with motorized traffic)
- no nuisance from parked vehicles
- illegal cycling in the opposite direction (in the case of one-way traffic)
- limited opportunities for cyclists to cross (only in the case of side roads, exits and alleys in the segregation verge)
- conflict situations with motor vehicles at junctions and exits (cyclists out of sight)
- in the case of bidirectional traffic on cycle path extra instances of conflict at junctions and exits (cyclists approaching from the unexpected direction)
- nuisance between cyclists and pedestrians if there is no pavement

Combination possibilities
- speed hump in side road

Alternatives
- cycle lane: see V15
- cycle/moped path: see V17



V17 Segregated cycle/moped path

Function
- separating motorized traffic and bicycle (or moped) traffic for the benefit of cyclists' and moped riders' safety and comfort

Application
- within built-up areas: see selection plan subsection 5.4.1
- outside of built-up areas: see selection plan subsection 5.5.1

Implementation
- design speed 30 km/h in built-up areas and 40 km/h outside of built-up areas
- verge present between cycle/moped path and main carriageway (raised or flush)
- always use centre line in the case of bidirectional traffic on cycle/moped path: see V5
- preferably asphalt or concrete surfacing
- siting sign G12a ('Mandatory cycle/moped path'): see V1
- colour of surfacing preferably red
- the same priority regime as for adjacent carriageway; if side road has right of way, then continue cycle/moped path surfacing over the junction surface (with exit construction in line with CROW publication 344): see V23

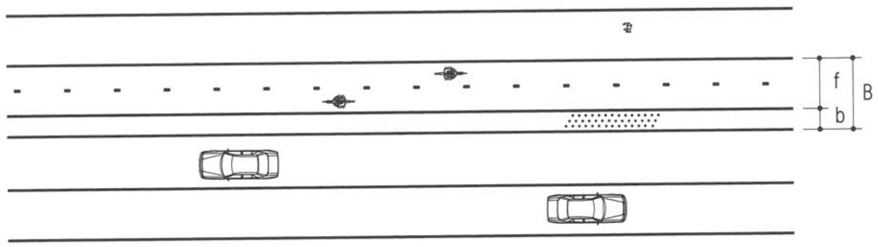
Dimensions
- width of cycle/moped path

One-way path		**Bidirectional path**	
rush hour volume (one-way) (bicycles/hour)	**width (b)**	**rush hour volume (bidirectional)**	**width (b)**
0-150	2.00 m	0-50	2.50 m
75-375	3.00 m	50-150	3.00 m
> 375	4.00 m	150-300	4.00 m
		> 300	5.00 m

- width of segregation verge: see V18

Considerations
- comfortable for cyclists and moped riders (if sufficiently wide)
- safe for cyclists and moped riders on road sections
- nuisance between cyclists and moped riders
- relatively significant differences in speed between cyclist and moped rider, particularly outside of built-up areas
- nuisance between cyclists/moped riders and pedestrians if there is no pavement
- illegal cycling in the opposite direction (in the case of one-way traffic)
- limited opportunities for cyclists/moped riders to cross (only in the case of side roads, exits and alleys in the segregation verge)

Combination possibilities
- speed hump in side road: see V9



V18 Segregation verge cycle path – carriageway

Function
- physical separation of motorized traffic and bicycle traffic

Application
- in the case of segregated cycle path: see V16
- within and outside of built-up areas

Implementation
- preferably flush and possible to ride on it in the event of unintended swerving manoeuvres (unpaved or [semi-]surfaced)
- if need be with raised kerb ('forgiving')
- segregation verge can be used for installation of street furniture, low plants and/or trees, on the proviso that the requisite object distance is taken into consideration

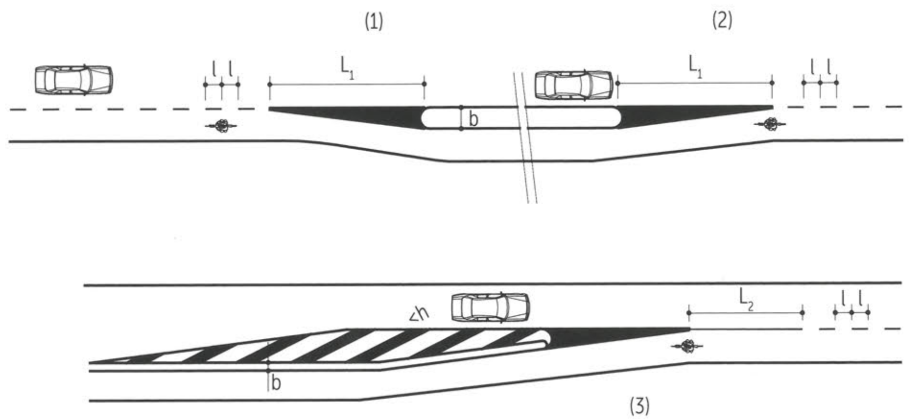
Dimensions
- width within built-up areas:
  - at least 0.35 m
  - in the case of objects in the segregation verge: sufficiently wide to satisfy the requisite object distance; on distributor roads in built-up areas, with a design speed of 50 km/h, at least 1.0 m; a distance of 0.50 m can be adhered to for cyclists
- width within built-up areas:
  in the case of v_{max} main carriageway 60 km/h: ≥ 2.50 (1.50) m
  in the case of v_{max} main carriageway ≥ 80 km/h: 6.00 (4.50) m
  in the case of v_{max} main carriageway ≥ 100 km/h: > 10.00 m

Considerations
- separating motorized traffic and bicycles is safe, provided that there are no hazardous verge obstacles
- if a raised edge is being used, then this should be 'forgiving' (sloping) or be a maximum of 0.05 m high (to prevent single-vehicle bicycle accidents due to pedals hitting the edge)
- limited opportunities for cyclists to cross (only in the case of side roads, exits and alleys in the segregation verge)
- wider (surfaced) verge can be used for the purposes of parking; this may or may not be desirable

Combination possibilities
- anti-dazzle protection
- public lighting

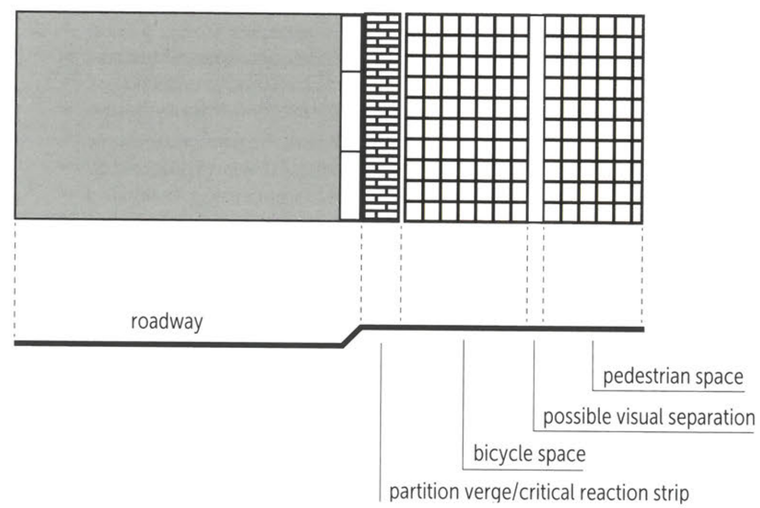
V19 Transition from cycle lane to cycle path and vice versa

Function	▪ guiding cyclists ▪ indicating profile change
Application	▪ transition from cycle lane to cycle path (1) or vice versa (2, 3) ▪ within and outside of built-up areas ▪ area boundary
Implementation	▪ thermoplastic material, road paint or surfacing material
Dimensions	▪ $l = 1.00$ m ▪ $L_1 = (10 \text{ to } 12) \times b$ ▪ $L_2 = 10$ to 20 m ▪ $b = 0.40$ to 0.50 (0.35) m ▪ $h = 1:2$
Considerations	▪ cover enhances safety for cyclists



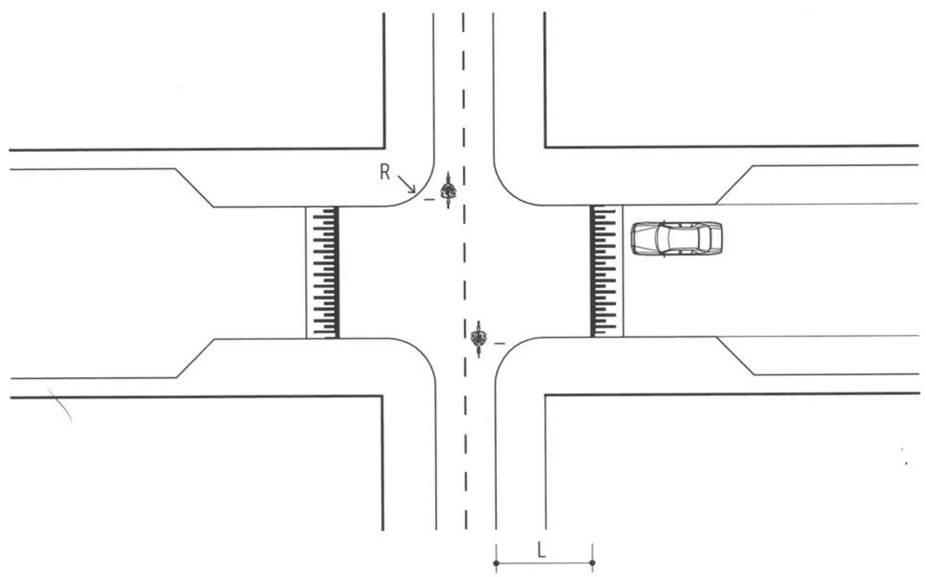
V20 Combined path

Function	▪ combined path for cyclists and pedestrians
Application	▪ alongside distributor roads ▪ in the case of extremely low volumes of bicycle and pedestrian traffic ▪ in built-up areas ▪ not in residential areas ▪ not on school routes
Implementation	▪ segregation verge/critical reaction strip a minimum of 0.50 m ▪ bicycle space a minimum of 1.50 m ▪ pedestrian space a minimum of 0.90 m ▪ no height differential between bicycle space and pedestrian space
Considerations	▪ this facility is in common use abroad, though there is scant experience of it in the Netherlands ▪ alternative is segregated cycle path that can be used by pedestrians: see V16



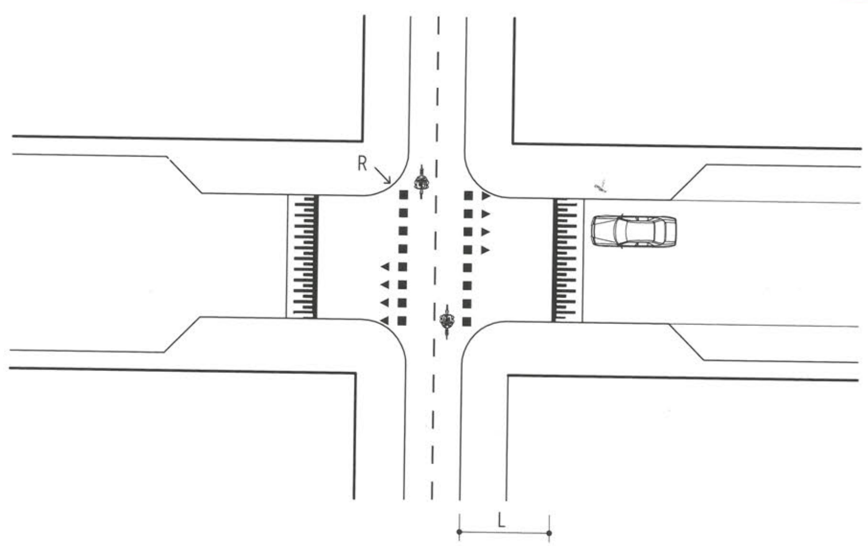
V21 Junction considered equal solitary cycle path – residential road

Function	- indicating crossing situation - improving crossing situation bicycle traffic - limiting speed of motorized traffic
Application	- residential road - within and outside of built-up areas
Implementation	- do not continue the cycle route's colour and surfacing type over the junction surface - do not use any block markings or channel markings - if need be, make the residential road narrow right before the junction - if need be, install a speed bump on the residential road
Dimensions	- level difference 0.08 to 0.12 m - L = 5.00 to 6.00 m - sinusoidal speed hump
Considerations	- good reduction in speed intersecting traffic (safe) - increase in noise nuisance and vibrations (particularly due to lorries) - poor bicycle traffic flow (no right of way) - possible doubt regarding right of way due to speed hump for motorized traffic
Combination possibilities	- visual aid - lighting
Alternatives	- bicycle roundabout (Zwolle bicycle roundabout) - cycle crossing with right of way (see V22)



V22 Junction solitary cycle path with residential road, with cycle route having right of way

Function	- optimizing directness of bicycle traffic - improving cyclists' safety - limiting speed of motorized traffic - indicating crossing situation
Application	- in built-up areas
Implementation	- continue the cycle route's colour and surfacing type over the junction surface - block markings, shark's teeth and signage support right of way for the cycle route: see V55 - if need be, make the main carriageway narrow right before the junction - span height differential in residential road by means of a semi-sinusoidal design - gradually compensate height differential for cyclists
Dimensions	- L = 5.00 to 6.00 m - R ≥ 5.00 m - level difference 0.08 to 0.12 m - centre line and edge markings 1-1
Considerations	- high-quality cycle route (no delay when crossing carriageway) - reducing speed of intersecting traffic - increase in noise nuisance and vibrations (particularly due to lorries) - possible influence on route choice motorized traffic - nuisance for cyclists on residential road when using straight approach (not recommended)
Combination possibilities	- arrow markings on cycle crossing to clarify bidirectional traffic - visual support by means of spatial elements - traffic island or central traffic island in main carriageway - traffic lights - lighting
Alternatives	- junction considered equal (see V21) - bicycle roundabout



V23 Exit construction

Function
- indicating priority situation, also for pedestrians
- possibly indicating entrance and exit to residential area

Application
- junction of distributor road and residential road
- connecting premises, car park, residential property and suchlike on residential road
- along main cycle routes (and main walking routes) in urban area
- within and outside of built-up areas
- width of pavement or verge ≥ 1.50 m
- preferably do not use in (main) cycle routes (transversely)

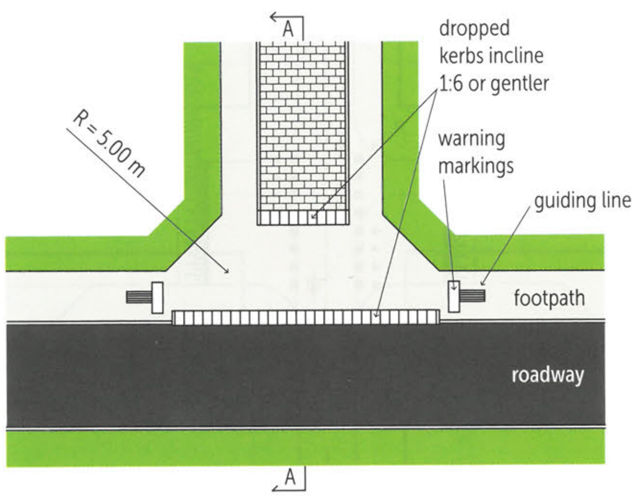
Implementation
- continue structure and colour of pavement and cycle path alongside main carriageway over exit
- no markings, bollards and suchlike on the pavement
- do not run cycle lane alongside main carriageway over exit
- in order to minimize the probability of damage, instead of paving slabs measuring 0.30 × 0.30 m, slabs measuring 0.20 × 0.20 m or 'thick' slabs can be used
- when connecting street or premises, also use dropped kerb on rear side

Dimensions
- length dropped kerb: 0.80 m
- L is variable (depending on road width and requisite room for manoeuvre design vehicle)

Considerations
- easily recognizable
- legal status clear
- clear delimitation
- relatively expensive
- dropped kerb constitutes a nuisance for cyclists
- greater probability of falling when slippery

Combination possibilities
- central traffic island on main carriageway

Alternatives
- statutory regulation (sign B6)



V24 Transition from bidirectional cycle path to one-way cycle path by way of crossing with transverse central island

Function
- securing cyclists' crossing if a crossing is not feasible at a junction

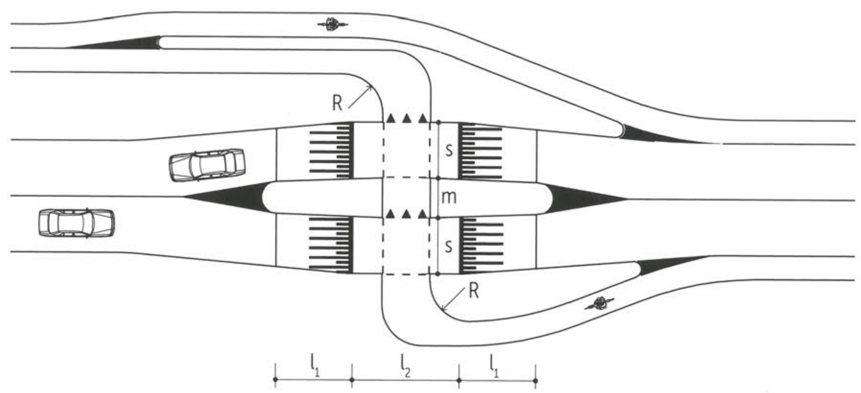
Application
- distributor road within and outside of built-up areas

Implementation
- safeguarding recognizability by means of vertical elements and public lighting
- safeguarding good visibility of bicycle traffic
- cyclists do not have right of way
- indicating priority situation, no block markings, no red vehicle path
- preferably raised

Dimensions
- l_1 = 4.80 m
- l_2 = 5.00 to 10.00 m
- m ≥ 2.50 m
- R = minimum of 5.00 m
- s = 2.90-3.50 m
- curve radii on the non-intersecting cycle path 17 m as a minimum

Considerations
- low speed for all traffic at crossing
- cyclists within field of vision of other traffic
- cyclists are able to cross in stages due to transverse central island
- use of space
- increase in noise nuisance and vibrations
- cyclists crossing diagonally

Combination possibilities
- area boundary



V25 Cycle crossing with central traffic island

Function
- improving crossing situation
- limiting speed of motorized traffic
- indicating crossing situation

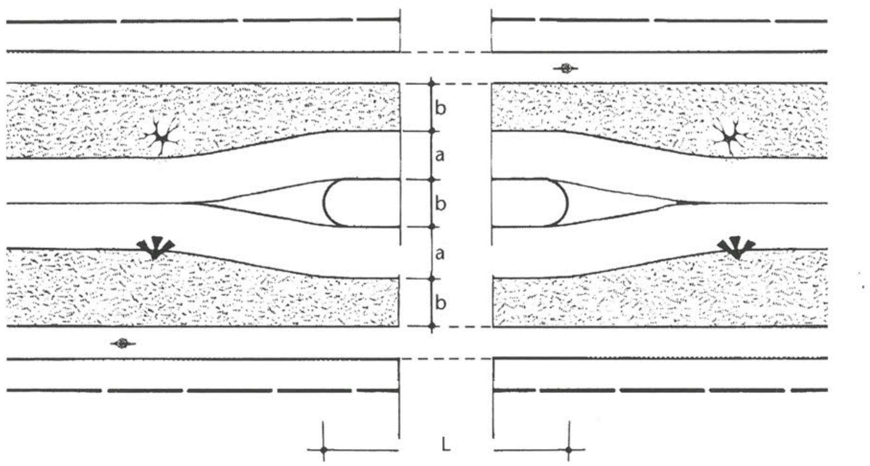
Application
- distributor road within and outside of built-up areas
- residential road within and outside of built-up areas
- bidirectional traffic on main carriageway
- for further information see text in box 'Crossability' in 6.2.1

Implementation
- traffic island preferably symmetrical in carriageway centre line
- safeguarding recognizability by means of vertical elements and public lighting
- if b is sufficiently big, then possibly low plants on central traffic island
- ensure good eye contact
- traffic island at cycle crossing, raised or otherwise

Dimensions
- a = 2.75 to 3.50 m, depending on function for motorized traffic
- width of central traffic island (b) ≥ 2.50 m
- L = 5.00 to 20.00 m
- bevelling outward bends depending on design speed, but at least 1:5
- height of any plants on traffic island < 0.60 m

Considerations
- increased attention
- lack of view
- moderate to good reduction in speed, depending on width of central traffic island
- crossing in stages
- the speed reduction effect is small with dimensioning for heavy traffic
- motorists may be too intently focused on the outward bend of the carriageway

Combination possibilities
- visual aid
- crossing facility
- speed bump: see V9
- regulating priority (in the case of distributor road)



V26 Gentle outward bend of cycle path

Function
- improving cyclists' visibility
- clarifying right of way

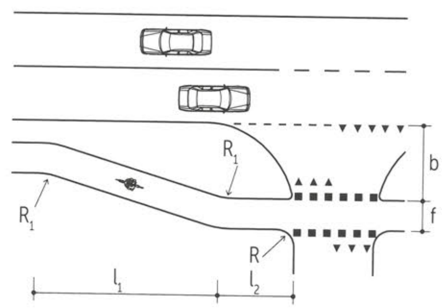
Application
- cycle path alongside priority road (distributor road)
- if cycle path occupies less than 4.0 m of the carriageway
- within and outside of built-up areas

Implementation
- continuing surfacing on side road
- shark's teeth (V55) and block markings
- no tall plants
- in the case of bidirectional cycle path, apply centre line and arrow markings on the cycle path and install additional signage (underplate J24 with OB0503) for the benefit of recognizability on the part of motorists

Dimensions
- width of cycle path: see V16
- b = 5.00 m
- f ≥ 2.00 m, in (1); f ≥ 2.50 m, in (2)
- l_1 = circa 30.00 m
- $l_2 \geq 5.00$ m
- R ≥ 5.00 m
- $R_1 \geq 12.00$ m

Considerations
- comfortable for cyclists
- stacking space for cyclists turning left on cycle paths around the junction
- stacking space for conflicting vehicles
- large-scale junction

Combination possibilities
- streamed cycle paths: see V35
- raised cycle path (on speed hump)
- speed bump in coordinating branch 20 m from point of conflict



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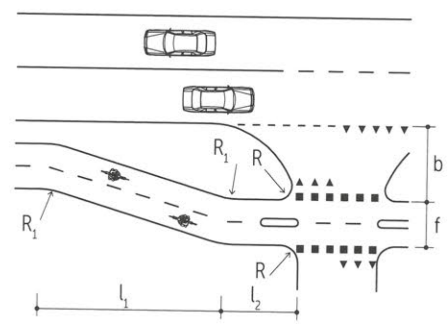


(2)

V27 Cycle crossing over side road in the case of cycle lane or road with narrow segregation verge

Function
- improving cyclists' visibility
- clarifying right of way

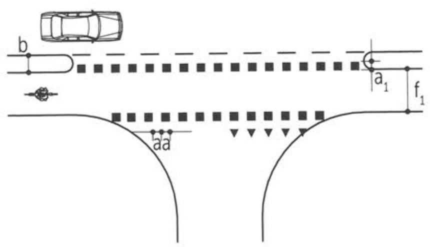
Application
- priority junctions within built-up areas

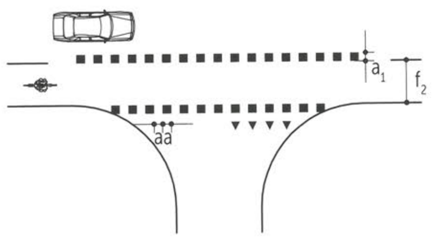
Implementation
- surfacing and colour of cycle path continue onto side road
- markings in thermoplastic material, road paint, preformed adhesive material or surfacing material
- site standard sign B6 (see also under Combination possibilities)
- if b > 0.70 m, then use shark's teeth on both approach directions for the cycle path: see V55
- there must be a sufficiently large vehicle path left between the block markings; if need be, apply block markings outside of vehicle path for bicycle traffic

Dimensions
- a = 0.50 m
- b = 0.50-2.00 m
- for f_1 see dimensions segregated cycle path (V16)
- for f_2 see dimensions cycle lane (V15)

Considerations
- less safe than a cycle path 4 to 5 m from the carriageway
- directness for cyclists is optimal
- crossing clearly and quickly recognizable
- chance of cars blocking cycle path or cycle lane
- no stacking space for left-turning cyclists on cycle path or cycle lane
- increased probability of rear-end collisions on main carriageway

Combination possibility
- sign B7 instead of sign B6 (hence also using stop line instead of triangular markings)





V28 Bidirectional cycle crossing over side road, in road with segregation verge

Function
- improving cyclists' visibility
- clarifying right of way

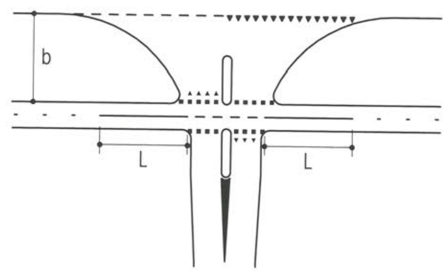
Application
- priority junction
- within and outside of built-up areas

Implementation
- as in V27 plus a number of 'extras'
- centre line on cycle path: see V5
- drawing attention to bidirectional path
- shark's teeth on both approach directions for the cycle path: see V55

Dimensions
- b = 5.00 m
- L = circa 10 m

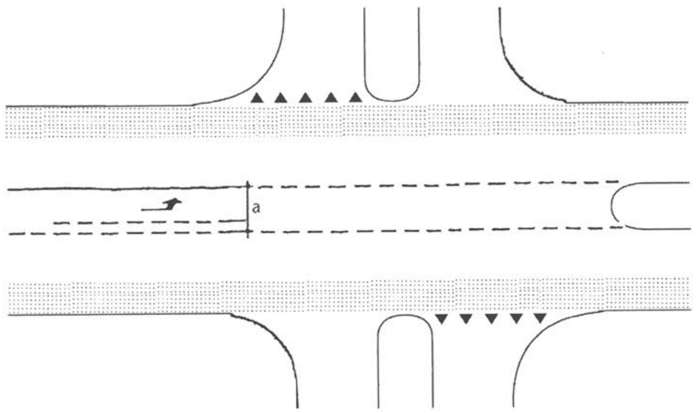
Considerations
- reasonable view of cyclists
- little chance of cars blocking cycle path
- generous stacking space for left-turning cyclists
- motorists are sometimes not expecting any bicycle traffic from the 'wrong' direction, increasing the probability of accidents for bicycle traffic coming from this direction

Combination possibilities
- sign B7 instead of sign B6; consider accompanying stop line instead of first row of triangular markings
- raised cycle crossing
- arrow markings on cycle crossing to clarify bidirectional traffic



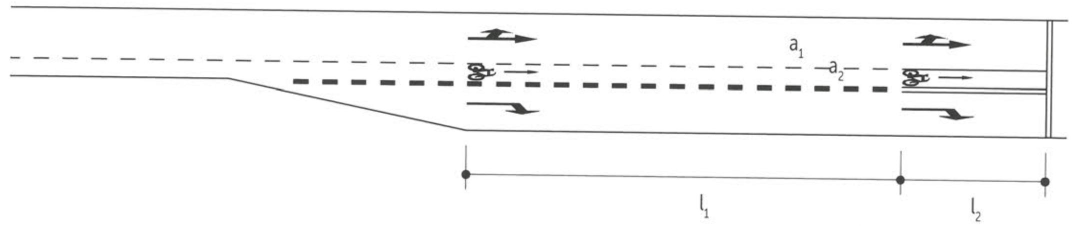
V29 Weaving on the part of left-turning cyclists

Function	- safe weaving on the part of cyclists and cars
Application	- junction in distributor road within built-up areas - junction in residential road within and outside of built-up areas - cycle lane - no more than one traffic lane for motorized traffic going straight on
Implementation	- preferably also use cycle lane in left-turn box
Dimensions	- width of left-turn lane (a) 2.75-3.25 m - see V15 for width of cycle lane - length of cycle lane in left-turn lane depends on length of left-turn lane, though it should be circa 15 m as a minimum
Considerations	- no conflict on junction - children and the elderly will perceive the crossing situation to be unsafe - left-turn lane will be difficult to reach in high volumes of motorized traffic - conflict between cyclists getting into lane and traffic approaching from behind
Combination possibilities	- Raised junction
Alternatives	- no cycle lane in turning lane for left-turning traffic (position of bicycle unclear) - convert junction to roundabout



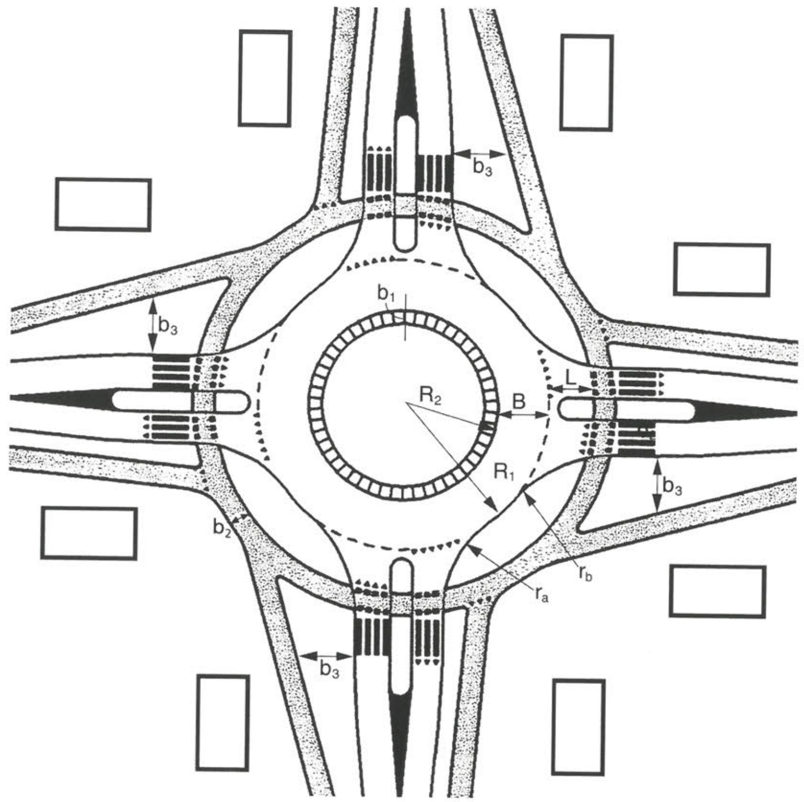
V30 Weaving on the part of cyclists with right-turning motorized traffic with right-turn box

Function	- safe weaving on the part of cyclists and cars
Application	- junction in distributor road - in built-up areas - cycle lane - a lot of conflict between cyclists going straight on and motorized traffic turning right
Implementation	- where lots of cyclists are turning right, perhaps consider a cycle lane in the right-turn box as well - cycle lane preferably in red
Dimensions	- a_1 = lane marking stripe 1-1, 0.10 m wide, transitioning to continuous stripe - a_2 = lane marking stripe 1-1, 0.30 m wide, transitioning to double continuous stripe, 3 × 0.10 m - l_1 = 15 to 30 (50) m - l_2 = 10 m
Considerations	- no conflict on junction - weaving is perceived to be awkward and unsafe
Combination possibilities	- lane for cyclists should be in a different colour and/or texture (e.g. red asphalt)
Alternatives	- convert junction to roundabout - segregated cycle path: see V16



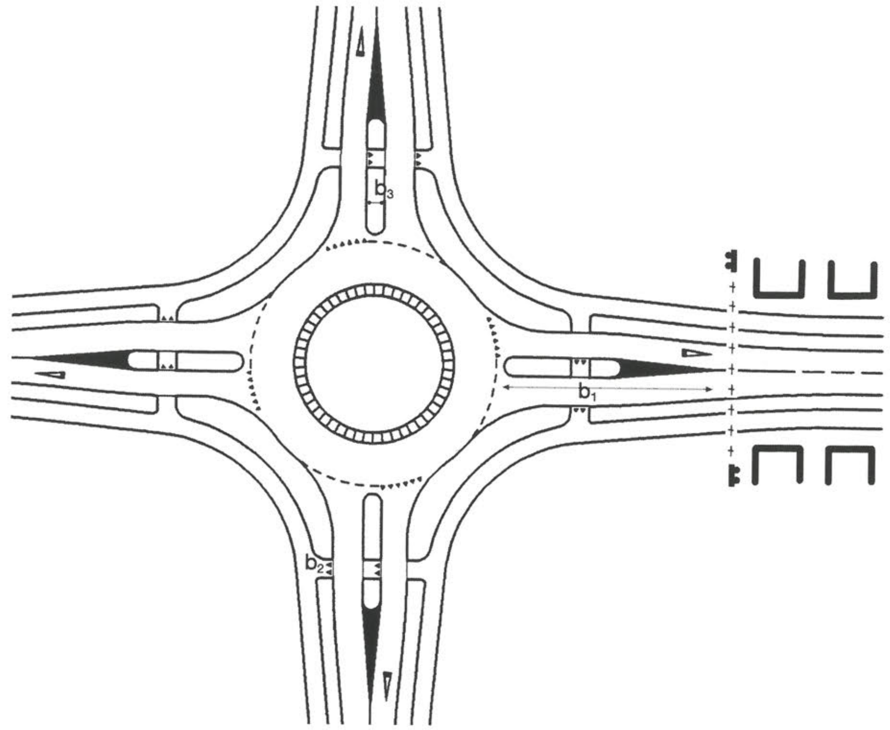
V31 Single-lane roundabout with segregated cycle path and cyclists given right of way

Function	- smooth, safe exchange of traffic flows
Application	- connection of distributor road to other distributor road or residential road - in built-up areas - sum of approaching traffic flows < circa 25,000 PCU/24-hour period (conflict load circa 1,500 PCU/h) - even distribution of traffic over the branches
Implementation	- bicycle crossing provided with block markings and shark's teeth, also for traffic leaving the roundabout - continue cycle path in different colour at the crossings over roundabout, parallel to the carriageway on the roundabout - cycle path around roundabout circular - consider gentle camber for cycle path (improved visibility) - get cyclists no longer following the roundabout off cycle path as soon as possible: see indicator b_3 - same priority regime for cyclists and pedestrians - vertical elements on raised central traffic island - safeguarding recognizability by means of public lighting - consider having no central traffic island(s) on quiet branch(es)
Dimensions	- R_1 = 12.50 to 20.00 m - R_2 = 6.50 to 15.00 m - r_a = 12.00 m, with central traffic island; r_a = 8.00 m, without central traffic island - r_b = 15.00 m, with central traffic island; r_b = 12.00 m, without central traffic island - B = 5.00 to 6.00 m (depending on R_1 and R_2) - b_1 = 1.50 (1.00) m - b_2 = 2.00 to 2.50 m - b_3 = as big as possible - L = 5.00 m
Considerations	- relatively safe: fewer points of conflict than with traditional junction - relatively high capacity - improved visibility of junction - considerable reduction in speed - good bicycle traffic flow - difficult for lorries to drive on in the case of small R_1 and R_2
Combination possibilities	- crossing facility - bidirectional cycle path - bus lane on approach branch
Alternatives	- priority junction with central traffic island



V32 Single-lane roundabout with segregated cycle path and cyclists not given right of way

Function	- smooth, safe exchange of traffic flows
Application	- only outside of built-up areas - junction distributor road with residential road or other distributor road - sum of approaching traffic flows < circa 25,000 PCU/24-hour period (conflict load circa 1,500 PCU/h)
Implementation	- cycle path around roundabout not circular - no block markings where there is a cycle crossing - no cycle path surfacing carrying over - central traffic islands sufficiently wide in connection with cyclists' stacking space - same priority regime for cyclists and pedestrians - vertical elements on raised central traffic island - safeguarding recognizability by means of public lighting
Dimensions	- for basic starting points see V31 - for the course of the cycle path around the roundabout: see appended figure - length of central traffic island (b_1) ≥ 14.50 m - stacking space on cycle path (b_2) 2.10 to 3.00 m - width of central traffic islands (b_3) 2.50 to 3.00 m (2.10 m)
Considerations	- extremely good increased attention - effective speed reduction - enhanced safety, few accidents involving injury - poor bicycle traffic flow
Combination possibilities	- moped shortcuts (moped on carriageway) if location of roundabout entails a change in speed regime - plants
Alternatives	- junction with traffic light control system



V33 Turbo roundabout with cyclists given right of way

Function	- smooth, safe exchange of motorized traffic
Application	- junction distributor roads - up to 40,000 PCU/24-hour period on the roundabout, depending on implementation - bicycle traffic on roundabout, only if grade-separated crossing and/or diverting are not possible
Implementation	- continue cycle path's red colour over the roundabout - create bicycle crossings on raised junction - for reasons of road safety, make all exits single lane (to prevent accidents due to obstructed view) - bicycle crossings on turbo roundabouts in built-up areas are always ridden in a single direction, so never create bidirectional cycle paths around them
Dimensions	- highly dependent on the roundabout design - the shape of the roundabout depends on traffic volumes, road safety and amount of space taken up - see CROW publication 257 'Turborotondes' [10]
Considerations	- high capacity - improved visibility of junction - considerable reduction in speed - easy for lorries and public transport to drive on - takes up a lot of space - risk of weaving accidents - risk of cyclists being hidden in the case of double exit - detour for cyclist due to one-way cycle path around roundabout
Combination possibilities	- crossing facilities
Alternatives	- turbo roundabout with cyclists not given right of way: see V34 - junction with traffic lights

V34 Turbo roundabout with cyclists not given right of way

Function	- smooth, safe exchange of traffic flows
Application	- junction distributor roads - up to 40,000 PCU/24-hour period on the roundabout, depending on implementation - bicycle traffic around roundabout, only if grade-separated crossing and/or diverting are not possible
Implementation	- do not continue cycle path's red colour over the roundabout - make cycle crossings raised if possible (table) - for reasons of road safety, make all exits single lane (to prevent accidents due to obstructed view)
Dimensions	- highly dependent on the roundabout design - the shape of the roundabout depends on traffic volumes, road safety and amount of space taken up - see CROW publication 257 'Turborotondes' [10]
Considerations	- high capacity - improved visibility of junction - considerable reduction in speed - easy for lorries and public transport to drive on - takes up a lot of space - risk of weaving accidents
Combination possibilities	- crossing facilities
Alternatives	- turbo roundabout with cyclists given right of way: see V33 - junction with traffic lights

V35 Streamed cycle path (Free right turn past red for cyclists)

Function
- improving flow of cyclists turning right

Application
- junction with traffic light control system
- within and outside of built-up areas
- all types of regulation

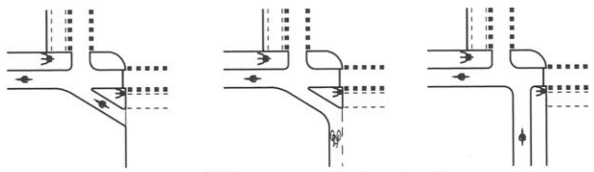
Implementation
- cyclists are guided past traffic light control system by means of cycle facility (small cycle path)
- joining traffic flexibly
- cyclists turning right will emerge onto cycle path, cycle lane or have sufficient cover behind them
- where the volume of pedestrians is high, endeavour to have as much space as possible between the non-controlled and controlled crossing
- adapting traffic light control system not necessary
- regulate right of way with conflicting cycling directions

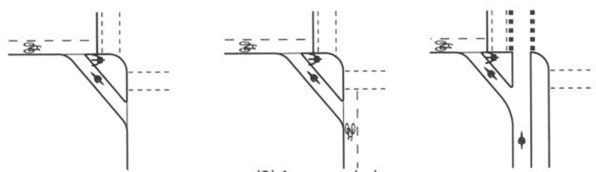
Dimensions
- width right-turn path dependent on volume (see V16), but 1.50 m as a minimum

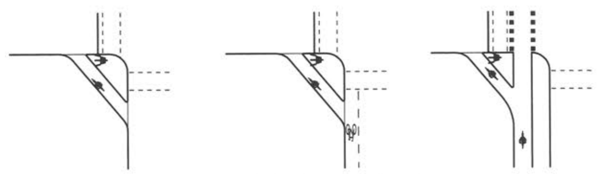
Considerations
- good flow of cyclists turning right (no waiting time)
- less going through red lights
- misuse of right-turn path on the part of other cyclists
- takes up extra space
- tricky for pedestrians crossing

Combination possibilities
- can be combined with any system (apart from cyclists free to turn right: see V36)

Alternatives
- cyclists free to turn right (V36)


(1) from segregated cycle path


(2) from cycle lane


(3) from carriageway

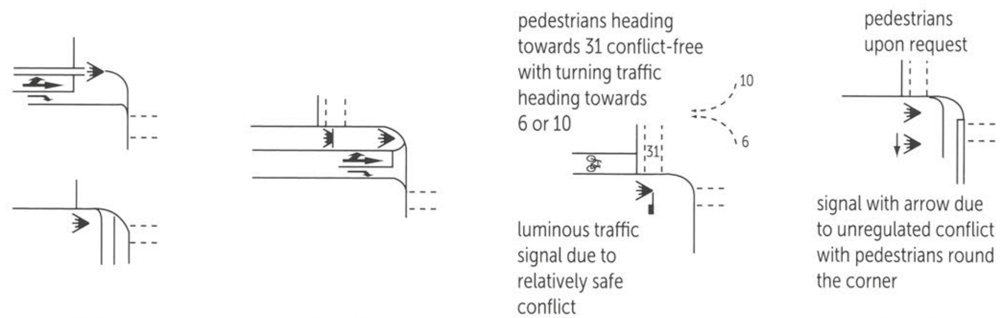
V36 Cyclists free to turn right

Function
- improving flow of cyclists turning right

Application
- junction with traffic light control system
- within and outside of built-up areas
- cycle lane or segregated cycle path
- fixed and vehicle-dependent system
- if there is no controlled pedestrian crossing or if a multi-phase system can include a phase that does not entail pedestrians crossing
- type 4: in the case of pedestrian control on request, at points with few pedestrians and a lot of cyclists

Implementation
- in the case of sufficient space for cyclists on side road
- adapt markings in the case of type 1 and type 2; no stop line for cyclists turning right, if possible; install a sign saying 'cyclists free to turn right' next to the traffic lights; preferably install traffic light for bicycles on the left
- type 4 is only possible if cyclists and the pedestrians around the corner can intersect without conflict or uncontrolled and a separate three-coloured light with an arrow is used (4); if a relatively minor conflict occurs with pedestrians around the corner or with traffic from other directions, then a luminous traffic signal is advised (type 3), on the proviso that this is not illuminated at the same time as the green aspect for bicycles
- critical attention to green aspect and clearance times

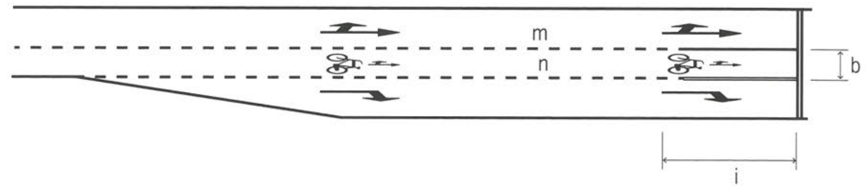
Considerations
- no waiting time for cyclists turning right
- system ties in better with actual behaviour on the roads
- no enforcement issues
- inconvenient for crossing pedestrians (particularly the blind and visually impaired)
- type 3 and type 4: expansion with traffic lights is not always possible for existing equipment
- types 1, 3 and 4: options for use in practice are limited

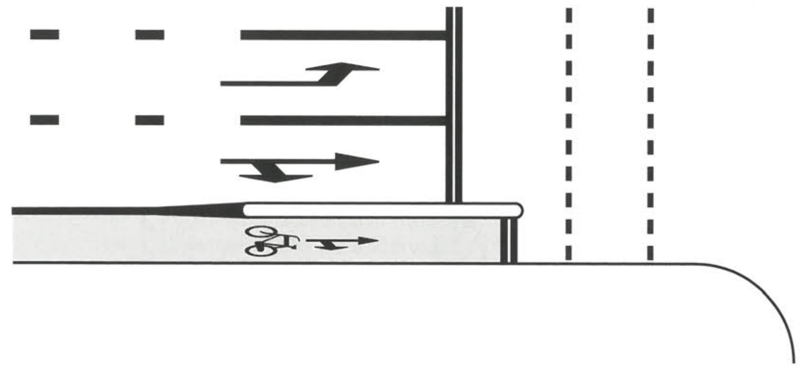


type 1 type 2 type 3 type 4

V37 Stacking space for cyclists going straight on at traffic light control system

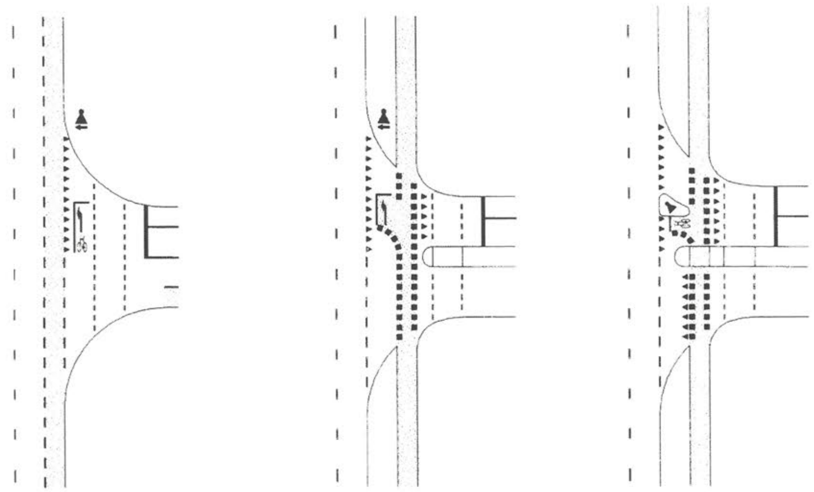
Function	- separately control cyclists going straight on at traffic light control system in the case of mixed traffic, cycle lanes or advisory cycle lanes
Application	- on approach carriageways of junctions with traffic light control system - in built-up areas - v_{max} main carriageway 50 km/h
Implementation	- maximum of one traffic lane per direction for motorized traffic - preferably with stacking lane for bicycles at stop line, if there is no cycle lane or advisory cycle lane on carriageway (length circa 10.00 m) - preferably with small physical traffic island right before the stop line (width circa 0.50 m, length $\geq$ 5.00 m - see detail) - in the event of conflict between cyclist going straight on and car turning right, put stop line for stacking space 2.00 to 3.00 m ahead of stop line for motorized traffic
Dimensions	- width of traffic lane for cars: > 3.25 (3.00) m without stacking lane; > 2.50 m with stacking lane - width of stacking lane for bicycles (b) $\geq$ 1.50 (1.00) m - length of stacking lane for bicycles (i) $\geq$ 10.00 m - m = lane marking stripe 1-1, width 0.10 m, transitioning to continuous stripe - n = lane marking stripe 1-1, width 0.30 m, transitioning to double continuous stripe (3 × 0.10 m)
Considerations	- stacking lane for bicycles provides clarity on position of cyclists - physical traffic island provides physical protection (prevent cyclist flow from being blocked) - placing stop line for stacking lane ahead leads to better visibility of cyclists (limiting blind spot) - increased flow capacity with stacking lane for bicycles - lack of stacking lane for bicycles is unpleasant for cyclists - lack of safety for cyclists: where there are more lanes, motorists are focused on traffic light control system in busy traffic and cyclists can be overlooked
Combination possibilities	- advanced stop line: see V39
Alternatives	- streamed cycle path: see V35 - segregated cycle path: see V16





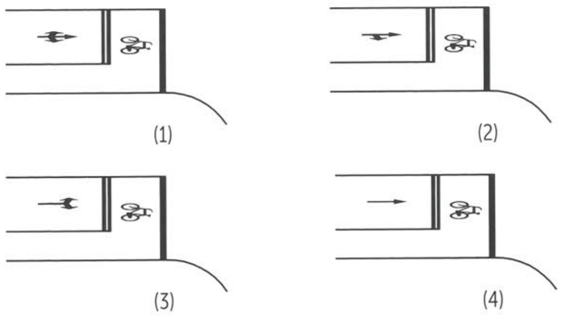
V38 Stacking space for cyclists turning left at traffic light control system

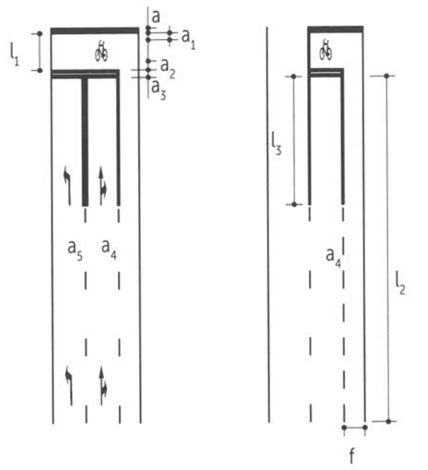
Function	– providing stacking space for cyclists turning left at traffic lights
Application	– junction with traffic light control system – within and outside of built-up areas (v_{max} outside of built-up areas 60 km/h)
Implementation	– marked stacking space; a gap light is necessary – in the event of there being insufficient space between cycle path and carriageway, left-turn stacking space can also be sited to the right of cycle path or cycle lane, between pedestrian crossing and cycle path
Dimensions	– depending on volume; width of stacking space > 1.20 m
Considerations	– cyclist in an illogical place – subjective risk – in the absence of physical refuge, unsafe should traffic control system fail – choose location of gap light carefully
Alternatives	– left-turn box to the right of cycle path or cycle lane – all directions green: see V48 – advanced stop line (with maximum of two lanes per branch): see V39



V39 Advanced stop line

Function	– safe crossing or left turn for cyclists
Application	– junction with traffic light control system – in built-up areas – in the event of a relatively high volume of cyclists turning left or in the event of a lot of cyclists going straight on and cars turning right – in the case of a well-organized junction – in the case of mixed traffic or cycle lane on carriageway or adjacent cycle path – maximum of two traffic lanes/stacking spaces per approach road – in the event of there being less than 500 PCU/h on a branch or 800 PCU/h at a junction
Implementation	– stacking space for cyclists ahead of stop line for motorized traffic – bicycle symbol in stacking space: see V54 – central traffic island to the left next to stacking space – in the case of left-turn box for motorized traffic, preferably separate advanced stop line with its own introductory cycle lane (necessary in the case of left-turning traffic having its own green aspect) – stacking space and introductory cycle lane preferably in red colour – preferably combined with central traffic islands, creating a physically screened off stacking space for cyclists on the approach roads
Dimensions	– a = 0.30 m (stop line) – a_1 = 0.50 m (space between stop line and bicycle symbol) – a_2 = 2.75 m – a_3 = 3 × 0.15 m – a_4 = lane marking stripe 1-1, 0.10 m wide – a_5 = lane marking stripe 1-3, 0.30 m wide – $f \geq 2.75$ m – f = circa 1.50 m, but $\leq$ 1.75 m, otherwise cars will misuse it as a turning lane – l_1 = 4.00 to 5.00 m; in general 4.00 m will suffice, though more space is required where bicycle traffic volumes are high – $l_2 \geq 25$ m – l_3 = 5.00 to 10.00 m
Considerations	– smooth flow of (left-turning) bicycle traffic – maximum visibility of cyclists (safe), particularly blind spot prevention as well – smoother flow of motorized traffic turning right – ample stacking space during red aspect – less nuisance from exhaust fumes when waiting – less conflict between cars and bicycles in front of the junction – less nuisance when approaching stop line – advanced stop line is not always respected by motorist – advanced stop line is not always used optimally by cyclists – in the case of advanced stop line for two lanes: subjective risk (cars overtaking on the right whilst cyclist is turning left)
Combination possibilities	– cycle lane: see V15 – free right turn past red: see V35 – cyclists free to turn right: see V36





V40 Short cycle time

Function	- reducing average waiting time for cyclists
Application	- junction with traffic light control system - within and outside of built-up areas - in the case of mixed traffic, cycle lane on carriageway and segregated cycle path - for all types of system
Implementation	- cycle time a maximum of 90 s - critical attention to green aspect and clearance times - the more compact a junction is, the easier it is to achieve a short cycle time - bicycle-bicycle conflict and bicycle-pedestrian conflict outside of the traffic light control system
Considerations	- short cycle time leads to short waiting time and lower probability of having to stop - smooth flow of all traffic, including cyclists - chance of having to stop twice on busiest directions

V41 Joint control with public transport

Function	- reducing waiting time for cyclists
Application	- junction with traffic light control system - within and outside of built-up areas - traffic control with priority given to public transport
Implementation	- when registering public transport, cycling directions situated in parallel (non-conflicting) are also registered when a cyclist is present
Considerations	- extra implementation options for bicycles, resulting in shorter waiting time - no adverse impact on other directions - additional probability of driving through a red light due to the often extremely short green aspect and clearance time for public transport directions

V42 Joint extension cycling directions with other directions

Function	- reducing waiting time for cyclists
Application	- junction with traffic light control system - within and outside of built-up areas - segregated cycle paths
Implementation	- by jointly extending with non-conflicting directions for motorized traffic, the cyclist will be given a green aspect more, resulting in the waiting time being limited - incorporate into system as standard - critical attention to green aspect and clearance times
Considerations	- extra implementation options for bicycles, resulting in shorter waiting time - no adverse impact on other directions

V43 Favourable phase order for cyclists turning left

Function	- reducing waiting time for cyclists
Application	- junction with traffic light control system - within and outside of built-up areas - on at least one branch there is a relatively high volume of cyclists turning left - in the case of segregated cycle paths - for all types of control system
Implementation	- create a link in the system between both crossings - critical attention to green aspect and clearance times
Considerations	- smooth flow of cycling direction turning left, motion possible without stopping - can give rise to additional waiting time for other directions, thereby extending cycle time

V44 Green wave for bicycle traffic

Function	- reducing waiting time for cyclists
Application	- junctions with traffic light control system a short distance from one another - within and outside of built-up areas - in the case of through bicycle traffic flow - in the case of mixed traffic, cycle lane on carriageway and segregated cycle path - possibly parallel to green wave for public transport or (for fast cyclists) car
Implementation	- linking traffic light controls will enable through bicycle traffic flow (straight on, right turn or left turn) without stopping - notification to initiate or extend green aspect phase of second set of lights is issued by the detector in front of the first set of lights - take average cycling speed or design speed into account - consider installing an extra detector between both bicycle traffic lights; green wave will be interrupted in the absence of notification - critical attention to green aspect and clearance times
Considerations	- smooth flow of through cycling direction, motion possible without stopping - lower incidence of cyclists ignoring red light - cyclists and riders of light mopeds cannot be 'captured in a single wave' - can give rise to additional waiting time for other directions, thereby extending cycle times - greater distance between the junctions and/or greater differences in speed between cyclists will give rise to 'pack diffusion' (the group of cyclists will break up)

V45 Advance detection/pre-request

Function
- reducing waiting time for cyclists

Application
- junction with traffic light control system
- within and outside of built-up areas
- in the case of cycle lanes and segregated cycle paths
- traffic-dependent and vehicle-dependent systems

Implementation
- advance detection an ample distance from the stop line enables the traffic light controls to respond more effectively to approaching cyclists; distance between detection and stop line will depend on control system, e.g. 40 to 50 metres
- in the case of bidirectional paths, make this direction-dependent or separate directions by means of a central traffic island
- critical attention to green aspect and clearance times

Considerations
- cyclists can be given a green aspect sooner and the green aspect can be extended
- chances of missing cycling direction is limited
- maintaining green aspect for cyclists in detection area (higher chance of being able to carry on)
- less nuisance than having to press a button
- can give rise to additional waiting time for other directions, thereby extending cycle time
- a high volume of bicycle traffic turning right (outside of the control system) will give rise to a lot of 'false' registrations of cyclists

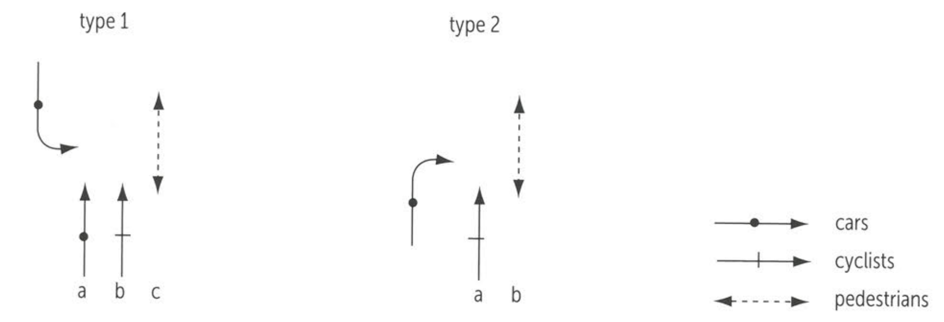
V46 Allowing partial conflict

Function
- reducing waiting time for cyclists

Application
- junction with traffic light control system
- within and outside of built-up areas
- not in the case of lateral conflict with motorized traffic
- only where volumes of motorized traffic turning are low
- not in the case of bidirectional cycle path
- not in the case of two left-turn lanes
- type 1 not in the case of segregated cycle path

Implementation
- permitting partial conflict (conflict matrix) in the control system will enable the cycle time to be limited (preferably to a maximum of 90 s)
- do not use any arrow lights in the case of conflicting directions (i.e. full lens); do include a warning, if need be
- later conflicts between slow-moving traffic can be kept out of the control system
- critical attention to green aspect and clearance times
- give cyclists a head start by setting bicycle traffic light to green earlier and/or putting stop line for cyclists ahead

Considerations
- shorter cycle time will lead to shorter (maximum) waiting time
- depending on volumes, possibly smoother flow of all traffic, including cyclists
- less safe (cyclists not fully relieved of conflict)

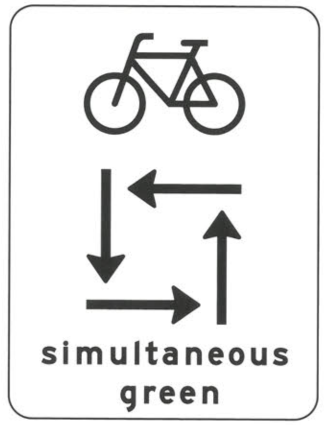


V47 Implementing addition cycling directions

Function	- reducing waiting time for cyclists
Application	- junction with traffic light control system - within and outside of built-up areas - in the case of cycle lanes and segregated cycle paths
Implementation	- implementing additional cycling directions will reduce the waiting time for cyclists on the relevant direction(s) - critical attention to green aspect and clearance times
Considerations	- waiting time for cyclists is reduced (increasing chance of being able to carry on) - longer waiting times for motorized traffic

V48 All cycling directions are given a green aspect simultaneously

Function	- reducing waiting time for cyclists
Application	- junction with traffic light control system - in built-up areas - cycle lanes as well as cycle paths close to the main carriageway - well-organized, compact junction situation - in the case of a relatively high volume of cyclists turning left (> 10%)
Implementation	- all cycling directions are given a green aspect simultaneously - critical attention to green aspect and clearance times is necessary, particularly clearance times for motorized traffic: at the start of the green light for cyclists, no motor vehicles should be in the junction area any more - consider introducing a narrow physical separation between motorized traffic and bicycle traffic on approach roads - indication using sign VKL04 pursuant to Administrative Provisions (Road Traffic) Decree (Besluit administratieve bepalingen inzake het wegverkeer, or BABW)
Considerations	- favourable for cyclists turning left (diagonal crossing, without an extra stop) - no partial conflict with motorized traffic: safe for cyclists - 'hard' laterally conflicting cycling directions in the same green phase: chance of bicycle-bicycle accidents - waiting time for motorized traffic will increase - integrating pedestrians with 'green for all cyclists' is difficult - people will not understand if cyclists are not allowed to move when motorized traffic is allowed to move - cycle will get longer (usually)



V49 Favourable idle mode for cyclists

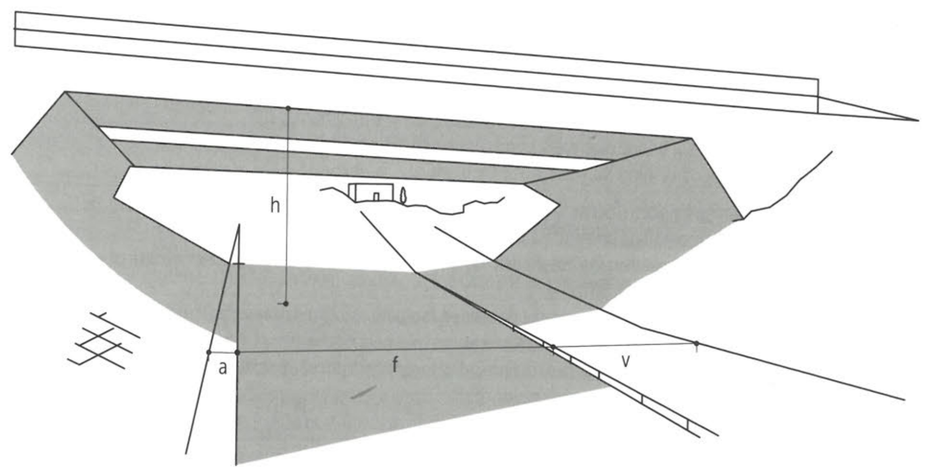
Function	- reducing waiting time for cyclists
Application	- junction or crossing with traffic light control system - within and outside of built-up areas - on segregated cycle paths and in main cycle routes - in the case of fixed or vehicle-dependent system - in the case of controlled crossing, two linked systems halfway; cyclists will be given a green aspect as soon as there is a gap in the traffic flow - type 2: if cyclists are crossing in groups (school route and suchlike) or if there are regular bursts of bicycle traffic, resulting in excessively reduced capacity for other traffic
Implementation	- type 1: idle mode green on cycle path; control system is car-dependent: in the absence of notification vis-à-vis other traffic, bicycle traffic light will remain green; good detection of motorized traffic is required to enable vehicle to carry on in the absence of cyclists - type 2: idle mode green on carriageway motorized traffic; control system is bicycle-dependent (advance detection of bicycles required): if there is no bicycle traffic, then the car direction will be kept green; good detection of bicycle traffic is required to enable cyclists to carry on in the absence of cars - type 3: idle mode red; direct influence: control system is car and bicycle-dependent - critical attention to green aspect and clearance times - good detection zone is required in all cases
Considerations	- increased chances of cyclists being able to carry on - there is some indication that idle mode red with a view to road safety is more beneficial than idle mode green - in the case of 1, the waiting time for motorized traffic at quiet times increases (due to clearing cycling directions) - in the case of type 1, there is a chance of motorized traffic ignoring red light (motorist expecting light to turn green, which is not always the case, however; hence potential danger) - in the case of type 3, green aspect can be given straight after notification (no clearance time on conflicting directions)

V50 Waiting time indicator

Function	- improving cyclists' comfort by providing an idea of the remaining waiting time
Application	- junction with traffic light control system - within and outside of built-up areas - cycle lanes and segregated cycle paths - fixed and vehicle-dependent system - particularly in places where lots of cyclists go through red lights
Implementation	- dimming the lights or a countdown provides an indication of the waiting time for cyclists - installing next to or in green bicycle traffic light, in bottom light or in button - lights are not allowed to revert to longer waiting time - critical attention to green aspect and clearance times
Considerations	- service improvement: if cyclists understand the waiting time, they will perceive it to be shorter - lower incidence of cyclists ignoring red light - no adverse effects on other traffic - in vehicle-dependent control systems with (for example) bus interventions, the waiting time is difficult to predict; this can cause a high degree of irregularity in terms of the dimming of the lights - extra equipment costs

V51 Cycle underpass

Function	▬ conflict-free intersection of motorized and bicycle traffic
Application	▬ junction distributor road with important cycle route ▬ within and outside of built-up areas
Implementation	▬ cyclists preferably at ground level; where this is not possible, raise carriageway for motorized traffic by about 2.00 m, thereby reducing the height differential to be spanned by cyclists ▬ make maximum use of daylight: in the case of separating carriageways, a central opening in the overhead structure can allow extra light ingression ▬ no high plants near entrance to underpass ▬ lighting in underpass should be vandalism-resistant (recessed) ▬ no corners/niches ▬ walls recede towards top ▬ straight course: exit must be visible upon entering underpass ▬ inclines before and after underpass should not give people with malicious intent the opportunity to conceal themselves (no plants, no corners and suchlike) ▬ consider combining with pavement for pedestrians ▬ outside of built-up areas, consider combining with fauna tunnel
Dimensions	▬ width of cycle path in the absence of footpath: 2 × 0.625 m (clearance closed wall) + width of approach cycle path, with a minimum of 3.50 m ▬ f: width of cycle path in the case of one-sided footpath: 0.625 m (clearance closed wall) + width of approach cycle path, with a minimum of 3.00 m ▬ width of cycle path in the case of two-sided footpath: width of approach path, with a minimum of 3.00 m ▬ width of footpath (if present): v > 1.00 m ▬ h > 2.50 m ▬ a = 0.5 m ▬ for dimensions of incline see section 3.5 ▬ underpass floor 2% on an incline (drainage)
Considerations	▬ conflict-free intersection (safe) ▬ multiple approach routes possible ▬ cyclists on lateral connections often have to take a detour in order to get on the route of the underpass ▬ unimpeded view through underpass ▬ good lighting situation ▬ shorter inclines than in the case of bridge (due to smaller height differential) ▬ usually no groundwater problems when raising intersecting road ▬ phased construction will be necessary in current situation ▬ lack of personal safety ▬ vulnerable to vandalism
Combination possibilities	▬ tiered incline
Alternatives	▬ cycle bridge (less beneficial for cyclists than a tunnel): see V52 ▬ crossing with traffic light control system

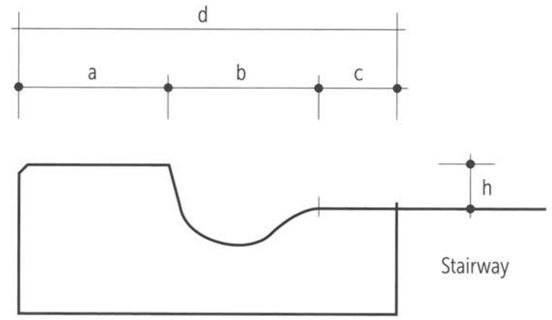


V52 Cycle bridge

Function	– conflict-free intersection of motorized and bicycle traffic
Application	– junction distributor road with important cycle route – within and outside of built-up areas
Implementation	– keep height differential to be spanned by cyclists to a minimum – in the case of bridge over road, consider lowering the road – consider combining with one-sided footpath
Dimensions	– clearance height ≥ 4.50 m – width of footpath (if present) > 1.00 m – width of cycle path in the absence of footpath: 2 × 0.325 m (clearance railing) + width of approach cycle path, with a minimum of 3.50 m – width of cycle path in the case of one-sided footpath: 0.325 m (clearance railing) + width of approach path, with a minimum of 3.00 m – width of cycle path in the case of two-sided footpath: width of approach cycle path, with a minimum of 3.00 m – for dimensions of incline see section 3.5 – height of bridge railing ≥ 1.20 m, preferably 1.30 m
Considerations	– conflict-free intersection – often cheaper than an underpass – possibilities for architecturally pleasing solution – conducive to personal safety (can be seen from road) – often longer inclines than in the case of underpass (due to larger height differential) – high bridge could trigger fear of height – wind nuisance
Combination possibilities	– stairs (with two-sided cycle channel) – tiered incline – escalator – inclined travelator – wind screen
Alternatives	– cycle underpass (often more beneficial for cyclists than a bridge): see V51 – crossing with traffic light control system

V53 Cycle channel alongside stairs

Function	– spanning height differential
Application	– always combined with stairs – in the case of access to bicycle storage – consider as an extra option for bridges and tunnels; but then always combine with travelator
Implementation	– channels on both sides of the stairs – preferably made of concrete – top of channel flush with top of steps – consider handrail tight against the wall, to prevent handlebars hitting it; ensure handrail does not not bend towards the ground at the ends – incline stairs 16% (maximum 25%); in the case of steeper inclines, use a 'track transition curve'
Dimensions	– a ≥ 0.20 m – b = 0.08 to 0.12 m (b = 0.10 m in the case of metal channel) – c = 0.03 to 0.05 m – d = 0.31 to 0.37 m – h = 0.03 m (h = 0.04 m in the case of metal channel)
Considerations	– preferably only use to supplement incline – cyclists need to make a lot of effort to ride in channel
Combination possibilities	– incline
Alternatives	– tiered incline – inclined travelator



V54 Bicycle symbol

Function
- designating cycle lane
- indicating advanced stop line: see V39

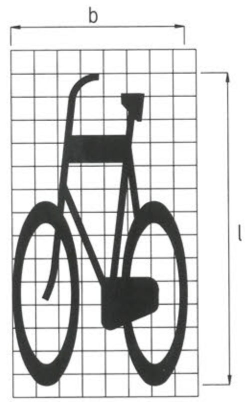
Application
- in cycle lanes
- in advanced stop line
- large version in lanes ≥ 1.80 m wide
- small version in lanes < 1.80 m wide

Implementation
- thermoplastic material, road paint or preformed marking material
- mandatory after each surfaced side road
- can additionally be used at a regular distance from:
  - 50 to 100 m within built-up areas
  - 500 to 750 m outside of built-up areas

Dimensions
- b = 1.10 m (small version) or 1.50 m (large version)
- l = 2.00 m (small version) or 2.75 m (large version)
- in exceptional cases (e.g. in the case of narrow introductory lanes to advanced stop line) b can = 0.75 m and l = 1.35 m

Considerations
- bicycle symbol has legal status: use of it brings into force a prohibition on stopping on a lane

Combination possibilities
- it is recommended that bicycle symbol only be used in combination with red surfacing
- standard arrow markings in stacking lanes



V55 Shark's teeth (triangular markings)

Function
- indicating priority situation

Application
- priority junctions
- within and outside of built-up areas
- use in combination with sign B6
- use of shark's teeth without sign B6 (Article 80 of the Road Traffic and Traffic Signals Regulations 1990) is limited to:
  - cycle paths and service roads, if the signs could cause confusion in other drivers
  - the side section of a T-junction that is subordinate to a through road, though only if the informal priority behaviour tallies with the priority regulation

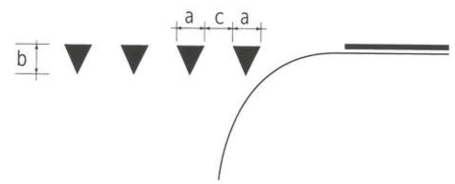
Implementation
- thermoplastic material, road paint, preformed adhesive material or surfacing material
- traffic decree is required

Dimensions
- a = 0.50 m
- b = 0.60 to 0.70 m
- c = circa 0.50 m
- d > 0.20 m

Considerations
- shark's teeth are not visible in snow

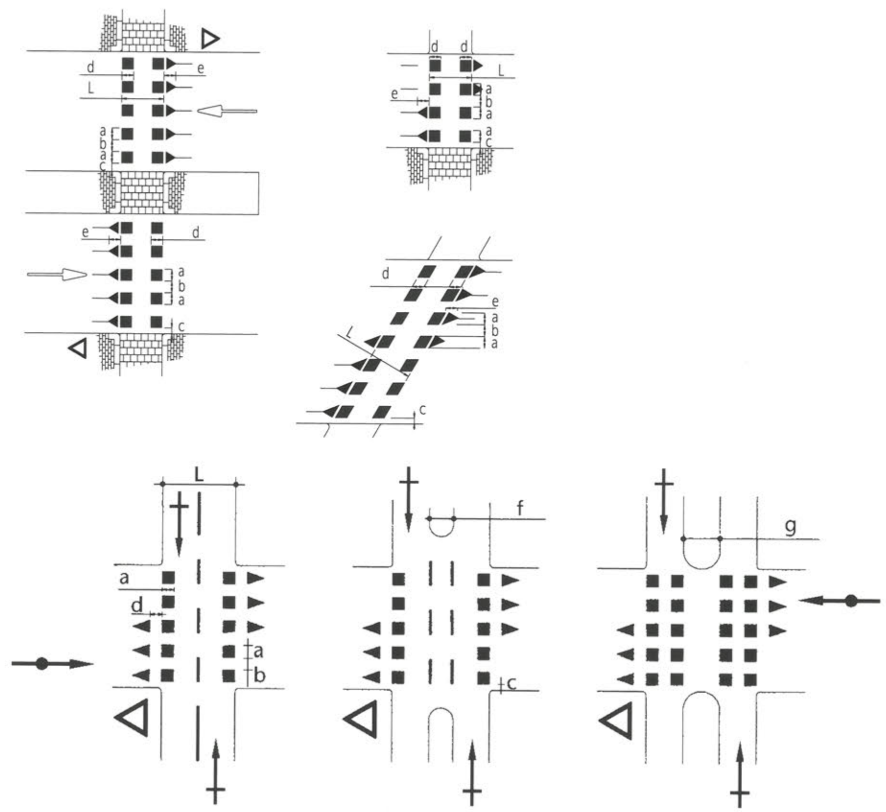
Combination possibilities
- sign B6
- outside of built-up areas: priority triangle as advance warning
- Raised junction
- central traffic island on main carriageway
- traffic island in side road (where right of way is regulated)
- cycle path alongside main carriageway on speed hump where crossing is (where right of way is regulated)

Alternatives
- exit



V56 Markings cycle crossing on road section with priority for cycle route

Function	- indicating priority situation
Application	- if intersecting traffic has to give way to cyclists crossing
Implementation	- sign B6 on intersecting direction of travel - continue cycle route surfacing onto carriageway (if possible) - there must be a sufficiently large vehicle path left between the block markings; if need be, apply block markings outside of vehicle path for bicycle traffic - shark's teeth on carriageway on both approach directions to the crossing point - preferably physical measures that reduce the speed of motorized traffic - extra attention to crossing if it pertains to a solitary cycle path (due to informal priority behaviour on main carriageway) - *no* block markings if crossing cyclists do not have right of way - in the case of bidirectional cycle path, arrows on road surface at the crossing to emphasize bidirectional traffic
Dimensions	- L > 1.50 m (in the case of one-way traffic) - L ≥ 3.00 m (in the case of bidirectional traffic) - a = 0.50 m - b = circa 0.50 m - c ≥ 0.5 × a - d = 0.50 (> 0.30) m
Considerations	- accentuating crossing point - reducing speed bolsters safety (provided that a speed bump is installed as well)
Combination possibilities	- visual aid - raised junction surface - speed reduction facilities: see V9 - reducing crossing length - traffic lights
Alternatives	- roundabout - grade-separated crossing



V57 Signage where there is a cycle crossing

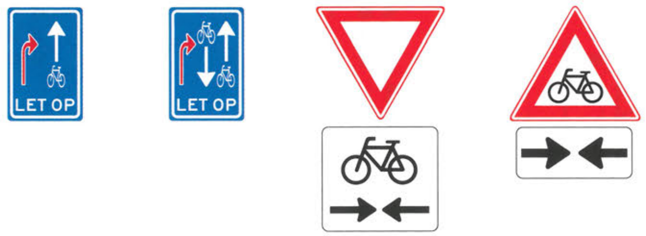
Function
- drawing attention to cyclists

Application
- junction with segregated cycle path
- within and outside of built-up areas
- (1) one-way cycle path ≤ 8.00 m from the carriageway and no regulation or parallel regulation of conflict type cyclist going straight on and car turning right
- (2) same for bidirectional cycle path, also for car traffic turning left
- (2) conflict types car turning right and cyclist going straight on (possibly from the opposite direction) and car turning left and cyclist going straight on (possibly from two directions)
- (3) bidirectional cycle path or solitary cycle path with right of way
- (4) bidirectional cycle path or solitary cycle path without right of way
- (3) and (4): in the case of bidirectional path, underplate indicating bidirectional traffic is compulsory pursuant to the Administrative Provisions (Road Traffic) Decree (Besluit administratieve bepalingen inzake het wegverkeer, or BABW)

Implementation
- (1), (2) and (3): continue cycle path surfacing, block markings and shark's teeth on junction surface

Considerations
- increasing attention benefits cyclists' safety
- signage only will have little effect

Combination possibilities
- physical refuges
- visual aid
- cycle crossing on raised junction
- traffic light control system



1 2 3 B6 4 J24

V58 Markings crossing over bidirectional cycle path

Function
- drawing attention to bicycle traffic coming from two directions

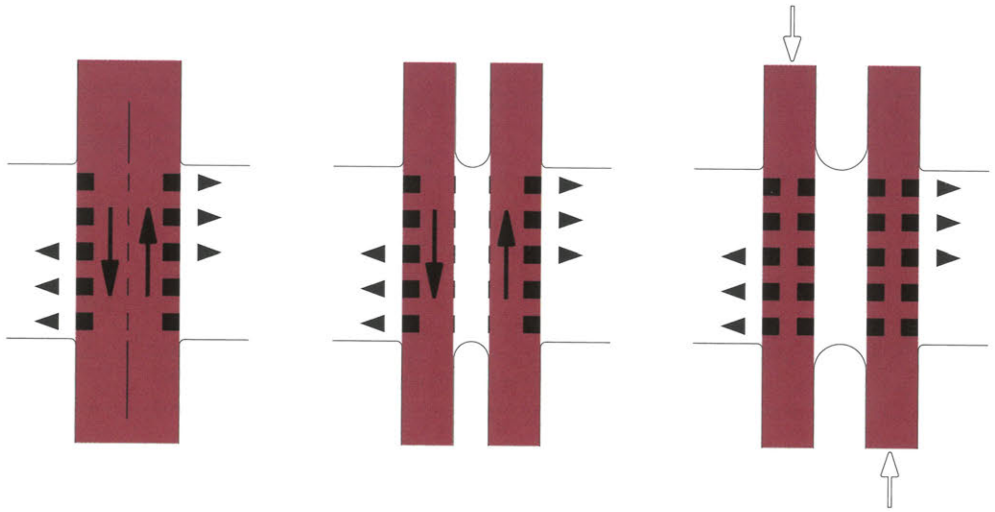
Application
- if intersecting traffic has to give way to cyclists crossing
- junction with segregated cycle path
- within and outside of built-up areas
- always in combination with speed bump for intersecting (motorized) traffic

Implementation
- continue cycle path surfacing, block markings and shark's teeth on junction surface

Dimensions
- length of arrow 2.50 m

Considerations
- increasing attention benefits cyclists' safety
- markings only will have little effect

Combination possibilities
- signage (V57)
- physical refuges
- cycle crossing on raised junction



V59 Narrow surfaced separation between cycle path and main carriageway

Function
- physical separation of motorized traffic and bicycle traffic

Application
- in the case of segregated cycle path
- only if there is insufficient space for segregation verge

Implementation
- (1), (2) and (3) in the case of cycle path in block paving
- (4) in the case of continuous asphalt surfacing
- interruptions to separation for the purposes of drainage
- interruptions at side roads and exits
- paint kerbs or edge white

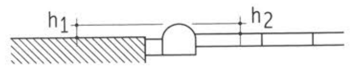
Dimensions
- width is variable
- $h_1 \leq 0.10$ to 0.12 m
- $h_2 = 0.05$ (0.07) m; if 0.07 m choose a profile that ensures pedals cannot catch on the separation

Considerations
- separation between motorized and bicycle traffic fosters safety
- in the case of small profile width, segregated cycle path will nevertheless be possible
- limited opportunities for cyclists to cross (only in the case of side roads, exits and alleys in the segregation verge)
- incorrect dimensions will create a hazardous edge for cyclists
- possible that car traffic might cross over
- chance of edge breaking away in (4)

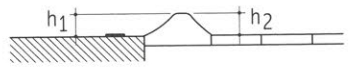
(1) two concrete kerbs back-to-back

1

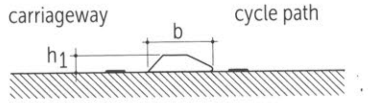

(2) semicircular concrete kerb

2


(3) hollow kerb profile

3


(4) asphalt kerb

4


V60 Kerbing for cycle paths

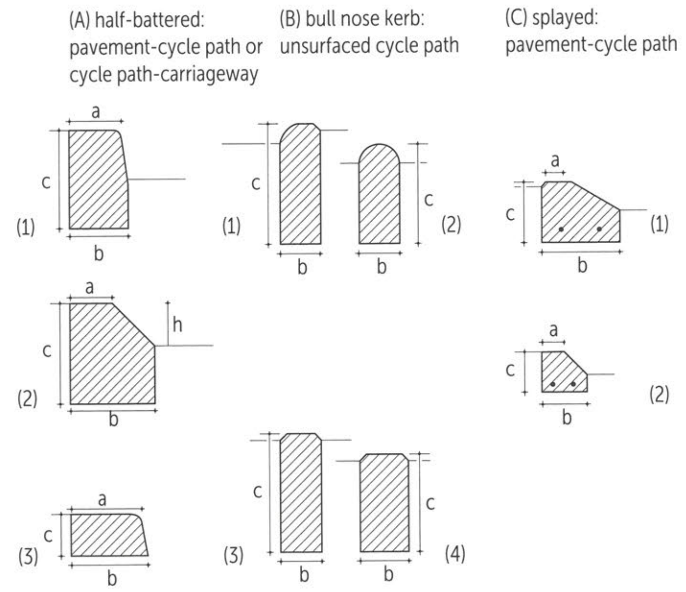
Function
- preventing block paving from shifting
- separating cycle path from other traffic spaces

Application
- separation between cycle path and pavement, carriageway or unpaved lane
- necessary in the case of cycle path in block paving
- A, B (1) and C where there is a difference in level
- B (2), B (3) and (B 4) in the absence of a difference in level

Implementation
- A (1) not alongside narrow cycle path (due to anxiety regarding obstacles)

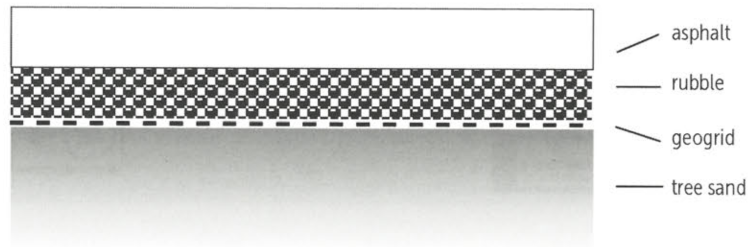
Dimensions
- A: a × b × c (in cm):
  - (1): 13 × 15 × 16/20/25
  - (2): 11 × 22 × 25; 18 × 20 × 16/20
  - (3): 13 × 15 × 10/12/14; 18 × 20 × 10/12/14
  - working length 100 cm; h = circa 11 cm
- B: b × c (in cm):
  - (1): 10 × 20/25/30; 12 × 25
  - (2): 10 × 25
  - working length 100 cm
  - bend kerbs R = 0.50 / 1 / 2 / 4 / 6 / 11 m
  - (4): 5 × 15; 6 × 15/20; 8 × 20; 10 × 20/30; 12 × 25
  - working length 110 cm, bend kerbs R = 0.50 to 12 m
- C: a × b × c (in cm):
  - (1): 7 × 20 × 15, working length 100 cm
  - (2): 6 × 12 × 10, working length 100 cm

Considerations
- A (2), B (1, 3 and 4) and C (1 and 2) are cycle-friendly; A (1 and 3) and B (2) are not
- kerbing prevents paving slabs/paving bricks shifting (in the case of cycle path in block paving)
- A (1) between carriageway and cycle path is the best way to keep other traffic off the cycle path and provides the best guidance
- in the case of A (1), cyclists could hit the kerb with their pedal and suffer a fall
- in the case of A (1), anxiety regarding hitting the kerb will effectively result in a narrower cycle path
- do not introduce a height differential between cycle path and overrun strip to the left



V61 Tree root and mole-resistant foundation for cycle paths

Function	- preventing damage to surfacing caused by tree roots
Application	- segregated and solitary cycle paths and cycle/moped paths with trees situated alongside them at a distance of one and a half times the treetop diameter - other cycle paths where tree root pressure can be expected
Implementation	- desired load-bearing capacity is calculated by means of joint use on the part of cars/lorries for the purposes of maintenance, winter maintenance and suchlike, and possibly unlawful use as well - rubble foundation of 4/40 to 10/70 (particles smaller than 4 and 10 mm in diameter respectively have been eliminated by sieving) - preferably geogrid under rubble to ensure better distribution of pressure - underneath this, tree sand (3-5% organic matter) to foster root growth there - do not use any sand between rubble and asphalt
Dimensions	- thickness of rubble 0.15 to 0.35 m, depending on subgrade and desired load-bearing capacity - thickness of asphalt 0.06 to 0.15 m, depending on subgrade and desired load-bearing capacity
Considerations	- no root growth under asphalt due to airiness and draining effect of rubble - hardly any more expensive than traditional foundations - slightly less load-bearing capacity (can be compensated by way of thickness) - not straightforwardly possible in combination with block paving



V62 Cycle signs

Function
- increasing findability of destinations (including interim destinations)
- providing route guidance
- indicating distance

Application
- (1) cycle fingerpost: in situations where good noticeability is desirable; is preferred over the combined cycle sign (2)
- (2) combined cycle sign positioned high up; will replace bicycle fingerpost if there is no room for this; also as a preliminary indication
- (3) 'toadstool' signpost, in nature reserves
- (4) cycle route number sign: in signposted and numbered urban and rural cycle routes
- (5) node sign
- (6) sign long-distance tourist route

Implementation
- (1, 2, 3 and 4) pursuant to Signage Directive 2014 [10]
- (5) and (6) green text on white background

Dimensions
- pursuant to Signage Directive 2014 [10]

Considerations
- (1) prevent alternating use of general and cycle signage

Combination possibilities
- (1), (2) and (4) with lamp post
- (5) and (6) with each sign or any other signpost

type 1

type 2

type 3

type 4

type 5

type 6

type 1 cycle fingerpost
type 2 combined cycle sign
type 3 'toadstool' signpost (side view of the cap)
type 4 cycle route number sign
type 5 node sign
type 6 sign long-distance tourist route

V63 Pictograms on signposts

Function
- increasing findability of specific destinations

Application
- (1) on cycle route; once on each sign or each of the sign's direction fields
- (2) at point where bicycle and moped route splits, on the sign indicating the moped route
- (3) on cycle route, in combination with (1)
- (4) on main cycle route and/or through route in urban area; in combination with goal, which can vary with the same route number
- (5) reference to a bicycle storage facility
- (6) reference to bicycle parking (bicycle racks)
- (7) reference to station
- (8) reference to ferry
- (9) reference to information point
- (10) reference to tourist office (VVV)
- (11) reference to recreational area

Implementation
- all symbols in red (shortest route) or green (recreational route)
- (1), (2) and (4): once for each sign or direction field
- (7), (9) and (10) possibly multicoloured, in accordance with the relevant logo
- (5) to (11) always behind destination long-distance, local (neighbourhood, centre) or object-specific (name or description) and on the same line
- where numbered routes converge, (4) will feature several times on a sign
- (5) sometimes featuring text 'bicycle storage facility' or 'secure storage facility'

Dimensions
- not standardized

Considerations
- pictograms are preferred over text (also for the benefit of those people who do not understand Dutch)

Combination possibilities
- (2) never with (4)


(1)


(2)


(3)

(4)


(5)


(6)


(7)


(8)


(9)


(10)


(11)

V64 Verge surfacing strip

Function	- providing a 'forgiving' roadside
Application	- alongside solitary and segregated cycle paths - alongside residential roads - within and outside of built-up areas
Implementation	- width of verge lane 0.40 to 0.50 m - concrete (StreetPrint), artificial turf or grasscrete flat side up - no height differential between cycle path and verge lane
Considerations	- alternative is to widen cycle path
Combination possibilities	- edge markings - centre line

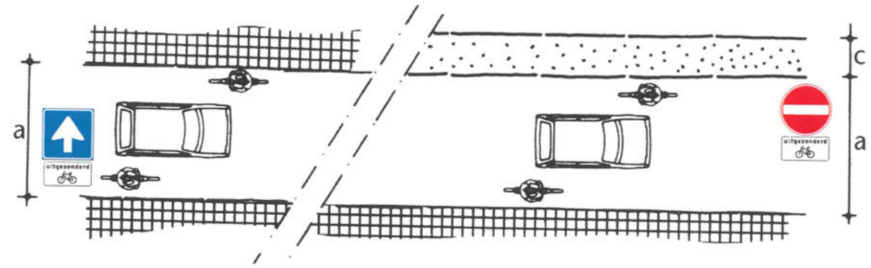
V65 Carriageway for mixed traffic, with partial one-way traffic

Function	- providing a connection for all vehicle types - influencing route choice motorized traffic without impediments to bicycle traffic
Application	- road with one-way traffic for motor vehicles - within and outside of built-up areas - v_{max} = 30 km/h in built-up areas, 60 km/h outside of built-up areas - I_{car} < 5,000 PCU/24-hour period
Implementation	- sign C2, C3, C4, with underplate 101 or 103 - asphalt/concrete surfacing or block paving - outside of built-up areas it might be possible to create a proportion of the requisite surface width using verge surfacing (see V64)
Dimensions	within built-up areas: - 3.85 m (based on combination passenger car/bicycle) - 4.85 m (based on combination passenger car/bicycle/bicycle) outside of built-up areas: - 3.50 m carriageway + 2 × 0.50 m verge surfacing (based on combination of passenger car/bicycle) - 4.00 m carriageway + 2 × 0.75 m verge surfacing (based on combination of passenger car/bicycle/bicycle)
Considerations	- low speed due to tight profile - allowing cyclists to travel in the opposite direction will ensure they do not have to take a detour - a tight profile is relatively generous at low volumes of car and bicycle traffic
Combination possibilities	- pavement or footpath - longitudinal lay-by (preferably with critical reaction strip for cyclists) on right-hand side of the carriageway (in view of the direction in which car traffic is moving) - outside of built-up areas: guidance (reflector bollards) in bends - speed bumps - outside of built-up areas: any edge markings (1-3) a maximum of 0.25 m from side edge of surfacing
Alternatives	- carriageway with mixed profile, with partial one-way traffic and oncoming cycle lane (see V66)

C2 C3 C4

C2: One-way road, closed in this direction to vehicles, riders and those leading riding animals, draught animals or livestock

C3, C4: One-way road



V66 Carriageway for mixed traffic, with partial one-way traffic and oncoming cycle lane

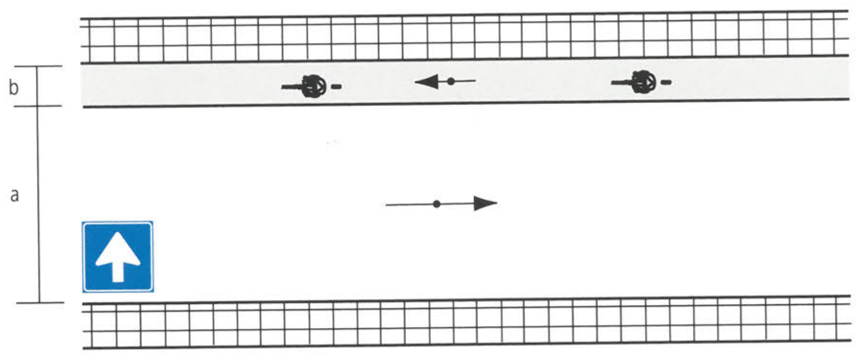
Function	▪ providing a connection for all vehicle types ▪ influencing route choice motorized traffic without impediments to bicycle traffic
Application	▪ residential road with one-way traffic for motorized traffic ▪ within and outside of built-up areas ▪ no parking on the carriageway
Implementation	▪ sign C2, C3, C4, with underplate 101 or 103 ▪ cycle lane in opposite direction ▪ cycle lane preferably in red ▪ consider physically screening off cycle lane from carriageway (only if width of cycle lane ≥ 2.00 m); if need be, only where there are side roads
Dimensions	▪ design of cycle lane: see design sheet for cycle lane (V 15) ▪ width of carriageway (a) ≥ 3.50 m ▪ width of cycle lane (b) 1.50 to 2.00 m
Considerations	▪ marked space for cyclists, with legal status ▪ road users other than cyclists and drivers of vehicles for the disabled may not use the cycle lane (where there is a continuous stripe), or may only use it if no cyclists will be hindered as a consequence (in the case of broken stripe) ▪ no vehicles are allowed to be stationary on the cycle lane and on the carriageway ▪ cyclists do not have to drive as a result of the set one-way traffic (for cars) ▪ chance of illegal loading/unloading ▪ chance of higher speed on the part of motorized traffic if carriageway is widened in connection with cycle lane
Combination possibilities	▪ lay-by (with critical reaction strip for cyclists), preferably on the right-hand side of the carriageway, in view of the direction in which car traffic is moving
Alternatives	▪ carriageway for mixed traffic, with partial one-way traffic (without oncoming cycle lane: see V65)

C2

C3

C4

C2: One-way road, closed in this direction to vehicles, riders and those leading riding animals, draught animals or livestock
C3, C4: One-way road



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Publications

342	Ontwerpwijzer bruggen voor langzaam verkeer	2014
340	Inspiratieboek snelle fietsroutes	2014
334	Gladheidsbestrijding voor fietsers en voetgangers – Beleid, organisatie en uitvoering	2013
291	Leidraad fietsparkeren	2010

CROW Fietsberaad publications

28	Evaluatie discussienotitie fiets- en kantstroken	2015
27	Evaluatie aanbevelingen voor palen op fietspaden	2014
26	Fietsen in Nederland: patronen, trends en beleid	2014
19a	Grip op enkelvoudige ongevallen	2011

Other

K-D029	P+Fiets - Snel en slim in de stad	2016