NTNU – Trondheim
Norwegian University of
Science and Technology

/Shared-use facilities on narrow streets in Norway

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Submission date: December 2013
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Report Title: **Shared use bicycle facilities on narrow streets in Norway**	Date: 20.12.2013 Number of pages (incl. appendices):			
	Master Thesis	X	Project Work	
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Abstract:

Bicycling is a very common mode of transport in countries with a suitable and feasible bicycle network. Many efforts have focused on separated bicycle facilities, but these solutions are not possible on all types of roads. This thesis focuses on suggesting shared-use bicycle facility solutions for these roads where there is not enough space to provide a separated bicycle solution. Safety should be reached in all the situations since motorists and bicyclists share the same space on the road.

Shared use bicycle solutions in different countries in Europe and US are studied in order to provide a shared solution in Norway. Advisory lanes, bicycle streets, contraflow bicycling lanes, shared use condition with and without on-pavement markings and woonerfs are the different solutions studied. Way finding measure is used in many countries.

To provide the suitable solution, street traffic regime (traffic volumes and speed limit) and width of the road are essential factors.

From other countries' solutions and the Norwegian recommendations about shared use facilities, suggestions are given for one lane, two lanes and parking streets types design registered in the Norwegian design guideline 017 in these situations in which traffic volume is less than 4.000 vehicles per day or speed limit is less than 50 km/h. For the lowest volume and speed limit type designs, width of street is similar to the other countries, for the highest, width of the streets is narrower, which rises the doubt if the solution given is totally feasible.

Seven streets have been studied in the city of Trondheim. To provide the most feasible solutions, on-streets factors including width of the street, AADT, speed limit, on-street parking, restrictions and vertical signs in the road are essential. All the streets are less than 3.000 vehicles per day and 30 km/h as a speed limit, and most of them are less than 1.000 vehicles per day (quiet and pleasant environment) in which shared use solution without on-pavement markings is proposed, except if it is on-street parking where on-pavement marking is suggested. In case of higher traffic volumes and presence of heavy vehicles, the width of the street is not wide enough if comparing with the solutions from others countries.

Vertical signs at the beginning and at the end of the street and way finding around the city are suggested to improve the shared use solution individually and the bicycle network.

To assess the effectiveness of the solution, both observations in situ before and after the measure is adapted and surveys to cyclists and motorists, are suggested.

Keywords:

1. Shared use facility
2. Narrow street
3. Street traffic regime
4. Safety

MASTER DEGREE THESIS

Fall 2013

for

Cristina Espinosa Mateo

Shared-use bicycle facilities on narrow streets in Norway

BACKGROUND

The Norwegian National Transportation Plan has the ambitious goal to accommodate all increased transport demand in growing urban areas through non-motorized or transit modes, which includes cycling. To accommodate the growing number of cyclists in already congested urban areas, it is important to consider how existing infrastructure could be better utilized. While it is optimal to physically separate bicycle traffic from motorized vehicle traffic, space constraints in the existing built environment often prevent this. One potential solution to accommodate both sets of users on narrow streets is that of shared-use facilities. Shared-use facilities are roadways where bicyclists and motorists share the same travel lanes without a designated separation between the two modes. Instead, street markings, signs, and street-use regulations indicate and direct the shared use of these roadways. Shared-use facilities have successfully been implemented in cities around the world, including Portland, Oregon (USA), Ghent, Belgium, and Ferrara, Italy, and can potentially be used to address the mobility needs of both motor vehicles and bicycles within Norwegian city centers.

TASK

The task is to investigate the potential for the use of shared-space bicycle facilities in narrow streets in Norway. Shared-use solutions from other cities in Europe and around the world will be identified and examined in order to develop suggestions for appropriate shared-use bicycle facilities for narrow streets here in Norway.

Subtasks and research questions

The assignment shall include:

- A literature review and assessment of the “state of the art” for shared-use bicycle facilities, considering among other factors, safety, operations, and community support.
- An assessment of appropriateness of different facility types within a Norwegian context, considering existing street design guidelines.
- Recommendations for design of shared-use facilities, including roadway plan and cross section sketches.
- A discussion of implementation challenges and methods to test performance of facilities

General about content, work and presentation

The text for the master thesis is meant as a framework for the work of the candidate. Adjustments might be done as the work progresses. Tentative changes must be done in cooperation and agreement with the professor in charge at the Department.

In the evaluation thoroughness in the work will be emphasized, as will be documentation of independence in assessments and conclusions. Furthermore the presentation (report) should be well organized and edited; providing clear, precise and orderly descriptions without being unnecessary voluminous.

The report shall include:

- Standard report front page (from DAIM, http://daim.idi.ntnu.no/)
- Title page with abstract and keywords.(template on: http://www.ntnu.no/bat/skjemabank)
- Preface
- Summary and acknowledgement. The summary shall include the objectives of the work, explain how the work has been conducted, present the main results achieved and give the main conclusions of the work.
- The main text.
- Text of the Thesis (these pages) signed by professor in charge as Attachment 1.

The thesis can as an alternative be made as a scientific article for international publication, when this is agreed upon by the Professor in charge. Such a report will include the same points as given above, but where the main text includes both the scientific article and a process report.

Advice and guidelines for writing of the report is given in “Writing Reports” by Øivind Arntsen, and in the departments “Råd og retningslinjer for rapportskriving ved prosjekt og masteroppgave” (In Norwegian) located at http://www.ntnu.no/bat/studier/oppgaver.

Submission procedure

Procedures relating to the submission of the thesis are described in DAIM (http://daim.idi.ntnu.no/).

Printing of the thesis is ordered through DAIM directly to Skipnes Printing delivering the printed paper to the department office 2-4 days later. The department will pay for 3 copies, of which the institute retains two copies. Additional copies must be paid for by the candidate / external partner. On submission of the thesis the candidate shall submit a CD with the paper in digital form in pdf and Word version, the underlying material (such as data collection) in digital form (e.g. Excel). Students must submit the submission form (from DAIM) where both the Ark-Bibl in SBI and Public Services (Building Safety) of SB II has signed the form. The submission form including the appropriate signatures must be signed by the department office before the form is delivered Faculty Office.

Documentation collected during the work, with support from the Department, shall be handed in to the Department together with the report.

According to the current laws and regulations at NTNU, the report is the property of NTNU. The report and associated results can only be used following approval from NTNU (and external cooperation partner if applicable). The Department has the right to make use of the results from the work as if conducted by a Department employee, as long as other arrangements are not agreed upon beforehand.

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The students do not have a full insurance coverage as a student at NTNU. If you as a student want the same insurance coverage as the employees at the university, you must take out individual travel and personal injury insurance.

Startup and submission deadlines

The work of the task starts 05 August 2013.

The paper is to be delivered at the latest in DAIM by 20 December 2013 at 15:00.

Professor in charge: Kelly Pitera

Other supervisors: Elise Egseth, SVV and Erik Jølsgard, SVV

Department of Civil and Transport Engineering, NTNU

Date: 07.10.2013

Kelly Pitera

Kelly Pitera, PhD

PREFACE

This master thesis is the product of work carried out during the fall semester 2013 from August to December and represents the last element of my Civil Engineering career; concluding my Civil and Environmental Engineering studies period at the Norwegian University of Science and Technology (NTNU). The thesis was performed at the Department of civil and Transport Engineering in collaboration with the Norwegian Public Roads Administration.

In the first place, I would like to thank my supervisor, associate professor Kelly Pitera for her support, excellent guidance and valuable comments as I developed and finished my ideas throughout the work period in my thesis research; and for her concern, help and advices as my life in Norway refers. Additionally I would like to thank the Norwegian Public Roads Administration for the financial support of this work and particularly to Erik Jølsgard and Elise Egseth, head of traffic Safety Division and transportation planner respectively at Norwegian Public Roads Administration, for their relevant information and response concerning the topic of this master thesis.

Finally, I would like to thank my family and specially my parents, Evaristo Espinosa and Petri Mateo for supporting me in everything I do since the beginning of my career and for their transmission of serenity and positivity to me. Additionally, thanks to a very special person, Javier Buitrago who has been there all time for me. His support, help and positivity have made everything easier here, where I am far from my family and friends who mean all for me.

SUMMARY

Bicycling is a very common mode of transport in countries where a suitable and feasible bicycle network has been provided within the cities. Usually, efforts to promote bicycling have focused on constructing separated bicycle facilities (bike path and bike lanes), but these solutions are not possible on all types of roads. The motivation of this thesis was the Norwegian government´s concerns about providing a safer and more efficient road bicycle network within the cities, and the lack of bicycle solutions in Norway for these streets in which the width is not enough to provide a separated facility solution (narrow streets). Different types of shared-use bicycle facility solutions have been suggested for these roads. Since motorists and bicyclists share the same space on the road, safety should be reached in all the situations. Similarly, as a better solution is providing for cyclists, motorists should not be greatly impacted for the shared use solution.

Shared use bicycle solutions and others measures used in different countries in Europe and US are examined in order to determine if and how shared use solutions are applicable in Norway. All of them are similar in general aspects, such the function or where are they placed; but adapted within each city and the situation or needs of the street. Advisory lanes, bicycle streets, contraflow bicycling lanes, shared use condition with and without on-pavement markings (sharrows) and woonerfs are the different solutions studied. Way finding is a measure than many countries have within the city in order to provide a more feasible bicycle network.

The need of a specific solution depends on important factors including street traffic regime, need for segregation and quality of service. For this reason, width of the street, traffic volumes and speed limit are key factors to provide the solutions.

From the facility solutions other countries/cities have and the Norwegian recommendations about shared use facilities in Norway, appropriate and feasible suggestions are given for one lane, two lanes and parking streets types design registered in the Norwegian design guideline 017 in these situations in which traffic volume is less than 4.000 vehicles per day or speed limit is less than 50 km/h (no cycle lane situation). For the lowest volume and speed limit type designs, width of street is similar to the other countries, having an appropriate shared use solution. For the highest volumes and limit speeds designs studied, width of the streets is narrower than other countries, which rises the doubt if the solution given is totally feasible.

Once the solutions for the existing Norwegian design roads are suggested, city of Trondheim has been studied in more depth, where seven streets interesting for the Norwegian Road Administration have been analyzed. To provide the most feasible solutions, on-streets factors including width of the street, AADT, speed limit, on-street parking, restrictions and vertical signs in the road have are essential. All the streets have in common the traffic flow less than 3.000 vehicles per day and 30 km/h as a speed limit and most of them have the traffic volume below 1.000 vehicles per day where a quiet and pleasant environment is done between motor traffic and bicyclists. These roads have been considered residential roads, and shared use solution without on-pavement markings is proposed, except in the case of on-street parking streets in which on-pavement marking shared use condition (sharrows) has been suggested. In the case of higher traffic volumes, also with presence of heavy vehicles, the width of the street is not wide enough to provide the most appropriate solution if comparing with shared use solutions studied from others countries.

Nevertheless, since there is not a unique solution, some suggestions are given for each street (advantages and disadvantages of each solution are included) in order to assess in a further study which solution is the most feasible.

Vertical signs at the beginning and at the end of the street are suggested in all the solutions in order to increase motorist´s awareness about presence of cyclists. Way finding is a measure that improves the bicycle network within a city.

To assess the effectiveness of a new measure, determined the effects (good and bad) that causes on the road users, and decide which the most appropriate/suitable facility solution is, are proposed both experiments in situ through observations before and after the measure is adapted and surveys and interviews to cyclists and motorists.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. Introduction

Bicycles can offer a good alternative to private motor vehicles, especially in cities with poor air quality, congestion and with high fuel prices. In order to encourage people to cycle, bicycling must be promoted as a safe and feasible means of transport for everyone and for all trip purposes. Some of measures, policies or programs taken in Europe to encourage the levels of cycling include development of an extensive system of separate cycling facility types, intersection modifications and priority bicycle traffic signals, traffic calming of neighborhoods, safe and convenient bike parking, coordination and integration of cycling with public transport, traffic education and training both for cyclist and motorist and traffic law that favor cyclist and pedestrians (Pucher & Buehler, 2008).

Netherlands, Denmark and Germany are Europe´s pioneers in initiating bicycling policies and practices, which have led to these countries having the highest bicycling share levels in the world. Within cities in these countries, cycling is an integrated mode of transport and at the forefront of city planners´ and engineers´ minds. In order for a city to promote and develop any social local policy (well connected with transport bicycle or any other field), it is very important that these policies have a solid basis in the national level that will initiate, assist and support their cities to acquire the right legal, regulatory and financial framework. This is the case for example of both the Netherlands and Denmark, which a high national commitment to cycling has developed in a high modal share of cycling in almost all their cities. Other factors, like community support, education/training/cities´ plans and programs, or the topography (hilly or flat city) influence in the integration of bicycles as a common and daily mode of transport and in the cohabitation of both motorist and cyclists.

Many efforts to promote bicycling have focused on the construction of bike paths (lane for bicyclist segregated from the roadway by a reservation or barrier) and bike lanes (space for bicyclist where motorist are not allowed to park, stop or drive), but these facility types are not possible on all types of roads and in all environments. For example, in city centers the existing built environment makes it difficult to widen roadways or add additional infrastructure. Additionally, to achieve a suitable cycle network, separated cycling facility types must be complemented by a comprehensive program to make all roads bike-able, through both physical measures and increased awareness of motor vehicles drivers and cyclists (Pucher, et al., 1999). Roads in which the width is not enough to provide a clear separated bike lane or path without changing the original constructed road are examined further in this study.

Shared bicycle facility, where bicycles and motor vehicles share the roadway, have some benefits compared to paths or lanes bicycles. These include, increased driver awareness of cyclists which also increases driver´s attention thus improving safety, freedom of movement for cyclist regarding access, and limited environmentally impact, space efficiency, and cost effectiveness because of the lack of construction when the traffic is low. Also, the lower speed for all road users and the low volume of traffic (the presence of bike traffic can reduce the motor traffic) results in less serious accidents. However as expected, these facilities also have some disadvantages like the choice of some cyclist to use the sidewalk instead of roadway for safety reasons or the traffic congestions produced due to cyclists blocking the roadway.

Determining the type of bicycle facility needed in a given locations depends on the adjacent traffic regime, the need for segregation, and the target quality of service. The width of the street is an important factor in this research such that, if an existing road is not wide enough cycle lane with the required (width to the left and right of the bike and space to support the cycling regime), a shared use solution should be provided (National Transport Authority A, 2011).

Many other cities are following the lead of the strongest bicycling cities, focusing their transport policies on support the cycling as a mode of transportation in their streets. Regarding to the shared bicycle facility, for instance Ghent and Murcia in Europe and Cambridge in USA, have developed feasible, strong solutions. Ghent was the first country in Europe that adopted a share bicycle facility as a solution within the city: FISHERIES, both marked on road and vertically signalized. Also, in the last few years, Murcia has integrated this solution with an on-road marking as an economical and appropriate facility for its streets with low speed limit or where traffic calming has been already applied. Sharrows (marking on the road: arrow + bike) are the solutions in the country of Cambridge, normally in on-road parking streets. All these solutions will be further studied in depth.

1.1. Norway

Norway is a country with a population just over 5 million people and an area of 385,250 km^2, making it one of the most sparsely populated countries in Europe. This has resulted in a lag behind other European countries with regards to developing bicycle infrastructure and promoting cycling as a means of transport.

Recent shifts within social-economic policies have resulted in Norway focusing its efforts on improving cycling infrastructures, to achieve goals related to making cycling safer and increasing the share of bicycle traffic. Better conditions for cycling can lead to more people cycling and help making the mobility system of Norway more sustainable. It is true that cycling is more and more popular in Norway but Norway´s cycling infrastructure needs to be improved in order to increase cyclist´s security and enough more people to choose bicycling as a usual mode of transport. Only 5% of all Norwegians commute to work or school by bicycle, compared with the neighboring countries Sweden and Denmark, in which the percentage of people is much higher than in Norway (13% and 17% respectively) (Vagane, 2006-2011). The Institute of

Transport Economics in Norway has calculated the potential for increasing cycling in Norwegian cities and towns that is focused in the area of short car trips. Half of all trips are shorter than 5 km which can be a potential increase foot and cycle traffic by 50% in cities and towns with over 5.000 inhabitants (Statens Vegvesen, 2003).

The Norwegian government´s concerns about providing a safer and more efficient road bicycle network have resulted in the Norwegian Public Roads Administration´s National Cycling Strategy (that is integrated on the National Transport plan 2006-2015) (Statens Vegvesen, 2003), which is a strategy for safer, greener and more efficient transport based on Vision Zero, no fatalities or permanent injuries in road traffic. By increasing safe facilities, bicycling is expected to be a more common mode of transport in Norway. The intermediate goals of the Norwegian National Cycling Strategy are:

- To increase safety such that the risk of fatalities or permanent injuries from road accidents are not higher for a cyclist than for a motorist.
- To increase the share of bicycle traffic in “bicycle towns” by 50%.
- To increase bicycle traffic in Norway to at least 8% of all travel (out of the total number of trips).

In addition to the National Cycling Strategy, the Norwegian National Transportation Plan has the goal to accommodate all increased transport demand in growing urban areas through non-motorized or transit modes, which includes cycling. Cycling has an intermediate position within the groups of road traffic users: foot traffic, bicycle traffic (not motorized traffic) and motorized traffic; as in the cities and towns has a speed that is close to motorized driving but has different requirements for road design. For that, to accommodate the growing number of cyclist in already congested urban areas, it is important to consider how exiting infrastructure could be better utilized. It is often optimal to physically separate bicycle traffic from motorized vehicle traffic for safety perspective, but space constraints in the existing built environment often prevent this. In these situations, existing roadways can be designated as shared-use facility.

The objective of this study is to examine how the same space on roads can be appropriate for both motorist and bicycles in a safety environment and with suitable conditions. The key of this sharing concept room is that motor vehicles have to be aware of cyclists and should understand them as partners on the road and not as invaders on the road. At the same time, the motor vehicles mobility should not be greatly altered. Planners and engineers must keep in mind the type of roads in which they are operating such as its speed and flow conditions (among other factors).

1.2. Objective

The main purpose of this research is to determinate if it is possible to provide a suitable, feasible, comfortable and safe solution for both motorists and cyclists in a shared traffic condition on the existing narrow streets in Norway, giving the existing bicycle regulations and the different types of roads sections registered in the Norwegian Handbook 233 (Stantens Vegvesen, 2003) and Handbook 017 (Statens Vegvesen, 2008). Shared use bicycle facility solutions from other cities in Europe and USA will be identified and examined in order to develop suggestions for the appropriate solution in Norway. Policies, education and pro-bike programs also are really important in providing a solid bicycle network. On-marking roads and vertical signs will have an important role in this research since they have been considered a key point at time of providing a clear and feasible bicycling network. Way finding signals indicate the best way or alternative to a high traffic volume road, in which cyclists will feel safer and more comfortable and will find advantages against the last road. Giving this, the possibilities of incorporation the shared traffic solutions with the directional signs will be studied.

Improving the conditions for cycling is dependent on both the national level where policy decisions are made and the local level where planning decisions allow cycling to “compete” with motor vehicles as a feasible mode of everyday travel. While the concept of shared use solutions are feasible throughout all of

Norway, this research will focus on the city of Trondheim in Sor-Trondelag County, where shared traffic solutions will be studied in physical and real streets of the city as suggested by the Norwegian Public Roads Administration.

2. Existing Shared Use Solutions

Many countries in Europe and around the world have extensive bicycle networks, some of which include shared use facility. Many of the cities/countries examined similar shared use solutions, which are then adapted for the given cities‘needs. The follow sections describe existing shared use bicycle facility solutions both generally and as applied by different cities. Relevant aspects of the cities, bicycle strategies and policies are shared. These existing solutions are used to help determine if and how shared use solutions are applicable in Norway.

2.1. General solution descriptions

These all countries/cities examined have similar bicycle solutions that are adapting then for each city and the situation or needs of the street. Some of these countries/cities have developed a method within their bicycle strategies to decide the appropriate bicycle facility for the road given.

This section will be described common shared use solutions and concepts provided in different countries/cities. These solutions include:

- Advisory lanes
- Bicycle streets
- Contraflow bicycling lanes
- Shared use condition
- Woonerfs

These solutions are also described in a more detailed manner in section 2.2.

All the shared use solutions are used on narrow roads. **Narrow streets** are all these roads where is not enough room for a cyclist and motorist to travel side by side on separated lanes. Nevertheless in urban planning field, there is not a unique definition for **"**narrow street**"** due the different regulations and transport design guide from all the countries. Planning Department of city of New York (Bloomberg & Burden, 2013) establishes as american´s measurements of roads less than 75 feet wide (23 meters) as narrow streets and roads between 8 and 15 feet (2,5-4,5 meters) very narrow streets or roads used only for pedestrians. In European countries, width of a narrow street is narrower. For example, National manual Dublin-Ireland (National Transport Authority A, 2011), arranges narrow streets as all these roads with width around 7-8 meters, as it will be seen later.

I. <u>Shared use solutions</u>

Advisory lanes are those bicycle lanes separated from the roadway that provide cyclists their own riding space in a safe condition but also give all its width to the roadway, letting vehicles to pass into the lane if it is necessary and safe. When two cars traveling in opposing directions meet in presence of bicyclists, they have priority on the cycle lane waiting vehicles for a safe condition to use the shared lanes. This solution is applied on street too narrow to provide a real separated bike facility: two-ways riding and two-ways for motor traffic; and bring a good awareness to motor vehicles of the roadway as shared space. The facility is painted with white broken lines that allow vehicles to pass. A good visibility is ensured between cyclists and motor vehicles at intersections. It can be said that this solution is a measure placed between shared traffic and unshared traffic condition.

Bicycle streets are the narrow streets where in a shared condition, cyclists have absolutely priority in the whole width of the street and motor traffic has not allowed overtaking them. It is usually design as a road bike thus cars have a limited use on the road. The streets are mostly located in residential areas with low-traffic volume and speed. On-street parking is provided. It is a type of shared traffic lane explained later.

Contraflow bicycling do not exactly represent a shared-use facility but within an urban one-way streets system can significantly improve in directness and the attraction of cycling. It is a facility used to designate the allowance of bicyclist travelling in the opposite direction of motor traffic in one-way streets. It is most often used on streets with light traffic volumes and low speeds and it can be used on narrow streets, streets with high pedestrians´ traffic and on-parking streets. They constitute a key part of a bike network since it is a good facility to apply in short one-way segments of the city, allowing cyclists to take shortcuts without violating the law: It is a safer or more convenient route for cyclists than an alternative route involving longer distances. Contraflow bicycling situation can be marked by a white cycle lane (to make drivers aware of the presence of cyclists and to allow them to pass into the lane), unmarked and contraflow with a physical divider. The last solution will not be studied because of belonging to a separated type (Brown & Demusz, 2013).

In marked contraflows, on-street parking is located between the curb and the contraflow lane.

These streets usually create fewer issues than bike lanes going with the flow of traffic because cyclists are facing drivers. Treatment at intersections is the biggest concern contraflows have but contraflow bikes always keep to the right side of the road, thus they will be facing the correct direction when arriving at an intersection. Vertical signs at the approaches of the intersection with a two-way street are needed because drivers do not expect cyclists coming from the opposite direction.

Shared use condition is streets where cyclists share the same space with motorist. In some type of shared traffic streets, cyclists have the whole preference on the road and overtaking is forbidden (Bicycle street). In other types of roads, overtaking is allowed if the conditions of the street make it a safe operation and motor vehicles and cyclists shared the same benefits of the street (Shared roadway). Shared traffic lanes are usually narrow streets with high cyclist traffic where there is not enough room to provide a separated way for bicycling. In enough wide roads to supply a separate lane for bicyclist but where the structure of the street will be preserved, shared lane traffic is presented.

Generally, these roads present markings on the pavement to signalize the type of street. The markings are usually composed by a bike symbol and an arrow and convey the message that motorist and cyclist must share the travel way on which they are operating and clarify the way where cyclists are expected to ride, guiding them along the street mostly if on-street parking is provided, reminding motorists to expect cyclist on the road. **Sharrow** (Shared + arrow) is the name that these on-pavement markings received in USA and they are very common as shared solutions within the American cities. The distance between sharrow and sharrow, and the distance from the curb to the middle of the marking is defined. For a shared condition in which bicyclists have priority on the road, some European countries as Germany and the Netherlands paint a big bike on the whole width of the road. In other situations, shared use has none markings on the road but bicyclists are expected due the light traffic volume and the low speed limit. They usually belong to 30 Zone or Urban streets.

Woonerfs are streets where pedestrians and bicycles have legal priority and where the space is shared by all the users, so it is design with extremely low motor vehicle travel speeds. The maximum speed allowed for a shared situation is 20km/h. “Home Zone” is a residential street with even more restrictions related to the speed limit, where 7km/h is the maximum allowed (walking speed). This last measure is only implemented in walking areas where only the pass of vehicles is permitted.

Many of the solutions are often used in conjunction with traffic calming. **Traffic Calming** is a typical scheme implemented in residential areas in town in order to reduce the safety and environmental problems caused by road traffic, improving living residential conditions. The measures include narrowed roads and speed bumps, street closures and one-way systems. Sometimes 30 zone rules are implemented in the street.

II. <u>Bicycle facility selection method</u>

The method used by some of the studied cities to determine which bicycle facility to use is represented by a graphic showing two important road factors: 85% percentile Speed that is the maximum value at which speed limit of the street is set (in this study, 85% percentile is analyzed/studied as the speed limit of the road since exact numbers are not needed), and AADT (Annual Average Daily Traffic) registered on the street. The bicycle facility solution will be adopted according to the relationship between AADT and speed limit of the street factors. These graphs are discussed further within the sections dedicated to the cities which they are used in. A similar graph has also been in Norway. This is discussed in section 3.1.

These graphical did not appear to be based on experimental data or theoretical studies. This assumption was confirmed by corresponding with the Oregon (USA) Department of Transportation, who indicated that these graphics are largely based on engineering´s experience and judgement.

2.2. Shared traffic use solutions in European countries

I. Netherlands, Denmark and Germany: Widespread bike use

GENERAL INFORMATION

When discussing the widespread use of bicycles, the Netherlands, Denmark and Germany are the three countries that emerge in our minds. Talking about one of them without including the others is rather difficult since these three countries, through a reversal in transport and urban planning policies in the mid-1970s have been concerned and successful in promoting safe and convenient cycling. In spite of being high rates of car ownership (among the highest in the world), these three countries have achieved high levels of bike shares of urban travel: 27%, 19% and 9% respectively (Pucher & Buehler, 2008). The key for achieving high levels of cycling appears from the extensive cycling rights of way in these countries complemented by ample bike parking, integration with public transport, good traffic education and training of both cyclist and motorist, and a wide range of promotional events to generate enthusiasm and wide public support for cycling. Safety is one of the most important reasons why the Netherlands, Denmark and Germany have the highest levels of cycling (Pucher & Buehler, 2008) (Pucher & Buehler, 2008)

These countries focused on making their cities livable and sustainable. In addition, driving is expensive as inconvenient in central cities through taxes, restrictions on car ownership and paid parking.

Cycling programs and policies carried out by the government, often at the municipal level; aim to make cycling safe and feasible for the general population. In the Netherlands, Denmark and Germany, these include extensive system of separated cycling facility integrated physical facilities and signals to improve the routes; modification of intersections and priority traffic signals for cyclists; a calming; bike parking supplied throughout the city, especially at train stations, center of city and at coordination points with public transport; and traffic education with training courses for children and motorist, what is very important at time of providing a solid cycling base within a country.

SHARED USE BICYCLE SOLUTIONS

Dutch, Danish and German cities have **traffic calmed** most streets in residential roads, reducing the speed limit to 30km/h and often prohibiting any through traffic or restricting traffic to one way in a street. Especially in Netherlands have been introduced alterations in the streets, including as road narrowing, parked vehicles, raised intersections and crosswalks, traffic circles, extra curves, speed humps and created artificially created dead-ends. Bicycling is always allowed in both directions, even in one-way streets.

"Bicycle streets" or Fietsstraad is a measurement that has been increasingly adopted in Dutch and German cities, in which bicyclists are expected to take the entire width of the road if they want and cars, driving with a speed limit of 30 km/h should drive behind them, being not allowed the overtaking. Cars are guests in this street and should give more room to cyclists. Bicycle streets road surface is smooth red asphalt (to be clearly understood) and the road has gotten priority over side streets on every junction. **Figure 1** shows two examples of Fietsstraad are (Anon., 2012).

Figure 1: Fietstraad (Netherlands) (Tarantino, 2012)

Many two-way roads are too narrow to allow both two lanes of traffic and two bicycle lanes in both directions. The solution in the Netherlands and in others countries has been to install shared bicycle lanes on these roads, **advisory Lanes**.

In the Netherlands normally utilizes shared bicycle lanes on narrow urban and rural collector roads with low-moderate traffic and without any centerlines that collect the traffic from small local roads and direct it to a main road. The traveling speed is from 30-50 km/h in urban areas and 60km/h in rural areas. These lanes ensure the best use of the entire width of the road. Figure 2 shows two pictures of rural collector advisory lanes in the Netherlands (Furth, 2012).

Figure 2: Advisory Lanes in the Netherlands (Furth, 2012)

Bicycling Contraflow (Brown & Demusz, 2013) lanes is another type of solution slow speed and low flow vehicles presented in the Netherlands, well in marked or unmarked lanes or on contraflow with physical divider (This last type will not explain due to be a separated path from the roadway).

Marked contraflow lanes are typically used only on short segments of road where contraflow might not be expected and the pavement signs designate both the area for two-way bicycle and one-way motor traffic. **Figure 3** represents the marked contraflow street off a main road in Delft.

Figure 3: Marked Contraflow on driveway off of Martinus Nijhofflaan in Delft (Brown & Demusz, 2013)

But Contraflow is most often implemented without any marked lane or centerline due to most local contraflow streets in Holland were not specifically designed for it, but it is expected cyclists ride contraflow because of the low speeds giving the cyclists enough time to react. The low-stress environment is the factor that makes cyclists going against the natural flow of traffic. In the Netherlands, unmarked contraflow is sometimes applied to service roads. Figure 4 shows an example of an unmarked contraflow street in Delft with vertical sings to allow bike traffic at the beginning of the Street.

Figure 4: Unmarked Contraflow in Delft (Brown & Demusz, 2013)

Contraflow streets used to be very narrow. The narrowest one in the Netherlands is the marked lane on the Voohofdreef driveway in Delft. It has 2,2 meters wide of the motor lane and 1,0 meter the bicycle lane. The widest lanes with contraflow are unmarked lanes along the canals in Delft. These local, mixed-use streets have 3,25 meters wide lanes and parking around 1,65 meter wide and it is represented in the Figure 5 below.

Figure 5: Unmarked Contraflow along the Canals in Delft (Brown & Demusz, 2013)

Dutch Contraflow is expected on most one-way streets because many streets in the Netherlands have the conditions needed for safe bicycle contraflow. The CROW manual does not have a lot of information of bicycle contraflow; but cyclists have priority on most streets, especially ones with implied contraflow.

It has been found a lot of good examples in Germany, where is probably the most extensive anywhere. Bike lanes are not designed in these installations except on arterial roads (arterial roads are high-capacity urban roads that deliver traffic from collector roads to highways and between urban centers). In narrow streets, there will necessarily be head-on conflicts.

In Bremen (Allen, 2006) and a few other cities, contraflow bicycle traffic streets have already proven themselves having no crashes resulting from this facility and obtaining a positive solution. German law specifically permits cyclists to use as much of the roadway as is needed to avoid the hazards of parked cars. The Germans appear to choose and enforce low speed limits consistent with the available roadway width.

On-street parking is an important factor to study since it can provide unsafety and dangerous situation to cyclists: “Right-way” contraflow with “wrong-way” parking exist in some of the German installations. “Wrong-way” parking raises serious issues because motorists who want to leave or enter in a parking spot must merge across on-coming traffic and since the bike lane is narrow, cyclists do not have enough space to avoid the motor vehicle on time. “Dooring” can happen, not in the higher likelihood because the driver´s door is in the sideway but also can be a problem (Allen, 2006).

A **Woonerfs** is another type of street that was developed in the Netherlands, and it is designed for extremely low motor vehicle travel speeds. "Home Zone" (7km/h) is another solution done but it is only implemented in residential areas/walking residential areas in which neighbors cars need to pass (Pucher & Buehler, 2008)

Dutch, Danish and German cities have **Traffic Calmed** most streets in residential roads, reducing the speed limit to 30km/h and often prohibiting any through traffic or restricting traffic to one way in a street. Especially in Netherlands have been introduced alterations in the streets, including as road narrowing, parked vehicles, raised intersections and crosswalks, traffic circles, extra curves, speed humps and created artificially created dead-ends. Bicycling is always allowed in both directions, even in one-way streets (Pucher & Buehler, 2008) .

For the speed relationship between the motor vehicle and the bicycle, the advice of Netherlands (CROW) establishes that the speed of the last one should not be more than 10km/h the speed of cyclist in a local street. The normal cycling speed is around 20km/h. Then, the optimal speed of motor vehicles is 30km/h (Cycling unit; Roads and Traffic Department, 2013).

II. Muenster, Germany

GENERAL INFORMATION

Muenster (Pucher & Buehler, 2008) has a long history of cycling, having for many decades the highest bike share of trips of any German city. It has a population of 291.754 inhabitants and with a density of 963 inhabit/km, it is considered with a compact urban form since 71% of the metropolitan region´s population living within a 7 km radius of the city center. The bicycling share of total trips has increased in the last decades, being in 2001 35.2%.

The overall goals of the city are to preserve its position as Germany´s premier cycling city, to increase cycling safety, to reduce bike theft, and to implement measures to enhance the convenience, feasibility, attractiveness of cycling for all age groups.

Within the more densely developed area of the city, 12 streets were officially designated as bicycling streets in 2007 **(Fahrradstrassen)**. The city has plans to designate 10 more, for a total of 22 bicycling streets in the coming years (Pucher & Ralph, 2007). Figure 6 shows an example of a Fahrradstrassen in Münster with the vertical sign at the beginning of the Street.

Figure 6: Fahrradstrassen (Office of Urban Development, urban planning, trans, 2010)

An integrated, comprehensive, separated from motorist´s system of **directional signs** for cyclists was developed in Muenster. They indicate directions and distances to various destinations, and are color-coded depending of the bike route network and the part of the city. These directional signs are called **Way finding** and this concept will be explained further in the thesis.

The **traffic calming** is used in almost all residential neighborhoods and it facilitates cycling without the need to provide bike lanes or paths. **"Home Zones"** (Spielstrassen) are also provided.

Throughout the city, cyclists are permitted to cycle in both directions on one-way streets for vehicles, finding the same **Contraflow lanes** situations as Bremen or any city in the Netherlands.

III. Dublin, Ireland

GENERAL INFORMATION

Dublin, with 527.612 inhabitants and a density of 4.588 inhabit/km^2, is the capital and most populous city of Ireland. As of 2012, the city has over 200 kilometers of specific on-and off road tracks for cyclist (120 km of bicycling on-road) (Cycling unit; Roads and Traffic Department, 2013) and in 2013 has been ranked 9th among major world cities on the Copenagenize Index of Bicycle-Friendly Cities (Copenhagenize design Co, 2013). The percentage of shared trips by bike is 10% but, through a numerous bike policies is expected to improve to 18% in the following years. With that, Irish transport policy seeks to reduce private car dependence from 65% to 45% for commuting by 2020 (National Transport Authority B, 2011).

The National cycle manual of Dublin (National Transport Authority A, 2011) encompasses all the possible bicycle facility types within city and establishes five principles of sustainable safety (main factor all the roads designs should reach) for cycling design. The principles of sustainable safety were developed in the Netherlands from 1992 and they have contributed to the Netherlands leading record in road safety. The principles are:

- Functionality, the design which is fit for purpose is safer. Urban streets, roads and spaces are always multi-functional.
- Homogeneity, reducing the relative speed, mass and directional differences of different road user sharing the same space increases safety. When the relative speed, mass or direction is not homogenous, different roads users may need to be segregated.
- Legibility, where all road users can read and understand the road is safer, expecting other users on the road and having a clear idea about the room where driving/riding.
- Forgivingness, where environments contribute to outcomes of accidents is safer. Designs considerations should be: who are the users on the

road, the space they need for operating safety and what are the risks to vulnerable road users.

- Self-awareness, where road users are aware of their own abilities and limitations to negotiate a road environment, the environment is safer. It should be provide a high Quality of service, alternative routes…

Quality of service (QOS) is a measurement of the degree in which cyclist´s attributes and needs are met: it describes the mode of the cycling environment. It is influenced by vehicular, cycle and pedestrian traffic and network characteristics. It is measured considering pavement condition, number of adjacent cyclist, number of conflicts or junction time delay. Heavy congestion and high traffic volume will limit the quality of service (National cycle manual).

SHARED USE BICYCLE SOLUTIONS

Type of road depends on the adjoining traffic regime, the need for segregation and the target Quality of Service (QOS). For the sharing option road, the national cycle manual of Dublin considers (National Transport Authority A, 2011):

Mixed/Shared streets, which are suitable in low traffic single lane environments where cyclists and pedestrians take precedence over vehicular traffic. These include:

- *Narrow Shared Street:* are these streets less than 5,5 meters in width. There should be no central lane marking, thereby ensuring all road users in either direction yield to each other. Figure 7 shows a drawing of a Narrow Shared Street.

  Residential areas, access roads and streets and shopping areas normally represent a narrow shared street in the city, where the traffic speeds and volumes are low, there is free access for cyclists and QOS is possible to be provided. Loading and parking exist on the road.

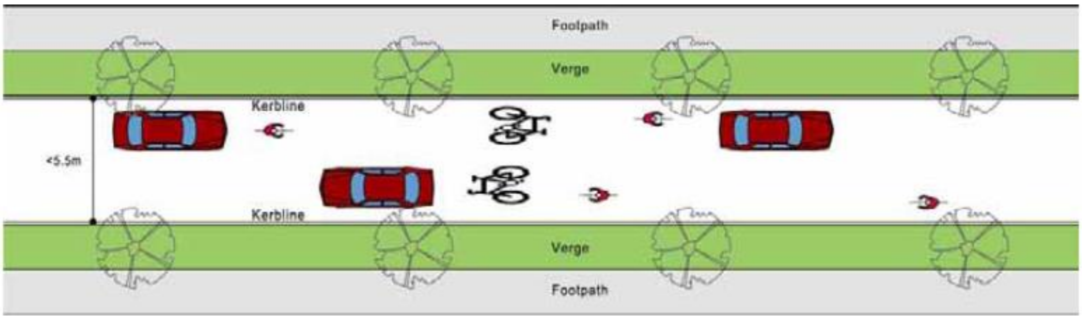


Figure 7: Narrow Shared Street (National Transport Authority A, 2011)

Cycle markings on the center of the lane emphasize the correct cyclist position. Overtaking cyclists is allow only if the opposing lane permit it and always at low speed.

- *Wide Shared Street* are considered all these streets with widths between 5,5 and 7,0 meters in which a central lane marking should be provided to separate opposing traffic. Typical Road environments and characteristics considered are equal to "narrow shared street". In this case, two way cycling should be the norm. A drawing of this type of street is represented in Figure 8:

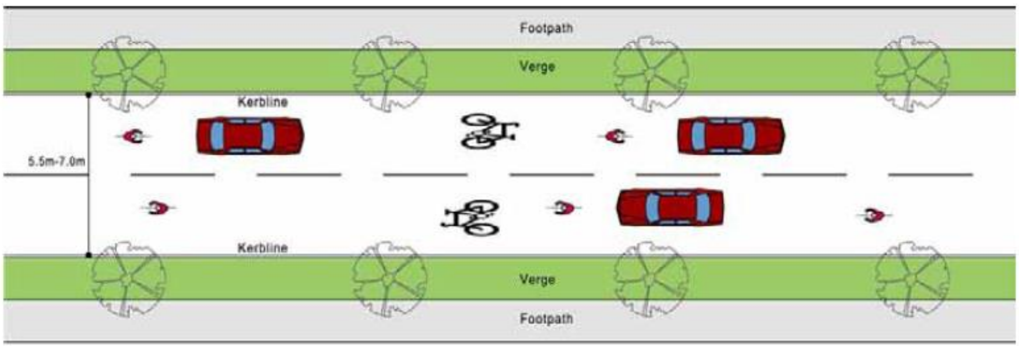


Figure 8: Wide Shared Street (National Transport Authority A, 2011)

Advisory Cycle lanes are considered in this study as shared space traffic although National cycle manual of Ireland classifies it as a standard cycle lane.

These streets are collector roads with single lane in each direction and with a maximum speed of 50km/h. In conflict points or zones where are might be confused with on-street parking (if the street had it) this solution has a red surface.

When the residual space for traffic is less than 6.0 meters, centerline is not used and low traffic speed is important, being traffic calming may require. In the Figure 9 is showed a drawing of Advisory Lanes without centerline.

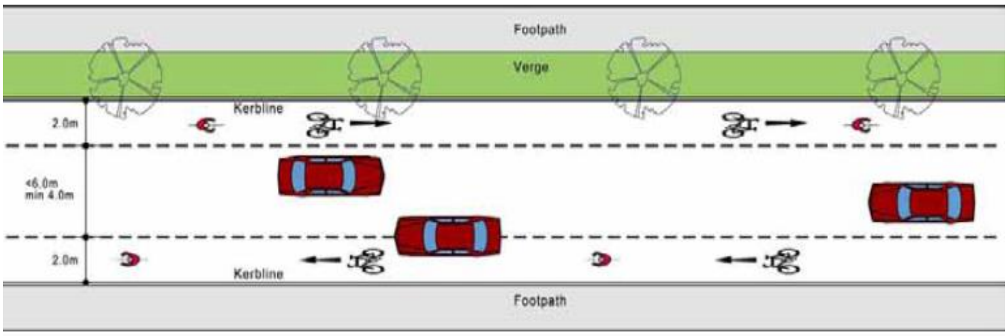


Figure 9: Advisory Lanes (National Transport Authority A, 2011)

Contra-flow cycle lanes are another example of shared use bicycle facility provided in the streets of Dublin. It is provided in access roads or quiet streets in centers where the speed limit is 30km/h or less. They are short streets with low parking and loading demand only in the contraflow side of the street being not suitable for areas with curbside loading and parking. It has been noted that being legible and signed, ensures continuity and coherence to the route. Figure 10 represents a drawing of the Contraflow streets in Dublin.

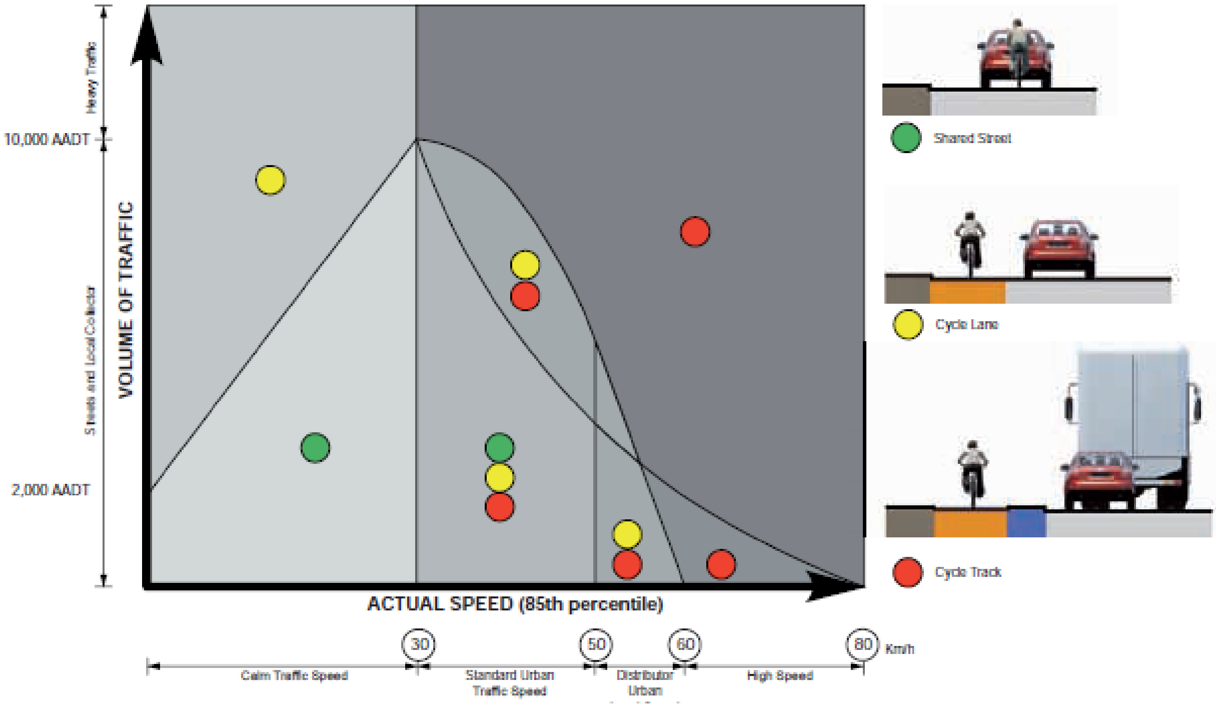
Figure 10: Contraflow Cycle Lane (National Transport Authority A, 2011)

It is important to provide cycle-friendly junctions and take into account the cyclist´s need, as opposed to traditional urban junctions which are designed for vehicular movements and often detract from cycling.

In **Roundabouts** shared use condition can occur with traffic volumes less than 6.000 vehicles per day. It is used a single circulation lane (cycle markings in the traffic lane or nothing). Shared roundabouts can be designed in shared use junctions with traffic volumes up to 6.000 vehicles per day if the speed limit is less than 50 km/h.

METHOD TO DETERMINE SHARED/SEPARATED TRAFFIC SOLUTION

Graphic 1 below is provided by the national cycle manual of Dublin and shows the facility to use according the speed limit and volume of the roadway. It ensures that the principles of Sustainable Safety, especially functionality, homogeneity and legibility are reached in the design.



Graphic 1: Guidance Graph-Mixed or Separate Facility (National Transport Authority A, 2011)

At 30km/h is represented the maximum level of traffic flow (AADT=10.000) at which mixed cycling is appropriate. Values below 30km/h speed belong with traffic volumes below 10.000 vehicles per day. The slopes of speed and flow vary directly proportional. Speed values above 30km/h can be appropriate for mixed traffic streets if AADT is less than the maximum level flow (which is belonging to peak hour's traffic). The maximum speed at which shared traffic lanes are appropriated is 50 km/h with the flow of vehicles per day less than 3500.

IV. Ferrara, Italy

GENERAL INFORMATION

Ferrara is a flat city in the northern Italy, capital city of the province of *Ferrara*. It is a municipality with a population of 134.000 inhabitants and 330 inhabit/km^2. Italy represents a country with the highest European car ownership rate and low levels of cycling for daily trips, but *Ferrara* is considered the "Italian city of bicycle". The reason is bicycle is greatly used as a mode of transport by the citizens. The trips made by bike represents 30,7% against 34,7% of trips made by motor vehicles. Commuting students from home to school are about 30% (ADEME; Energy cities; Ferrara (IT), 2001).

Within the municipally staff in Ferrara Administration, a technical group is organized to co-ordinate cycling mobility with general urban mobility issues. They elaborated and adopted its Bicycle Mobility Plan with the General Mobility Plan, creating a real and quite complete bicycle network that provides solutions for risky situations for cyclists and guarantee safety trips (Province of Ferrara; AMI, 2011).

The local Administration spread via local press or in the municipal website information about bicycle mobility news. **Cycling education** courses are provided to primary school, cycling network map has been published, measures to facilitate the access by bicycle to commercial zones and the intention of reducing car use to make the school surroundings safer.

SHARED USE BICYCLE SOLUTION

In Ferrara, shared use bicycle facility is the solution most used within the city, using cycle lanes only if the road allows it. Traffic calming measures are very used.

Cycle facilities used in the city are 30 speed limit zone, residential streets and contraflow solutions (Province of Ferrara; AMI, 2011).

The 30 speed limit zone (speed limit 30 km/h) is roads or local roads on-street parking is provided. Public transport must be in a state of stop accessing of 30 speed limit zones. It is a narrow street. As it is showed in Figure 11, the 30 speed limit belong to a street as constructed where the speed limitation has been imposed.

Figure 11: 30 Speed Limit Zone (Province of Ferrara, 2010)

Residential streets are another example of Shared traffic condition in Ferrara but it is referred to Woonerfs or Home zones where pedestrians, cyclists and motorists equal rights on the roadway. Only it is allowed residential motorist or those who have business in the area.

Contra-flow lane is another type of solution suggested in the Bicycle Policy of Ferrara, but still not used. The facility will be signage with vertical signs at the beginning of the road due to the elaborated pavement of historic centers, pedestrian and shopping areas and with yellow and white stripe on the pavement. In the traffic direction would be painted a warming sign.

Warming signs for drivers are used on bicycle routes with a sentence or word written to indicate danger. This could guarantee the safety of cyclists in shared use routes.

Some measures/interventions, including **traffic calming** are used on the road as a more economical solution to supplement the Bicycle Policy (Province of Ferrara; AMI, 2011). The measures are restrictions in vehicle speed, narrower the road providing on-street parking, roads remarked and intersections marked for bikes which can be seen in Figure 12.

Figure 12: Intervention in intersections for bikes (Province of Ferrara; AMI, 2011)

V. *Ghent, Belgium*

GENERAL INFORMATION

Ghent is a city and a municipality in Belgium. It is the largest city and capital of the East Flanders province. It has 250.000 inhabitants and a density of 1.600 inhabit/km^2.

This city is a clear example of what a "bike city" is. Ghent is a city in whit the use of motor vehicles high respect the other mode of transport, 50% against 15% of trips made by bike (Witlox & Tindemans, 2004) but in summer of 2011, this city established the **first bicycle street** in Belgium: **FISHERIES**, **Bicycle Street**. They made extensive research and consultation with people living in the area, and after discussing 4 redesign scenarios for bicyclist, 88% of participants showed interest in the bicycle street concept. For this reason, once the community gives the support, the solution will be accepted and used for people.

Some months later, there was a doubling of the number of cyclists. Accompanying the increase in the number of cyclist, a decrease in the number of cars was achieved. In addition, number of vehicles traveling faster than 50km/h decreased by 80%, decreasing the V_{85} from 46km to 39km (ELTIS, The Urban Mobility Portal, 2012).

SHARED USE BICYCLE SOLUTION

As it has been mention before, a **Bicycle Street facility** or **FISHERIES** was the solution that most people/surveys bet for and finally it was successfully introduced in the streets of Ghent. To raise the "street concept", a bicycle road sign was designed by researchers to identify the street. In addition, a layer of red paint was applied on the road and cyclists were allowed to ride in the middle of the street. Figure 13 and Figure 14 shows two FISHERIES or Bicycle Streets in the city of Ghent.

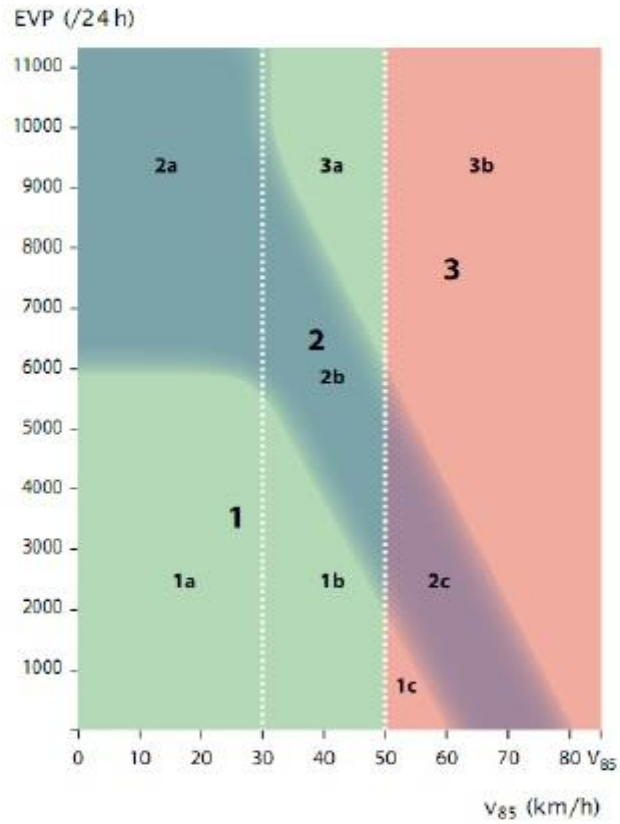
Traffic signals identify the beginning and the end of a bicycle street and motorist speed could not exceed 30 km/h.

Figure 13: Bicycle Street (FISHERIES) in Ghent (ELTIS, The Urban Mobility Portal, 2012)

Figure 14: Street for cyclists in Ghent (ELTIS, The Urban Mobility Portal, 2012)

All areas remain accessible to local motorists and parking spaces were not lost to install the bicycle street.

The following Graphic 2 belongs to cycle lanes and markings Brussels' guide (Vertriest & Institut Belge pour la Sécurité Routière asbl, 2007) and establishes the border between providing a shared bicycle facility or a separated way for bicycles (cycle lanes or cycle tracks). This Graphic 2 has been followed in the cities of Belgium at time of deciding the type of street regarding to the AADT and speed limit.



Graphic 2: Separated or mixed traffic (Vertriest & Institut Belge pour la Sécurité Routière asbl, 2007)

Shared-used bicycles facility (number 1) can be supplied always the flow is less than 6.000 vehicles per day and the speed limit less than 30 km/h. If the speed is higher than 30km/h, traffic flow needs to be lower. Shared use solutions can be provided for 60km/h if the AADT is lower than 2.000 vehicles per day.

Cycle lanes belong to number 2 and cycle tracks to number 3. These two facility types are provided for a combination of higher speed limits and higher flow vehicles that will not be into the research area.

VI. Murcia, Spain

GENERAL INFORMATION

Murcia is a city of Spain, and the capital of the community of Murcia. Since the years 90s and especially at the beginning of the new millennium, the request of the use of bicycles has increased in this city. But the demand has been limited by a lack of structures that guarantee the safety of cyclist. In November of 2010, *"Plan director para el uso de la Bicicleta-PDBM"* (IDOM-Ingeniería y Arquitectura, 2010) was published to make the bike a common and safe mode of transport. Nevertheless, the percentage of displacements made by bike is 1,1% against the 50% of the trips by car.

SHARED USE BICYCLE SOLUTION

PDMB (IDOM- Ingeniería y Arquitectura, 2010) propose several solutions to improve the bike situation in Murcia, being the 83% of the proposals, **Ciclocalles**. This solution should be provided always the AADT is less than 5000 vehicles per day and the road speed limit, 30 km/h. The street is signalized through horizontal markings (bicycle + arrow = Sharrows) each 25 meters and in all the junctions. As we can see in the Figure 15 below, vertical signs are provided as well (“shared lane” + Speed Limit) at the beginning of the bicycle street to make motorist aware about the presence of cyclists.

Ciclocalles can be streets in which the speed limit is low, streets where traffic calming has already been applied, residential zones or 30 zones (30km/h Zones where the roadway and the sidewalk are at the same level to make the pedestrian has the priority).

Figure 15: Ciclocalle with Vertical Sign at the beginning of the Street (IDOM- Ingeniería y Arquitectura, 2010)

This solution does not provide a total priority for bikes: it is a shared roadway, where all users share the benefits. However, overtaking is forbidden in the most of roadway sections. Residential zones with speed limit really slow, whit more than 3 meters width of the road, overtaking is allowed. Anyhow, is recommended to cycling in the middle of the lane to avoid any overtaking.

Traffic in **roundabout** placed in a mixed traffic street will be carried out in the same way than cycling in a shared road: cyclist will share the space with vehicles and the speed limit is 30km/h.

Shared area by pedestrians, bicyclist and vehicles, **Woonerfs**, is another proposal into Murcia´s solutions. Speed limit of “wheels” traffic is 20km/h but pedestrians have the priority on the road.

METHOD TO DETERMINE SHARED/SEPARATED TRAFFIC SOLUTION

At time of elaborating the Cycle Plan of Murcia, engineers and qualify staff have supported their conclusion with the Brussels Graphic 2 explained in the Ghent section.

EXAMPLES OF STREETS WHERE CICLOCALLES IS INTRODUCED AS A SHARED MEASURE

Some examples registered in the Plan Director de la Bicicleta en Murcia are presented below. They are local roads where, after propose the Bicycle Plan, Ciclocalle solution has been applied served with traffic calming solutions whether it has been necessary.

Street Juan Ramón Jiménez Street is shown in Figure 16. It is an One-way street with parking on both sides of the road. It is proposed a Ciclocalle.

Figure 16: Juan Ramón Jiménez Street (IDOM- Ingeniería y Arquitectura, 2010)

Figure 17 represents Marqués de Covera Street. It is one-way direction road but width enough to drive a high speed. Ciclocalle + Speed reducers are proposed.

Figure 17: Marqués de Corvera Street (IDOM- Ingeniería y Arquitectura, 2010)

VII. Alicante, Spain

GENERAL INFORMATION

Alicante is a city in the community of Alicante, in the north of Murcia´s community. Although the city has not a Bicycle Plan as city of Murcia has, they have adopted the same solution: Ciclocalles. To supply more examples of Ciclocalles is the purpose of including Alicante in this study that will not be further developed.

Concept of cycling is being introduced each day more in Alicante, but the percentage of trips realized by bike is really low, being the lack of information and education and the lack of confidence the main factors of this issue.

In almost the whole city center zone, **shared road solution** has been introduced. Streets are marked with two red lines and one red bicycle in the middle of the roadway with the role that cyclists occupy the center of the street.

The selected streets are **narrow streets** and an example of them is shown in the Figure 18. Most of them are one-way traffic direction streets. In some streets on street parking is provided both in one or two sides of the road, with 5-7 meters of width. Other streets has not on-street parking and are not more than 3 meters of width.

Figure 18: Ciclocalle in the center of Alicante (Gilabert, 2012)

VIII. Vienna, Austria

GENERAL INFORMATION

Vienna is the capital and largest city of Austria with a population of about 1.741 million inhabitants and a density of 4.000 inhabit/km^2. It is considered a **hilly** town. In Vienna, cycling is all the rage, taking the bike an important place in the city. The city has set itself the target of increasing the proportion of cycling from the current 6% to 10% in 2015 (Weninger, 2012). The Department of Transport and traffic technical matters fight to provide a high quality and attractive cycling network.

SHARED USE BICYCLE SOLUTIONS

Different bicycle facility solutions are required around the town regarding to the specific characteristics of each road. Vehicle traffic volumes, speed limit, traffic composition and the final target of safety are essential factor for the decision. Shared roadway proposals are: Multi-purpose strip, bicycle road and cycling in in mixed traffic (Municipal Department A, Vienna, n.d.).

Multi-purpose strip is a marked for bicycle traffic by warming lines portion of the road. Basically is similar to Advisory Lanes. To provide this solution, the traffic volume is needed to be up of 7.000 vehicles per day or a 6% of trucks should be presented on the road. However, cyclist´s situation can be unpleasant in heavy or fast traffic. Overtaking is possible since the adjacent lanes are for common use. At short distances (<100 m) crossroad and driveways, this solution is very used (Meschik, 2012).

Figure 19 shows a multi-purpose street in the city of Vienna. Probably the only characteristic that difference both Multi-purpose Street and Advisory lanes is the presence of heavy vehicles in the first one.

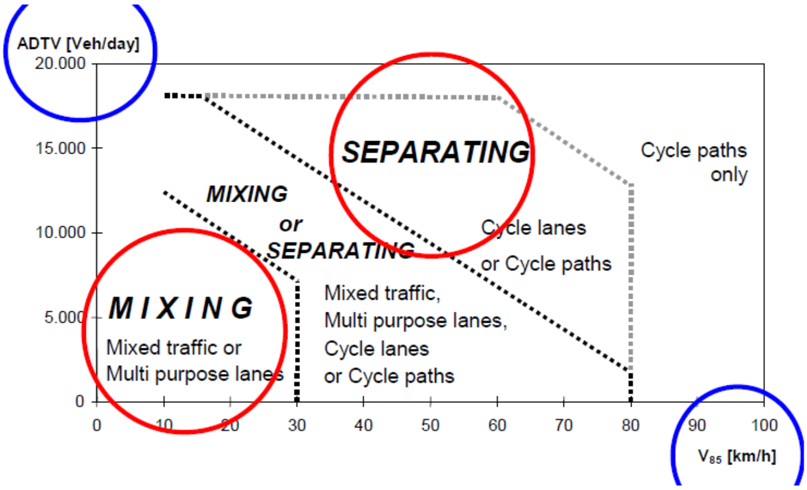
Figure 19: Multi-purpose strip in Vienna with narrow space for cars (Meschik, 2012)

Bicycle road is provided for a light flow of motor vehicles and speed limit of 30 km/h. Bicyclists are allowed to drive next to each other and overtaking is forbidden. Signals ensure it is a bike street.

Cycling in the mixed traffic (Municipal Department B, Vienna, n.d.), cyclists ride with the flow of traffic especially in 30 zones or in residential area and there is not any on-road making that ensures the shared use condition, but the environment is appropriate for a shared situation due the restrictions already applied to the street. Figure 20 above shows cyclists riding in normal streets without any special cycling mark.

Figure 20: Cycling in mixed traffic on streets without any mark in Vienna (Municipal Department B, Vienna, n.d.)

A study carried out by the Institute for Transport Studies, Vienna (Meschik, 2012) establishes Graphic 3 as planning principle to determine if a separated or mixed bicycle facility is provided.



Graphic 3: Car & cyclists: The planning principle (Meschik, 2012)

In the Graphic 3 above, 30 km/h is the speed limit in a mixing traffic built street. When the speed limit is more than 30 km/h, the bicycle facility provided (mixed or separated) is a point to discuss. The higher flow of motor vehicles for a mixed traffic situation is 18.000 vehicles per day.

The information supplied previously in the section 2.2 Shared traffic use solutions in European countries will be summarized in **¡Error! No se encuentra el origen de la referencia. ¡Error! No se encuentra el origen de la referencia.** in Table 2: Characteristics of shared use facility in the Netherlands, Europe and Table 3: Characteristics of shared use facility in European cities studied.

2.3. Shared traffic use solutions in USA

The bike share of travel in the United States is 1% due the lack of safety on the roads where to battle with motor vehicles in streets without any separation for cyclists is found every day (Pucher & Buehler, 2008). In many cities, bicycling is a more recreational used mode of transport that with practical purposes, every day travel needs. In others, commuting by bicycle is gaining in popularity. In these cities, efforts to improve bicycle infrastructure exist. Characteristics of roadways, such as the width of roads (which are typically wider in the US than in Europe), result in shared use bicycle solutions which may not be appropriate within the context of Norwegian streets (Pucher & Buehler, 2008).

I. *Cambridge, Massachusetts*

GENERAL INFORMATION

Cambridge is a city in the State of Massachusetts with a population of 109.000 inhabitants and 2.675 inh/km^2 density. The city of Cambridge has gained the title of “walkable city” rarely found in America. Most policies and efforts (realized by citizens, elected officials, developers, business community, academic institutions and city staff, including elements of policy, engineering, community plans and enforcements) advocate a life without car, focused on the concept that a community should be designed around walking, cycling and transit rather than the automobile and strongly concentrate on walking life. Motivated by the environment, good health, economic development and quality of life, Cambridge sets aggressive goals to reduce car ownership and traffic while improving safety (Parenti, 2008).

Bicycling constitute a healthy, **environmentally friendly way** of getting around as an important part of the City´s efforts to improve mobility and protect the environment. Cambridge is suitable for bicycling and more people are using their bikes every day for commuting, shopping and general transportation. The percentage of commuters who travel by bike has also been raising in the past two decades: The 1990 US Census reported that 3% of residents commuted by bicycle. In the year 2000 that number rose to 4% and the American Community Survey for the three year period 2009-2011 showed 7% of residents commuting by bike (Seiderman, 2012).

SHARED USE BICYCLE SOLUTIONS

Sharrow (share lane markings) is the marking for shared use bicycle solution that city of Cambridge, as most American cities with shared street condition, has on its streets.

Due the "wide" street structure and the higher speed allowed in most American streets; in absence of bicycle lanes, motorists would not travel safety with cyclists and would make them to ride closer to the parked vehicles where dooring crash happens representing a 20% of all crashes (Seiderman, 2012). Because of that, sharrows are placed a certain distance from the curb line especially when parking is presented. The spacing recommended by the 2009 version of the Manual on Uniform Traffic Control Devices (Hunter, et al., 2011) (US. Department of Transportation - Federal Highway Administration, 2009) is 11ft from the curb line to the center of the sharrow in streets with parallel parking. This distance has been examined in some others cases: when there is a lane outside way with no on-street parking, when there is a bike lane in the uphill direction being the sharrow in the downhill direction and when sharrows are place at 10 ft (3,05 m) as an alternative to the 11 ft (3,4 m) with parallel parking that showed in the Figure 21. The last issue will be further explained in the section 5: How We Assess? in this document (Hunter, et al., 2011).

Figure 21: Operating Space with Sharrows markings (Hunter, et al., 2011)

Contraflow bicycle lanes (Allen, 2006) have been also provided in Cambridge. This solution is becoming more common in the U.S. because it can be adapted to many local streets and in cities like Cambridge is a feasible and suitable method due to its many shorter one-way streets to connect bike networks throughout the city. The method has been approved under the MUTCD (Manual on Uniform Traffic Control Devices). Nevertheless Contraflow can be unsafe for both bicyclists and motorists. U.S. streets tend to have higher speeds and less traffic calming measures.

Contraflow bicycle lanes are located in Cambridge in low traffic streets with the purpose of avoiding high traffic volumes of some arterials streets. The selected roads are situated in residential areas/quiet zones and on-street parking is presented between the curb and the contraflow lane. The traffic flow of any of the contraflow streets is not more than 2.000 vehicles per day. On the contraflow lane, bike symbols and arrow are painted at very frequent intervals. **Vertical signs** showing the contraflow bicycle lane or the allowance only for cyclists in that direction of the street, are located on the approach to the intersection or at the beginning of the street. Some examples of contraflow streets are Scott Street, Concord Avenue or Waterhouse Street. Figure 22 shows the contraflow lane situated on Waterhouse Street in Cambridge, where on-street parking is provided.

Figure 22: Contraflow bike lane on Waterhouse Street in Cambridge, Messachusetts (Allen, 2006)

But sometimes, in streets with contraflow lanes and on-parking street, situations of “wrong-way” parking can occur. On one-way Scott Street (Cambridge) with parking on both sides was added a contraflow bike lane: there happened a situation in which cyclist travelled very close to the oncoming vehicles (48km/h) and to the door zone, what was very dangerous with a high likelihood of crashes.

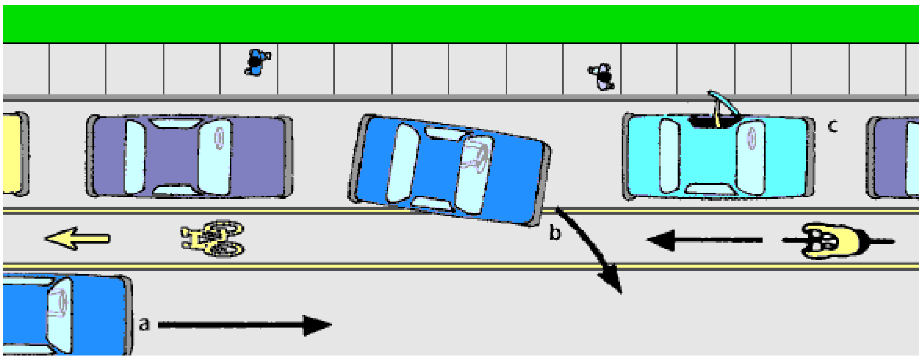


Figure 23: Issues with a contraflow bike lane adjacent to parking. (Allen, 2006)

In the Figure 23 above is represented the possible issues with a contraflow bike lane adjacent to parking. Driver C can exit to sidewalk without opening door into contraflow bike lane, but driver B existing parking spot is on curb side and may not see car A or the cyclists in time of avoid a collision.

Regarding to the operation of its **traffic signals**; the traffic, parking and transportation department has written a formal policy to encourage the non-automotive modes in function with the VTRO goals. Different types of verticals signals are found to permit bicycles to take the street or to avoid vehicles to pass into the road. Signalizing to make drivers aware of bicyclist is presented on the necessary streets (Parenti, 2008).

Traffic calming is one of the strongest traffic calming programs in USA as solution of fatalities produced, being speed reduced on all the streets, including arterials. Data indicate that fatalities occur 85% of the time at 40MPH (65 km/h) and only 45% of the time at 30MPH (50 km/h) (Parenti, 2008).

Coordination between **intersections** is designed to keep movements of regional traffic at a reasonable speed along arterials because of a good transition to neighborhoods. A speed of 25MPH (40 km/h) is assigned to corridors and drives have learned that if they drive at that speed, catching the green wave without stopping is possible (Parenti, 2008).

II. Portland, Oregon

GENERAL INFORMATION

Portland is a city located in the U.S. state of Oregon. It has a population of 584.000 inhabitants with 1.690 inh/km2 of density. Because of its public transportation networks and efficient land-use planning, Portland has been referred as one of the most environmentally friendly or "green cities" in the world (Kiest, 2011), where cycling represents a significant mode of transport ranking the city as one of the most bicycle-friendly cities. The percentage of people who bikes will reach soon the 10%, around 10 times the national average, representing the highest proportion of any U.S. city (Geller, 2011).

SHARED USE BICYCLE SOLUTIONS

Shared roadways, bicycle boulevard and Woonerfs are the different solutions for shared on-road use bicycle facility used in the city of Portland (Oregon Department of Transportation, 2011). Woonerfs are located in residential areas.

Shared Roadways are the most common bikeway type within Portland streets and other cities of Oregon (not specific bicycle standards, narrow roads as constructed). This type of street is suitable in urban areas with light traffic and low traffic speed and rural roads/highways with low traffic volumes. **Traffic-calming** techniques can be applied if the shared street for bicyclists carries excessive traffic volumes at speeds higher than they were designed to. Figure 24 represents a too wide and high traffic street in Portland to provide a Shared condition.

In general, there are **no signs for shared roadways** but **warming signs** "Share the road" or "bikes may use full lane" are located at the beginning of the street indicating a permanent shared condition. They are normally used in combination with sharrows in non-intuitive streets for bicycling.

Figure 24: Street in Portland no suitable for a Shared road solution. (Oregon Department of Transportation, 2011)

Bicycle Boulevards (Bike streets) are local streets and constituted a refinement concept of shared roadways (bicyclists have priority on the street). They are highly prepared for bicyclists: Traffic- calming devices that reduce motor vehicle speeds are used and traffic controls limit the conflicts between motorists and bicyclists giving priority to bicyclist’s movements. **Directional signs** or markings are placed in Bicycle Boulevards to route and guide cyclists to key destinations and crossing improvements are provided on the intersection with high speed/volume streets: activated signals to cross the street and median refuges that can be seen in the following Figure 25.

Figure 25: Mini circle slows traffic: creating conditions for Shared Roadway (Oregon Department of Transportation, 2011)

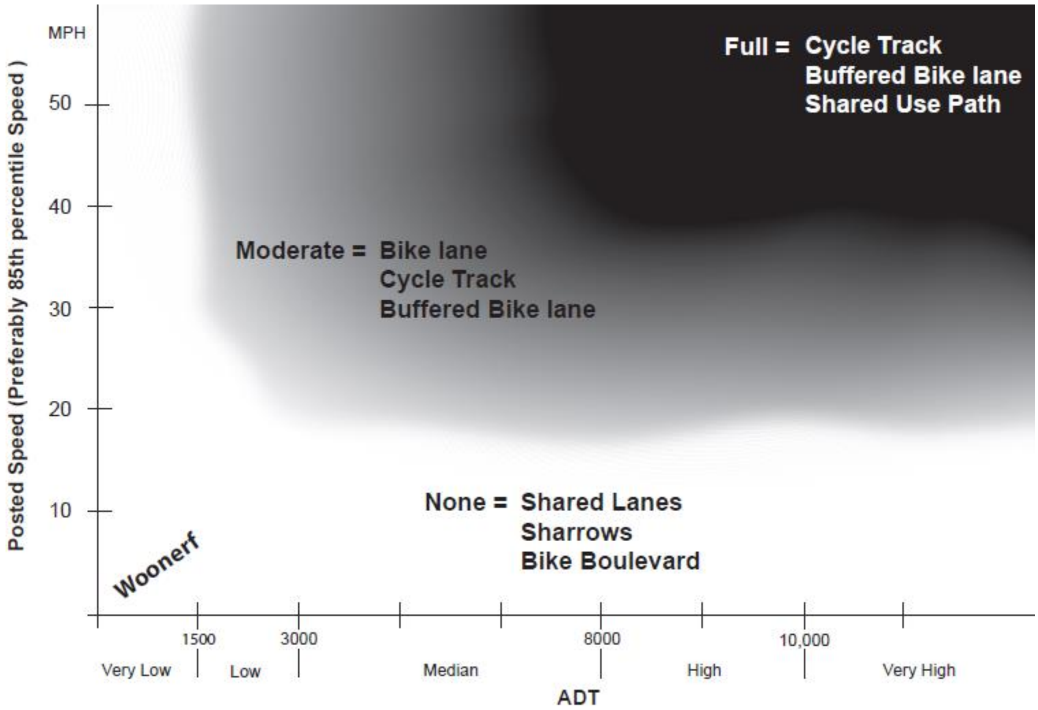
Signals in Bike boulevards should convey route information to cyclists. Additionally to other city of the State, Portland has developed bike boulevard route signs by adding the name of the bike boulevard, complimented with a **designated bicycle boulevard pavement marking**. The pavement marking used are **sharrows** that helps where there is competition between cyclists and motorists for the use of a narrow lane. Figure 26 shows Sharrows indicating the way of riding for cyclists.

Figure 26: Sharrows (Oregon Department of Transportation, 2011)

There are found **Woonerfs** (Figure 27) in very narrow streets belonged to residential areas where both the speed and traffic volume are very low. The speed limit is 20 miles per hour (33km/h).

Figure 27: Woonerf (Oregon Department of Transportation, 2011)

Bicycle and Pedestrian design Guide of the Oregon Department of Transportation explain how they understand the different levels of roads and which the most important factors are at time of designing the type of street. As other cities from Europe studied before like Dublin, Vienna or Brussels, they establishes a method to determine if a Shared use bicycle or a separated lane facility should be provided on a certain street.



Graphic 4: Urban/Suburban bike facility separation matrix (Oregon Department of Transportation, 2011)

Graphic 4 above establishes which level of bicycle road facility is appropriate according with the speed and vehicles flow. For very high volume of vehicles, share lanes/sharrows/bike boulevards can be provided if the speed limit is very low: 12,5 km/h. Contrarily, if the speed is high (>18,5 km/h) shared use solution can be provided if low traffic is presented (< 1500 vehicles per day). The border between different types of bicycle facility is not clear enough, what means a margin in the decision. This margin is related with other factors, like width of the street, environment, structure or characteristics of the street in the city.

Regarding to the Guide of the Oregon Department of Transportation, there are some factors that clarify the final decision and they are represented in the Table 1 Separation context matrix. These factors, briefly explained later, increase or decrease the need of Separated lanes for bicycles.

Table 1: Separation Context matrix (Oregon Department of Transportation, 2011)

Context	Need for Separation
1. Land Use indicators	
Urban Center, CBD	Decreases
Suburban	Increases
Buildings at back of sidewalk	Decreases
Buildings set back from roadway (parking lots front street)	Increases
On Street Parking	Decreases
Short block length	Decreases
Long block length	Increases
2. Traffic speed/volume indicators	
Signal coordination timed at higher than posted speeds	Increases
Signal coordination timed at lower than posted speeds	Decreases
Peak Hourly Traffic Volume greater than 10%	Increases
3. Roadway characteristics	
Wide roadway / multiple travel lanes	Increases
Steep grades: uphill	Increases
Steep grades: downhill	Decreases
4. Bicycling demand indicators	
Popular Route to School	Increases
Provides continuity of bike lanes, routing or trail	Increases
Other high-use indicators	Increases

Land Uses influences traffic patterns and the comfort and confidence of bicyclists: center narrow streets, on-street parking… (Make the motorists more aware and slow down). Buildings Setbacks reduce motor vehicle speeds and provide direct access to destinations (minor needed of separating lanes). On-Street Parking also reduces motorists speed.

Block Length makes cycle lanes more necessary as rides need to travel further to reach the destination. Prevailing Speed is related to posted speed, but motorists will drive faster if the roadway allows them to, so needed of separating lanes increases. Bike lanes are needed too, if an intense traffic volumes peak is experienced.

Roadway Width/number of travel Lanes influences the behavior of drivers and the comfort and confidence of bicyclists. Steep Grade determinates the needed or not of bike lanes since bicyclists ride slowly and meandering in the uphill direction.

The information supplied about the Shared use bicycle facility solution adapted in each city in the Subsection Share will be summarized in Table 4: Characteristics of shared use facility in Cambridge and Portland, USA in the Subsection **¡Error! No se encuentra el origen de la referencia. ¡Error! No se encuentra el origen de la referencia.**.

2.4. Way finding

As important as to define the type of road (road defining) is to signalize the way to find a better road for bikes. **Way findings** (Seattle Master Plan, n.d.) (City Department, 2013) are directional signs within a bike route that indicate the best way or an alternative to a high traffic volume road, in which cyclists will feel safer and more comfortable and will find advantages against the last road. **Directional signals** can be described as signals that inform bicyclists which direction travelling to get to a specific destination, normally with the name of the destination written with a common or neighbor name to be easily known. The number of minutes to the destination (based on time of a rider travelling) should be included along with the distance to reach it.

Directional signs are very positive within a bike route because they help with safety by increasing awareness to drivers to watch the bicyclists. The best location for these signs is between nearby destinations (schools, transit hubs, parks, urban village centers…)

For a better operation in shared roads, pavement markings will also be used to assist with way findings.

There are many examples from cities that are using this directional information to help people to be oriented.

For instance the **Netherlands** (Furth, 2011), has adopted a separate system of signposting linked to the bicycle network according to CROW´s Design Manual for bicycle Traffic to fit the needs of cyclists that are different than the needs of drivers. This system of signposting includes Main Directional Signs (red and white lettering), Route Numbers, signs for Recreational Routes (green on white lettering), Long Distance Routes and Junction Network (nodes).

In **Main Directional Signs** each sign indicates a destination, usually a town or city or a specific location within the city: school, center, church… with a directional arrow pointing at the direction and showing the distance to ride to reach the destination. A more distance in a specific direction, more destinations (intermediate destinations) are included. It can be two types of signs: finger-pointing placed at intersection are very common because they most clearly show the direction to follow; and placard signs located before intersections to provide information in advance because of the lack of a good angle to see the before sing to a person travelling straight. A main Directional finger-pointing sign is showed in Figure 29 where it can be appreciated both final destinations and intermediate destinations.

Signs for Recreational Routes indicate a route that maybe is less direct but offers nice views of the countryside or of the city. The final destination use to be a green space or a park.

Figure 28 shows main directional and recreational routes signalized through both finger-pointing and placard signs.

Long Distance Routes designate national bicycle routes (part of a national network for longer tours and cycling holidays) usually on green and white rectangular signs.

Figure 28: Main Directional signs (red on white) and recreational directional signs (green on white) in the Netherlands (Furth, 2011)

Figure 29: Finger-pointing showing the distance to reach a specific destination (Furth, 2011)

In Shared Roadways in the city of **Portland**, directional and route signals are used where bicyclists will follow a route that differs from the motorists´ route. The recommended route have advantages against others ways, such as safety, convenience, because of a hostile situation from the main roadway (higher volume and speed in USA). But sometimes the bike route sign lack sufficient information and lead to poorly bicycling areas (Oregon Department of Transportation, 2011).

City of Gresham in the State of Oregon has introduced way finding signs along major bike routes throughout the City. Way finding helps to encourage residents to ride their bikes to promote health and a livable community. Figure 30 shows the directional signal in Gresham where the direction, destination, distance and time to reach the destination is provided (City Department, 2013)

Figure 31 shows Way finding signs in the city of Seattle, Washington (Seattle Master Plan, n.d.).

Figure 30: Way finding in the city of Gresham, Oregon (City Department, 2013)

Figure 31: Way finding signs in city routes in Seattle, State of Washington (Seattle Master Plan, n.d.)

2.5. Cycling in Bus Lanes

Some of the examined countries have taken as a solution within Shared use bicycle facility, bus lanes, including Norway:

Bus lanes can be improved bicycle solution with increasing width, signage and markings indicating that it is allowed to ride in the area through improved operation and maintenance, as well as the supplementary training and information measures. If it is high speed or many cyclists and motor vehicles in the public transport field, should establish bicycle lanes or cycle tracks (Sørensen, 2012). Shared bus lanes reach the safety status since collisions between the bicyclist and buses do not constitute a traffic problem. Nevertheless it will not be analyzed in this research due to the rarely situation in which buses drive on narrow street.

2.6. Summary

In this section 2.6, the information about the different solutions provided in the cities from Europe and from USA already explained will be summarized on tables. Split mode percentage, measure provided and the environment of the street in which the solution is applied and the use of others traffic measures will be shown in Table 2, Table 3 and Table 4 below.

Table 2: Characteristics of shared use facility in the Netherlands, Europe

EUROPE													
FACTORS/ CITY	**% MOTOR TRAFFIC**	**% BIKE**	**MEASURE PROVIDED**	**WHERE?**	**STREET MARKED**	**AADT STREET**	**LIMIT SPEED**	**WIDTH OF STREET**	**PARKED VEHICLES**	**ANY SOLUTION AT INTERSECTIONS?**	**FACTORS OF THE STREET**	**SIGNS**	**OTHER MEASURES**
Netherlands (the whole country)	50%	27 %	**Bicycle streets**: cyclists have priority on the whole width of the street	Around all the city. Mostly residential streets	On-marking red color streets with a bike symbol 30-sign	-	30km/h	-	YES: narrower the street and motorist drive slower	Intersections modifications and priority traffic signals	Overtaking is not allowed	Vertical signs at the beginning of the street	**Traffic calming** applied in most residential streets: narrowing street, parked vehicles, speed bumps, raised intersections and crosswalks **Way finding:** directional signals of different colors regarding to the place (green zone or any interesting place in the city) indicating the distance as well
			Advisory lanes: cyclists have priority. Allowed pass of vehicles when necessary and safe	Narrow urban and rural collectors roads	White broken line on both sides No centerline	low-moderate traffic	30-50 km/h 60km/h on rural roads	< 9 m (too narrow to allow 2 cycle lanes and 2 traffic lanes)	It is forbidden	-	Collect traffic from small local roads to main roads Ensure best use of theroadway width	-	
			Contraflow cycle lane: one way street. Cyclists ride against the traffic	narrow and short segments of roads	Marked or unmarked lanes	low flow	slow speed	very narrow the widest (unmarked)=3,25 m wide the narrowest (marked): 3,2 m roadway width	Can be provided	Signs informing cyclists driving on the contraflow when contraflow speeds approaches two-way street	It is expected cyclists ride contraflow in most streets	Vertical sign that designate the situation	
			Home zone/Woonerf: vehicles, cyclists and pedestrians can share the same space	Residential areas	Residential area, so not on-marking street	low flow: neighbors	< 20km/h It is a home zone with 7km/h	-	Normal street, so it can be provided	-	-	Vertical sign for or home zome	

Table 3: Characteristics of shared use facility in European cities studied

EUROPE													
FACTORS/ CITY	**INHAB./ DENSITY**	**% MOTOR VEHICLES**	**% BIKES in City**	**MEASURE**	**WHERE?**	**STREET MARKED**	**AADT STREET**	**LIMIT SPEED**	**WIDTH OF ROAD**	**PARKED VEHICLES**	**ANY SOLUTION AT INTERSECTIONS?**	**OTHER FACTORS**	**SIGNS**
DUBLIN (Ireland)	527.612 inh 4.588 inh/km^2	65%, expected to be reduced to 45% in 2020	11%, expected to be 18%	**Mixed/Shared Street: Narrow Street**	Residential areas, access roads and streets and shopping areas	No central line marking Cycle logos in center of lane to ensure the correct cyclist position	Low volume	30km/h	< 5.5 m	Loading and parking exist on the road	Weaving, basic right turn in junctions. In roundabout bicyclist can be mixed with traffic if AADT< 6000 per day. Single circulation lane marked or not with logos on the road. Miniroundabouts --> for narrow single lane approached	Overtaking is allow if the opposite lane permit it	
				Mixed/Shared Street: Wide Street		Central line marking should be provided to separate opposite traffics Cycle logo in center of lane			between 5,5 - 7 meters				
				Advisory lanes	Collector roads with single lane in each direction	Broken white line and red surface at conflicts points or where it might be confused with on-street parking	Low volume	≤ 50km/h	> 8 m (min residual space for cars: 4 m + 4 m of 2 cycle lane)	It is not permitted	Weaving, basic right turn in junctions.	if residual space for traffic < 6 m--> Low traffic speed, not center line and **traffic calming**	
				Contraflow cycle lane	Access roads or quite streets in centres Short streets On-way street for motor traffic	Cycle lane clearly separated, with bike symbol on the street. Bike symbol on the shared lane legible and signalized	low volume	≤ 30km/h	≈ 5 meters (2 m cycle lane+ 3 m motor lane)	Low parking and low loading demand on the side where is not the lane			On-street signals: at the beginning of the street

FERRARA (Italy)	134,000 inh 330 inh/km^2	34,70%	30,70 %	**The speed limit zone 30**	Local road: access allow to all traffic	Marking on the roads for bikes (Ensure the space for bike between the sidewalk and the roadway)	Low access road. Low volume	30 km/h	-	YES, except for public transport Use on-street parking to narrow the road	Marking some intersections for bikes	**Traffic calming**: limit the car speed	
				Woonerf	Residential streets	-	Neighborhood volume	20 km/h	-	-	-	-	
GHENT (Belgium)	250.000 inh 1600 inh/km^2	50% (before fisheries) After--> significantly increase	15% (before fisheries) After--> almost the double	**Bicycle streets- FISHERIES:** bike preference	Residential streets	Bicycle road sign Layer of red paint	< 6.000 vehicles per day < 2000 veh/day	30 km/h < 50 km/h	-	parking spaces not lost to install the bicycle street	-	Motor vehicles cannot overtake cyclists	On-street signals: Traffic signals that identify the begining and the end of the street
MURCIA (Spain)	441.354 inh 515 inh/km^2	50%	1,10%	**CICLOCALLE:** Bike streets (83% of the proposals), but bicyclist and motorists share benefits. Overtaking is forbidden in really narrow streets (3m).	Residential areas 30 zones(sidewalk and roadway at the same level) streets where the limit speed is low Streets where traffic calming has already applied	Horizontal signals: Bicycle + arrow each 25 meters	< 5000 vehicles per day	30 km/h	from width of car	Sometimes is already placed in the streets Sometimes is applied as reduction traffic solution	Horizontal signals: bicycle +arrow Vertical signs warming the motorist Advance stacking locations roundabout shared traffic is equal to bike streets: cyclists and motorist sharing the street at 30km/h limit speed	**Traffic calming**: narrower the street: parking and slow down the limit speed	Yes. At the beginning of the street (share lane+limit speed sign)

MÜNSTER (Germany)	291.754 inh 963 inh/km^2		35.2 %	**Bike streets (Fahrradstrassen):** bike preference	Narrow streets in the city	On-marking red color streets with a bike logo	-	30 km/h	Narrow enough	-	-	**Traffic calming** used in all the residential neighborhood	Directional Signs: **Way finding-** direction and distances to various destinations with different colors
WIEN (Austria)	1.741.000 inh 4.000 inh/km^2	27%	6% --> 10% in 2015	**Multi-propose street/Advisory Lane**	Road not wide enough for cycle lane Short distances Crossroad and driveway	Warming lines portion on the road	> 7.000 per day or 6% of trucks	30 km/h	narrow enough for not providing a cycle lane	It is not permitted	Not. But a good visibility is ensured between cyclists and motorists.	It can be used by heavy vehicles Overtaking a cyclist is possible	-
				Bicycle road: bicyclists share the same space with motor traffic	Narrow streets in the city	Signals that ensures it is a bike street	low flow	30 km/h	-	Sometimes placed in the streets others, as reduction traffic solution		Overtaking is forbidden	Yes. To ensure its use
				Cycling in mixed traffic	Residential areas 30 zones	NO any mark or sigh that ensure it is a bike street	low flow of traffic	≤ 30 km/h	-	Yes. Normal street	-	Restrictions (traffic calming) have been applied already on the street	

Table 4: Characteristics of shared use facility in Cambridge and Portland, USA

UNITED STATES AMERICA														
FACTORS/ CITY	**INHAB/ DENSITY**	**% MOTOR TRAFFIC**	**% BIKE**	**MEASURE**	**WERE?**	**STREET MARKED**	**AADT ROAD**	**LIMIT SPEED**	**WIDTH OF STREET**	**PARKED VEHICLES**	**ANY SOLUTION AT JUNCTIONS?**	**OTHER FACTORS**	**SIGNS**	
CAMBRIDGE (Massachusets)	109.000 inh 2.675 inh/km^2	40,50%	7%	**Sharrow**: motorists and cyclists share the travel lane	Very common in USA: around the whole city. Also Avenues	bike logo and arrow painted a certain distance from the curbline, actually 11ft (3,4 m)	low-high	30 mph (48 km/h)	from narrow to wide Avenue	Usually there is on-road parallel parking	**Reduce speed limit** solution imposed at intersections in order to provide a good transition between arterials streets and residential areas	**Traffic Calming:** speed is reduced in all the streets including arterials because of the high number of fatalities (there are streets with 65km/h speed limit)	-	**Traffic vertical signals** are found around the city to permit bicyclists to take the street or to avoid vehicles to pass into the road: make drivers aware of bicycling
				Contraflow bicycle lanes: allow cyclists to avoid high traffic volume of some Arterials streets	Residential areas/quite zones Shorter one-way street to connect bike networks through the city	White color lines between the road way/parking zone and the contraflow lane	low volume		Narrow street -	on-street parking between the curb and the contra-flow lane			**Vertical signs** indicating the contraflow or only the direction allowed for cyclists at the beginning of the street or on the approach to the intersection	

PORTLAND (Oregon)	582.130 inh 1.656 inh/km^2	70%	6%	**Shared Roadway:** bicyclists should be expected in all the streets	residential streets, low volumen rural roads and highway Streets with high bicycle demand	Sharrow as on-street marking in non-intuitive streets for bicyclists	Low: < 1.500 -> High > 80 km/h (depends the type of road) 0-15.000 (very high)-> 30km/h		Not specific dimension. Fairly narrow. Street as constructed	On-street parking to reduce motor vehicles speed. Sharrow make sure cyclists drive safety. Ensure space between motor and parked vehicles	Bicyclist crossing point signed by vertical sign	**Traffic calming** to make the street more amenable to ride if the speed and volume is very high	**Vertical signs:** permanent shared lane condition **Warming signs**
				Bicycle boulevard: bicyclists have priority	local streets	Bicycle boulevard pavement marking			-	Yes. It is a normal local street	Traffic diverter limits motor vehicle traffic and allows bicyclists. Turning stop signs Crossing improvements: signals and median refuges	**Traffic calming** devices that reduce motor vehicle speeds and **traffic control limits conflict** between motorist and cyclists--> priority to cyclists´ movements	**Directional signs: Way finding** are provide to route and guide the cyclists to key destinations In the route sigs: **name of the boulevard**
				Woonerf: all-users street	Very narrow street in residential area		very low flow--> < 1.500 vehicles per day	very low speed: 10 km/h	very narrow	-	-	-	Vertical signs to ensure share condition

2.7. Conclusion

GENERAL INFORMATION

For a bicycle solution to be provided, cyclists´ safety feeling needs to be reached. For shared use solutions, where cyclists and motor vehicles share the same space on the road, this objective is even more important because the unsafe feeling increases or decreases in function of the adjacent traffic.

The shared use condition is a facility where the cohabitation between motor traffic and cyclists must exists, thus as the measure reaches cyclists´ need, it must also reach motor vehicles´ needs and they should not feel greatly impacted by the new condition applied on the road. Experiments from Cambridge (Hunter, et al., 2011) proved that after sharrows were placed in some roads of the city, cars followed cyclists very impatiently or under took cyclist aggressively. This should be avoided. The reason was the moderate speed limit and the high traffic volume of the road that perhaps was not appropriate for a shared use condition. For the proper functioning of a shared use facility solution, quality of service for both motor vehicles and cyclists should be fulfilled.

Safety is a key factor in the design of any traffic facility, but in some situations it is not found in the street although the design of the road provides it. In this case, safety is also linked to the driving education of the population. The Netherlands, Denmark and Germany are European countries which have the higher rank on bike trips made in Europe and USA. One of the main reasons is they focus on training children, cyclists and motorists in safety and cycling techniques and encourage a safe cycling. The support from the national level to the local level and their policies based in a green environment is a very important factor to the development of a city. In the other side, countries like Ferrara struggles for the bicycle development but without the correct support of the national government, the process is slower.

SHARED USE BICYCLE SOLUTIONS

There are four different main solutions of shared use bicycle facilities conditions that the countries/cities previously analyzed, have adapted within their streets to provide a good environment for the cohabitation of motor vehicles with bicycles. These solutions depend on the different on-street factors such as the total width, on-street parking, speed and traffic flow and the structure of the street. The different shared use bicycle solutions within the cities are: shared use/shared street, advisory lanes, contraflow lanes and Woonerfs. The solution is summarized below and will be used in determining if such solutions are feasibly in Norway.

1. Shared use/shared streets

Shared Streets are all these streets where bicycles ride on low speed roads (around 30 km/h) without the “separated line marking”. After studying the different cities, shared use facility condition can be divided in three different categories depending of the signage they have and depends the benefits/characteristics they offer to cyclists.

Bicycle Street (Europe)/ Bicycle Boulevard (USA) are the streets in which bicyclists have priority in the whole width of the road and overtaking is forbidden. The road is marked with a bike symbol on the pavement in the middle of the roadway and; in case of the European countries, a red color surface is painted on the pavement. In some cities these streets are very narrow, located mostly in residential areas.

The minimum width is even 3 meters. The flow and speed are low. The speed limit is around 30km/h with low-moderate traffic flow (in Europe until 6.000-7.000 vehicles per day and in the USA at higher traffic volume, until 15.000 vehicles per day). At speed limit below 30km/h higher traffic volumes are allowed.

Vertical signs are located at the beginning and at the end of the street.

Existing on-street parking is allowed, and is, sometimes introduced to narrower the street (traffic calming), others because it was before there.

Portland in USA (Bicycle Boulevard) and the Netherlands, Münster, Ghent and Vienna in Europe (Bicycle Street) are cities where this facility is provided.

Shared roadway/shared streets are all these streets located in residential areas, access roads or shopping areas with a high demand of cyclists in which the relationship between cyclists and motor vehicles grows in an equal environment. Roads are marked with a bike and arrow symbols (Sharrows).

Overtaken is allowed if there is enough safety to do that.

The width of these streets is typically between 5 meters and 8 meters in European countries and it is supposed that in USA cities the streets are wider because of the structure of its roads, although not specific width has been found about that.

Speed limit and traffic flows are the same magnitude as for bicycle streets (around 30km/h and low-moderate traffic volume). Parking and loading is allowed on the road.

Portland and Cambridge in USA (shared roadway) and Dublin (Mixed traffic), Murcia (Ciclocalles) in Europe are cities where this facility is used. In this last city, vertical signs are also provided at the beginning of the street to ensure vehicles are aware of cyclists.

Cycling in mixed traffic/30 zone occurs in residential streets or 30 zones with a moderate demand of cyclists and with very low volume of motor vehicles. In this case, the relationship between both modes of transport is pleasant and on-road markings are not necessary thus the presence of cyclists on the road is expected.

The street is a very narrow and the speed limit and traffic flow are low.

Vertical signs that ensure motor vehicles are aware of the presence of bicyclist are enough to ensure safety.

The speed limit zone in Ferrara and cycling in mixed traffic in Vienna in Europe are the cities where this type of solution has been used.

2. Advisory Lanes

Advisory lanes are marked with broken white lines in both sides of the road on two direction motor vehicles street. Two “shared” bicycle lanes are provided and the centerline of the roadway is eliminated. Normally, advisory lanes are introduced in collector roads.

The width of the street is around 9 meters or less than 9 meters in almost all the cities found and parked vehicles is forbidden.

Not vertical signs are used to signalize the street.

Both the speed limit (always less than 50km/h) and the traffic flow are moderate, with values higher than a shared road solution. In Vienna, where this facility is called “Multipurpose strip”, the traffic flow is higher than 7.000 vehicles per day or less that 7.000 if there is presence of heavy vehicles.

In Dublin and the Netherlands in Europe, advisory lanes are also used.

3. Contraflow streets

Contraflow lanes are located in one-way street for traffic, short segments or streets that provide shortcuts for bicyclist to a high flow level traffic in arterial streets. White color lines mark the contraflow lane, but sometimes because of the very low traffic flow and because of the social cyclist acceptance (like in the Netherlands) cyclists are expected to ride on the contraflow direction (unmarked condition).

In some cases on-street parking is provided between the curb and the lane as is the case in Cambridge and the Netherlands, and vertical signs ensure the awareness of this situation.

The speed of the motor traffic is equal or less than 30km/h and the width of the street is very narrow: 5-6 meters the normal width for on-street parking and around 4 meters the width for non-parking Street.

Cambridge in USA and Dublin and the Netherlands in Europe have contraflow solutions in some streets.

4. Woonerfs

Woonerfs are located in all the countries in residential streets and allow bicycles and vehicles to share the same space. Woonerfs are considered the residential narrow street as constructed and the width is around 7 meters depending of the city and the allowance of on-street parking . The speed limit is less than 20km/h, reaching in some cases the speed limit of 7km/h (imposed through a vertical signal in European cities). In Portland (USA), a speed limit < 10km/h and flow light traffic flow (less than 1.500 vehicles per day) are given in Woonerfs Graphic 4.

Parking can be provided because the street is considered a normal residential street.

Ferrara and the Netherlands in Europe and Portland in USA are examples of cities which use woonerfs.

OTHER MEASURES

To provide a good and feasible bicycle network, sometimes is not enough with the bicycle facility. **Additional measures** improve the shared traffic condition, encourage the pleasant environment between cyclists and motorists and to supply positive aspects and easier ways for cycling. Additional measures are provided when it is needed to offer a suitable bicycle network.

Traffic calming is applied in all the studied cities to slow down the vehicles speed and to reduce the traffic flow when the speed and traffic flow is higher than the appropriate level a shared-use traffic condition require. Narrowing the street through on-street parking and providing speed bumps and raised intersections are measures commonly taken to calm traffic. In some intersections, measures are applied as well. Advance stacking in advisory lanes or bikes markings on the road at roundabouts are examples of these measures applied.

These measures involve changing the rules of the street which might not be so easy to do.

Way finding is an additional method that helps to connect the bicycle facilities within a city, creating a safer and more appropriate bicycle network. It encourages people cycling because it is showing a good bicycle way to reach a main destination.

The Netherlands and Germany have introduced way finding within their cities. In the Netherlands, the different types of destinations (green area or city center or special building) are signalized with different color what is a manner of better orientation around the city.

Graphics in Figure 32 have been used by the cities to provide a suitable bicycle facility attending to the speed limit and the traffic volume of a particular street.

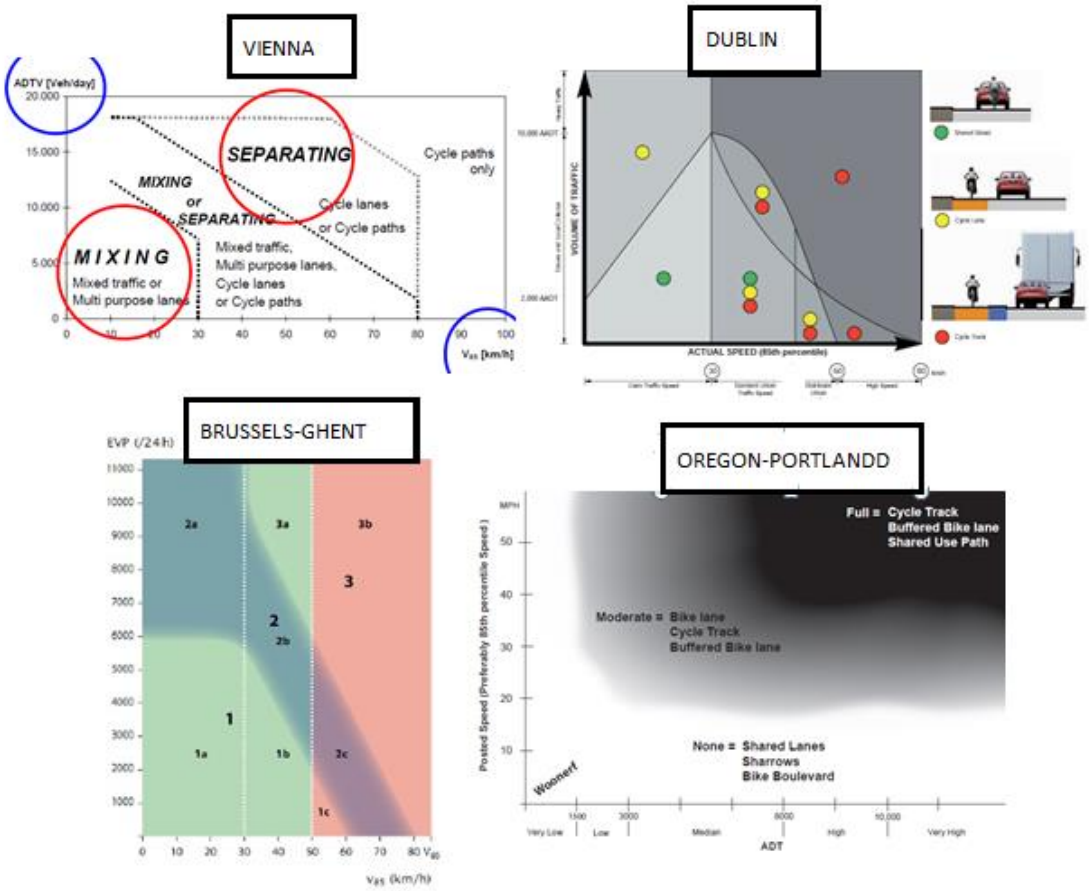


Figure 32: Graphics used for the research

After analyzing the four graphics, similarities between them in regards with the speed limit and the traffic volume given for a bicycle facility are obtained:

- If the speed limit increases, the traffic volume decreases for a shared use bicycle condition in European countries. The maximum speed limit at which the shared use condition is recommended is 30 km/h.
- Portland´s graphic establishes shared use solution can occur for a high traffic volume is the speed is low and for a high speed is the traffic volume is low. For a speed limit of 30km/h, high traffic volume can be done.
- In the graphic of Portland (USA) and also Belgium´s graphic, border between separated or mixed solution is not clear (same happens to Norwegian´s graphic as seen in Graphic 5). It is impossible to have clear boundaries between different types of facility because of the intervention of others factors.

If all the graphics methods in Figure 32 are superimpose in one unique graphic, the following common (approximated) situation occurs:

- Shared use bicycle facility can be provided for speed limit of 30km/h and traffic flow volume < 8.000 vehicles per day.
- For speed limit > 30km/h, shared use bicycle facility can be provided if the traffic volume is less than 2.000 vehicles per day.
- For speed limit >50km/h, shared use bicycle condition can occur but this situation will occur outside of the city. Probably, riding on the road shoulders will be the solution used.

3. Possible solutions

3.1. Bicycle Norwegian Legislation

GENERAL INFORMATION

Norway is a large country with low population. With a total area of 385,252 m^2 and a population of a little above 5 million, Norway is the 2nd least densely populated country in Europe. Because of the low population, a high level of congestion is impossible (congestion only can exist in two or three of the biggest cities at peak hours) that will make the AADT of the cities´ roads to be low.

Cycling Handbook 233 -*Sykkelhandboka- Utorming of sykkelanlegg-* (Stantens Vegvesen, 2003) is a NPRA handbook that provides guidance in planning main cycle networks in cities and towns in Norway and encompasses all the different bicycle facilities solutions presented in Norway.

The principles for the cycling facilities according to the Norwegian legislation are:

- **Comprehensive** traffic plans so that bicycle traffic solutions should be adapted to traffic conditions, including also solutions for bicycle parking.
- For a bicycle network to work well, it must be designed as **unified system**, that means that motorist, pedestrian and bicycle elements will work together to provide a system that allows for better understanding of the road rules.
- **Simple** for all users to understand the solutions to avoid any misunderstandings or conflicts between users. These solutions are also the easiest to build and maintain.
- **Attractive** for cyclist since the solution represents a safe solution including, avoiding any obstacles.

- **Safe network** that allows motorist and cyclists to see each with good visibility at intersections being very important.
- Road markings should be adapted to the bicycle plan and are important to show the cyclists their route.
- Operating procedures should be adapted for bicyclists and included in the standard operating program for street network.
- Provide secure bike parking.

CYCLE SHARED USE SOLUTIONS

According to the Norwegian Handbook (Stantens Vegvesen, 2003) non special on-road solution is provided for shared use roads. However, the **presence of vertical signs** is required to identify designated bicycle facility. The change of bicycle facilities should be signalized as well. **Signals** in the Figure 33 below can be added to the intersection between both paths/ways and shared road to make motorists aware of the oncoming cyclists or to exalt the intersection to reduce vehicles speed.

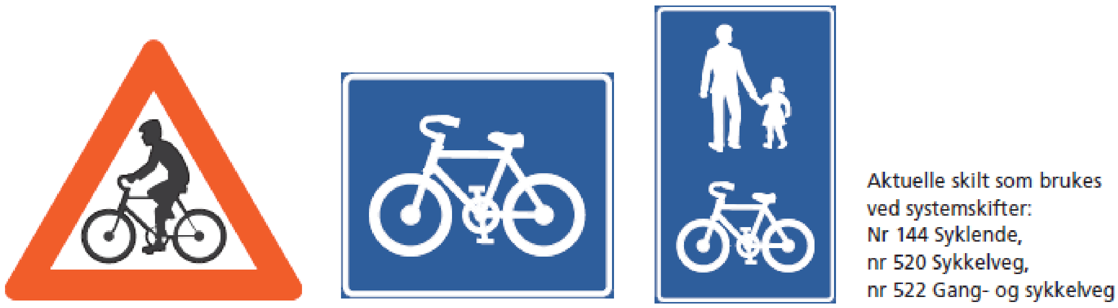


Figure 33: Signals to make motorists aware of the presence of cyclists. (Stantens Vegvesen, 2003)

Bike directional signs or **"way finding"** should be include within a bicycle network and they provide both information for cyclists and also indicate motorists they are on a bike route. However the "way finding" alone does not define the usage of a road.

Overtaking is a point to discuss depending on the street structure, but the Norwegian guide inclines towards allowing overtaking on the street. When overtaking occurs, the lateral distance from the cyclists to the car should be 0,85 meters if the posted speed is 30km/h and at least 1,05 meters if the speed limit is 80km/h.

Contra-flow solutions are considered for the Norwegian Road Administration since this method has been used successfully in some countries in Europe (Muenster, Germany Dublin, Ireland) as it was noted before in Dublin and Netherlands, Denmark and Germany: Widespread bike use sections.

Speed reduction or traffic calming is usually applied on streets adapted to bicycles. Speed bumps are a general and often used method to do that and they should be placed every 50-100 meters at 30km/h and every 80-120 meter at 40km/h to make running not attractive to motorists. Speeds can also be reduced raising pedestrian crossings, narrowing or providing offsets in some points of the street, or simply reducing the speed through posted signals combined with physical measures. Speed reduction is also applied **at intersections** for a safer situation or at **roundabouts** where the speed is more than 30km/h at the conjunction of two lane-roads belonged to a cycle route.

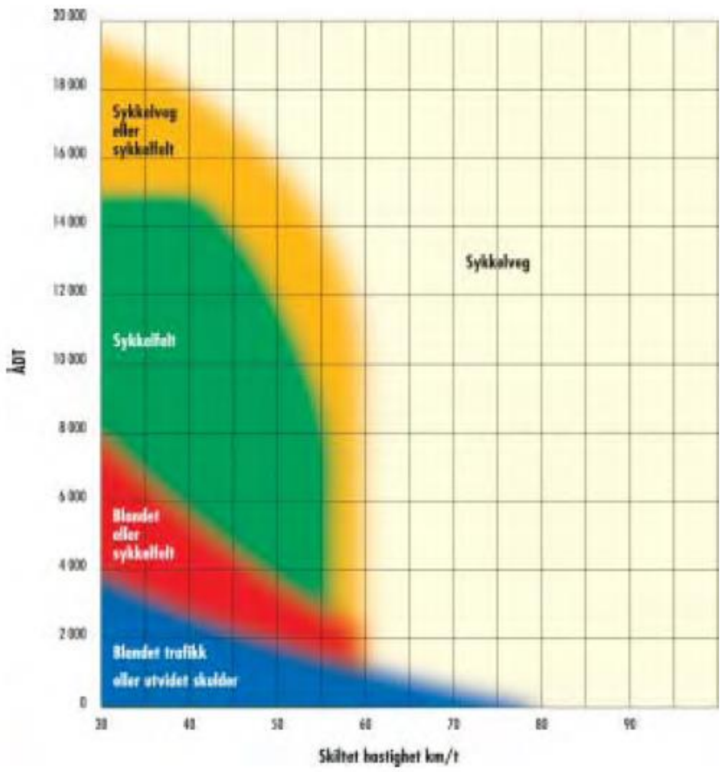
Reduction of traffic through **the closure of a segment** of the street to adapt the street within the bike route is another measure but it is not a very favorable method because it produces a change on the traffic direction restricting the motor traffic movements. With this, traffic flow registered so far changes as well.

Narrow one-lane streets are good streets for shared bicycle use condition. The posted speed should not be more than 20km/h, so that bicyclists travel at about the same speed as cars.

Similar to other cities/countries examined earlier, the Bicycle Handbook 233 establishes that the choice for solutions for cyclists must be determined by the speed and traffic volume of the traffic and besides, by the area type. The area type is an area defined in the Norwegian Handbook 017 (Statens Vegvesen, 2008) that defines three different types of area within city, considering the surroundings as well. Shared use bicycle solutions can be a solution for Area 2 and Area 3.

- Area 2 refers to areas with medium-dense developed areas, cities and towns outside of the center, suburbs, and smaller towns where the normal speed limit is 50, 60 or 70 km/h.
- Areas 3 refers to areas with heavy-density in city centers, numerous (row) buildings, and streets and blocks where the speed limit is 50km/h or lower (if cars and bikes share the same lane, 30km/h is the speed limit).

The Graphic 5 below (Stantens Vegvesen, 2003) shows when it is appropriate to choose the different solutions for cycling traffic given different combinations of speed and motor vehicle volumes. There are no clear boundaries between the different facility types, which mean that a detailed examination of other factors is needed to make a decision on facility type. Factors that the handbook considers include shoulder width and presence of heavy vehicles. The width of the road, including the shoulder, is very important since it is a factor that “forces” the traffic speed to be lower.



Graphic 5: Cycle facility-Speed/traffic volume of motor vehicles. (Stantens Vegvesen, 2003)

For a shared use condition the major AADT values occur at 30 km/h speed limit. Values until 4.000 vehicles per day are registered for a clear shared use condition and values between 4.000-8.000 vehicles per day show that the solution adopted: shared use or separated facility will be discussed. A speed limit of 50 km/h is the highest allowed within city. In the Norwegian case, a shared use solution can be adapted at 50 km/h if the traffic flow is less than 4.000 vehicles per day (discussed solution) and less than 2.000 vehicles per day for a clear shared use solution. For light traffic volume, higher speeds (even 80 km/h) can be accepted, occurring this situation outside the city and cyclists will ride on shoulders.

3.2. Norway: Existing streets design Guideline

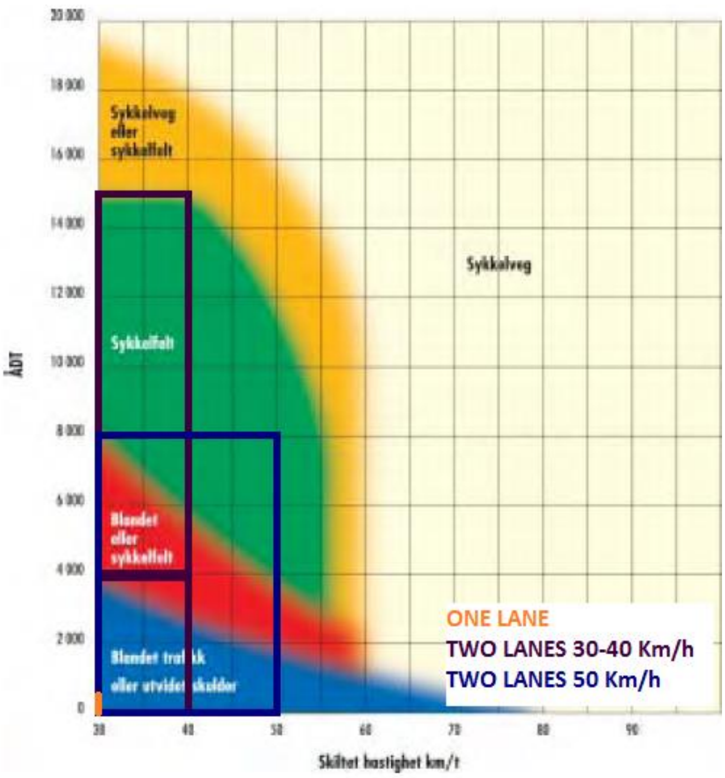
In this section 3.2, shared use facility solutions for the different types of existing streets design in Norway registered in the Norwegian design guideline 017 (Statens Vegvesen, 2008) are described. Both the research done about different cities around the world and the Norwegian recommendations about shared use facilities design in Norway (Stantens Vegvesen, 2003) will be key aspects of determining feasible and appropriate solutions.

Given the scope of this thesis, solutions for one lane and two lanes streets and streets with parking are considered.

According to the Norwegian design guideline, cycle lanes should be supplied as bicycle facility if:

- AADT > 4.000 vehicles per day **or**
- Speed Limit is 50km/h

Where the two conditions are not necessary presented at the same time. Given this criteria, type of existing Norwegian streets represented by the squares marked on the following Graphic 6 are considered.



Graphic 6: Cycle facility-Speed/traffic volume of motor vehicles with the analyzed existing streets in Norway

I. <u>One Lane</u>

The one lane street is a very narrow street and that undoubtedly is linked to low flow of **vehicles (< 300)** and low speed limit **(30km/h)**. The total width of the street is **3,5 meters** as seen in Figure 34.

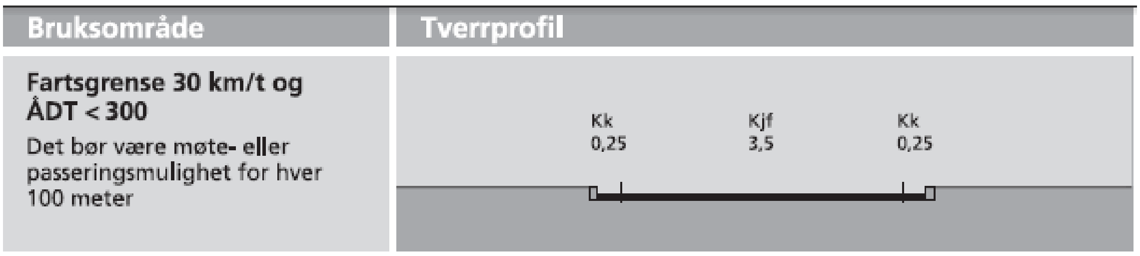


Figure 34: Road with one lane driving (Statens Vegvesen, 2008)

- FIRST SOLUTION

Contraflow lane facility is a suitable solution for one-way traffic street mostly if it is a short street, access road or a very quiet center street. In this case the width of the road is very narrow, but it cannot be considered a problem due to others solutions found in others cities like in the Netherlands that the narrowest contraflow street is 3,25m wide (Figure 5: Unmarked Contraflow along the Canals in Delft). The street should be signalized for two directions for bikes by **vertical signs** at the beginning and at the end of the street and at the approaching intersection. The contraflow direction can be **marked** with a white line of 1,25 meters according to 017 handbook, or it can be an **unmarking** solution because of the light traffic volume and because cyclists are expected on the road. **Sharrows** are painted on the road along the traffic direction for the marked contraflow. In the Figure 35 below is represented in a) the contraflow situation when a vehicle follows a cyclist in presence of another cyclist in the contraflow lane and in b) a vehicle overtaking a cyclist without any oncoming cyclist in the contraflow lane.

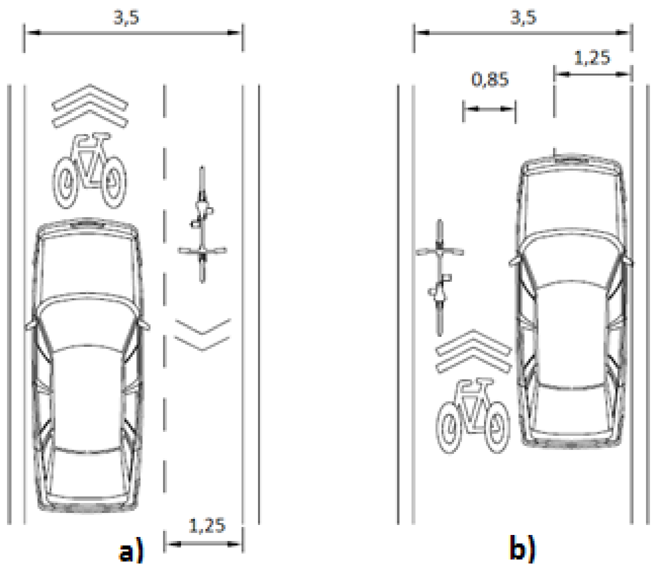


Figure 35: Contraflow solution

According to the Norwegian bicycle guide 233, the required distance between the cyclist and the motor vehicle is 0,85 meters. Taking into account that the width required for the bicyclist is 0,75 meters, the roadway space is 2,55 meters. The width of a personal car is 1,8 meters, for what it will be possible to drive side-by-side with the cyclist. Nevertheless the distance between the cyclist and the personal car (in a situation side-by-side) would be less than 0,85 meters that could not be a problem due the low traffic of this type of roads. Given that, for a shared use condition in the same direction, overtaking is feasible if no cyclists are coming on the contraflow direction. If marked contraflow is provided, it should be painted with a white broken line to allow the pass of vehicles overtaking as it can be seen in Figure 35. With the presence of cars, since they have width of 2,55 meters, this situation will not be feasible because there would be enough distance from truck to bicyclist. In handbook 017 the width a cyclists and motor vehicles have are registered.

- SECOND SOLUTION

Shared use condition can be supplied without the contraflow facility for what it will be a one-way solution for bicyclists and for vehicles. A pleasant condition can be occurred without any on-pavement marking due the light traffic volume. **Vertical signs** are needed to notify drivers the type of street they are operation on.

- THIRD SOLUTION

Bicycle Street could also be a feasible solution. In this shared use facility, cyclist has preference in the whole width of the street and overtaking is forbidden. On-pavement markings are provided almost in the whole width of the street: a bike symbol could be adopted. This solution supposes a change of the rules of the street changing the driver´s benefits what can make vehicles to follow bicyclists impatiently and bicyclists to feel unsafe.

- FOURTH SOLUTION

Probably the road is located in a residential area due the light volume traffic belong to residential vehicles. Residential roads are very pleasant and there, **Woonerfs** can be provided as a shared use solution, but the speed limit of the street is needed to be less than 20 km/h. Vertical signs that notify the new condition should be provided at the beginning and at the end of the street.

II. <u>Two Lanes</u>

There are three cases analyzed for a two lanes road according the width of the roadway. In the second case three situations are studied for the same width of roadway in relation to different conditions of speed limit, AADT of personal vehicles and presence of heavy vehicles.

FIRST CASE

The following roadway cross-section with two lanes (and two directions traffic) is for use when the speed limit is **30-40 km/h** and the AADT is **0-4.000 vehicles** per day with less than 100 **heavy vehicles.** The total width of the street is **5,5 meters**, as seen below in Figure 36.

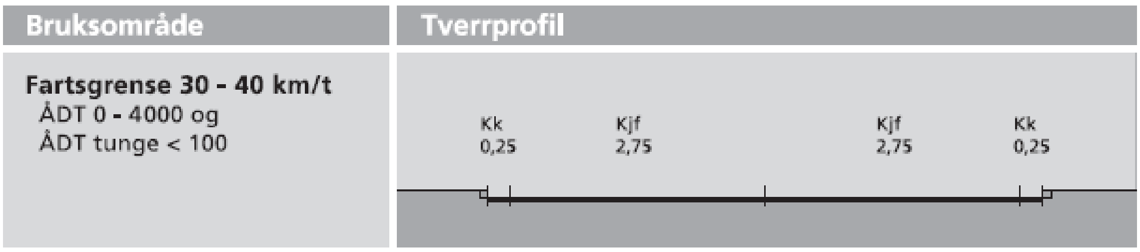


Figure 36: First condition of Road with two lanes driving (Statens Vegvesen, 2008)

SUGGESTED SOLUTIONS

- FIRST SOLUTION

The roadway section is very similar to **Shared road solution** in the city of Dublin represented in Figure 7. For this reason, a good solution for the street could be marking the road with **“Sharrow”** in the middle of each lane. If the situation of the street allows it, overtaking can be allowed. Similar to Dublin, the centerline can be omitted on the road.

- SECOND SOLUTION

If the traffic flow of the road is light, a possible pleasant environment occurs and **shared use** situation without any on-pavement marking can be considered. The street would be signalized with vertical signs that ensure people understand the shared use condition.

- THIRD SOLUTION

As the solution for the one lane street, **Woonerf** facility can be a good solution if the traffic volume is very low, not reaching 1.000-1.500 vehicles per day (only residential traffic).

SECOND CASE

The next type of roadway section can be used for several conditions of both speed limit and motor vehicles volume that makes the appropriate solution to be different. The total width of the street is **6,0 meters** as seen in Figure 37.

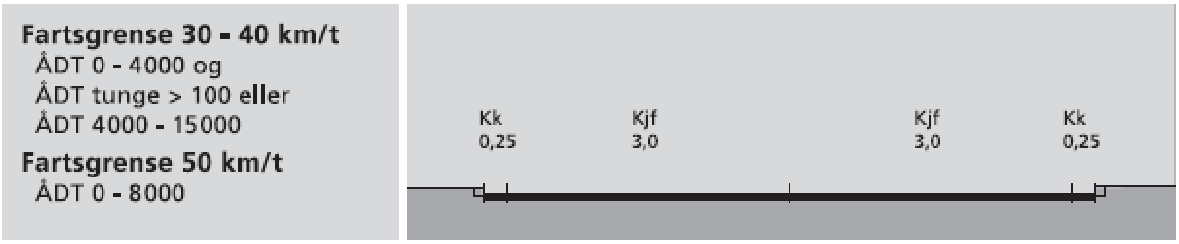


Figure 37: Second condition of Road with two lanes driving (Statens Vegvesen, 2008)

FIRST SITUATION

The first situation has the same speed (**30-40 km/h**) and volume (**0-4.000 vehicles** per day) conditions than the case explained previously (Figure 36), but in this case there is presence of heavy vehicles (**> 100 heavy vehicles**). Due to the number of heavy vehicles, the total width of the road is wider.

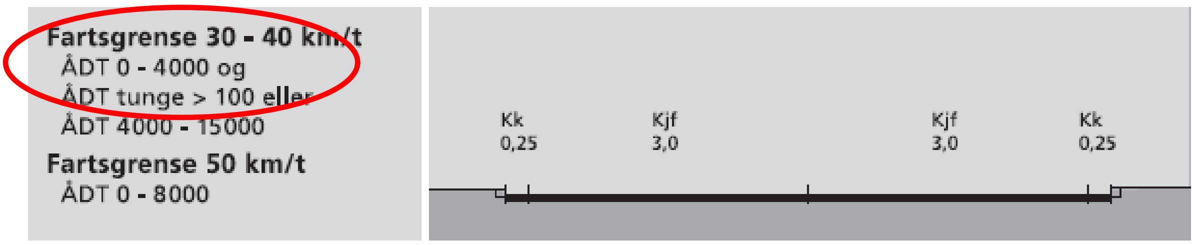


Figure 38: Second condition of Road with two lanes driving (Statens Vegvesen, 2008)

SUGGESTED SOLUTIONS

- FIRST SOLUTION

As with the FIRST CASE, a feasible solution for this roadway section will be the **Shared road** condition in which the road is painted with sharrow markings.

- SECOND SOLUTION

Because of the presence of heavy vehicles, the street environment is similar to the facility adapted in Vienna: **Multipurpose Streets**, commonly called **advisory lanes:** This solution supplies a shared traffic condition with more safety for cyclists in case of high traffic flow (heavy vehicles), in which the solution functions as bike lanes. Given the characteristics of the roadway, the advisory lanes can be designed in two different ways:

Attending to the Norwegian handbook 017, for Speed Limit 30-40 km/h and AADT > 4.000 (In this case the AADT < 4.000 but >100 heavy vehicles, so it is assumed the same situation), bike lanes are 1,25 m wide. The situation is shown in Figure 39:

- Advisory lanes on both sides of the street, 1,25 meter wide from the curb gap, represented by broken white lines that permit vehicles pass into the lanes if it is necessary.
- Roadway lanes of 1,75 meter each one, being 3,5 meters the total width.
- No centerline.

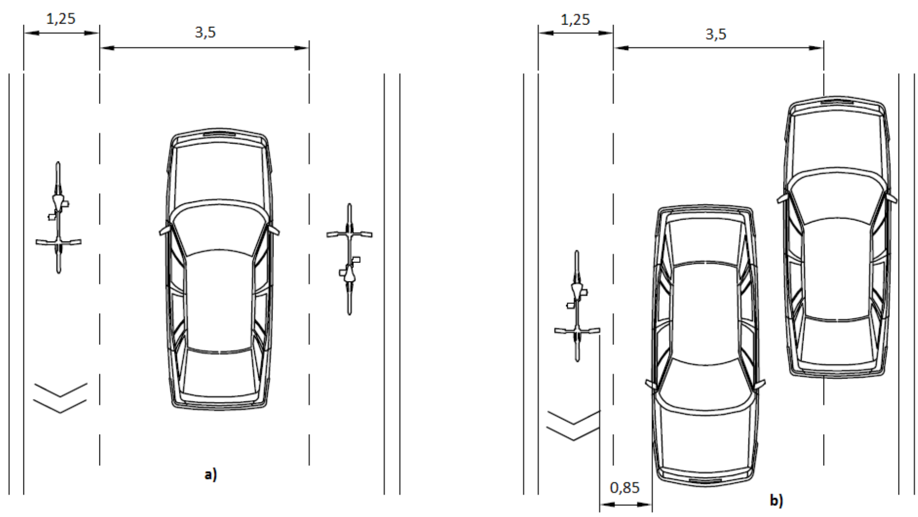


Figure 39: Advisory lanes 1,25 meters

It is possible that the first alternative does not leave enough space for the roadway, thus, another alternative can be considered Figure 40:

- Advisory lanes (broken white lines) 1 meter wide in both sides of the street,
- Roadway lanes of 2 meter each one.
- No centerline.

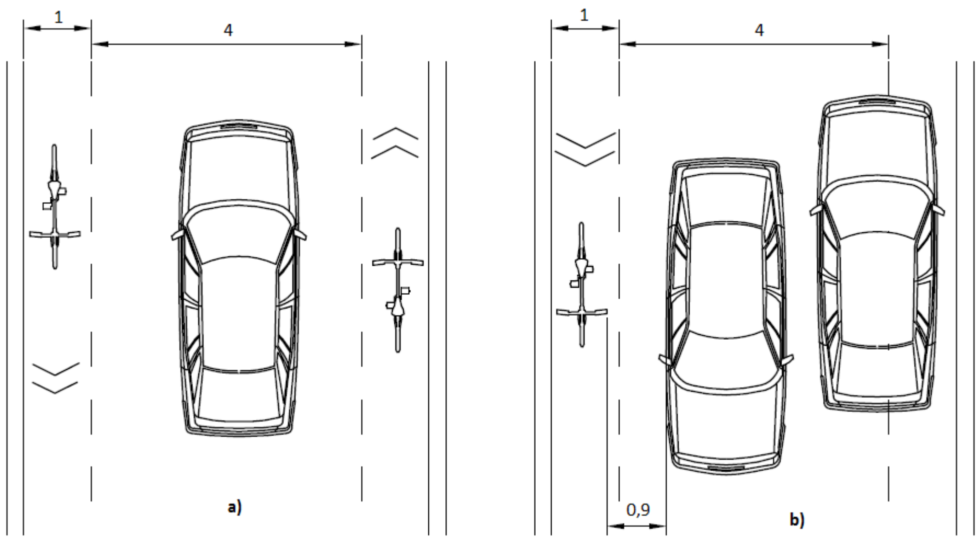


Figure 40: Advisory lanes 1 meter

In Figure 39 and Figure 40 is represented: a) the situation in which a motor vehicle travel alone on the roadway lane and there are two cyclists riding in the advisory lane and b) how vehicles have not enough room to travel side-by-side in the roadway and one of them needs to pass into the advisory lane with not presence of cyclists.

The only difference between both situations represented in Figure 39 and Figure 40 is if it is given more space to the roadway or to the advisory lanes. It would be needed to be studied the consequences of applying one another solution.

The most unfavorable situation would be when 2 trucks are traveling opposite one another. In that case, assuming 2,6 meters wide trucks as maximum wide, they will have enough space if both vehicles make use of the advisory lanes (given not presence of bicycles).

SECOND SITUATION

Using the same roadway section, the speed limit has the same value **(30-40 km/h)**, but traffic volume has increased to **4.000-15.000 vehicles per day** but without presence of heavy vehicles. AADT values are signalized in the Figure 41 below.

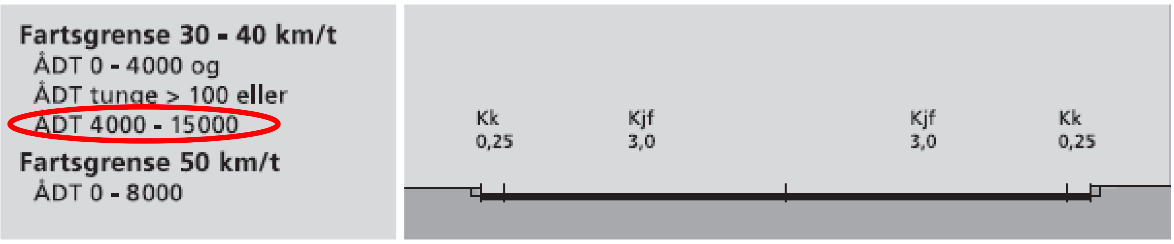


Figure 41: Second condition of Road with two lanes driving (Statens Vegvesen, 2008)

SUGGESTED SOLUTIONS

To suggest the best solution in this case, it is necessary to provide two different solutions for different ranges of volume. The speed limit is low (30-40 km/h) and appropriate for a shared condition but the range vehicles volumes, is too wide for one all-encompassing solution.

- FIRST SOLUTION

In the first interval, AADT is 4.000- 8.000 vehicles per day. Attending to Graphic 5 low speeds and moderate volumes conditions, a suitable solution is a **Shared Road** facility. Motor vehicles can overtake cyclists, but they should be aware both drivers and cyclists share benefits on the road. **Sharrows** will be marked on the road to ensure awareness and increase safety. This solution should also be complemented by **vertical signs-warming signs** indicating the permanent shared road condition.

- SECOND SOLUTION

In the second interval, AADT is 8.000-15.000 vehicles per day. According to the Graphic 5, bicycle lanes facility will be necessary. Since the current section is not wide enough to provide a cycle lane, if a cycle facility is desired on such a street an alternative must be considered. In this case **advisory lanes** will be provided as most feasible solution. Because it is the same case as "in Two Lanes roadway section, SECOND CASE, FIRST SITUATION", both alternatives shown in Figure 39 and Figure 40 (lanes 1,0 meter wide and lanes 1,25 meters wide) analyzed before, will be considered. For this situation (high traffic volume), advisory lanes seem the solution from Vienna: **Multipurpose Street**.

THIRD SITUATION

The last situation (Figure 42) is for a speed limit of **50km/h** and AADT of **0-8.000 vehicles** per day. According Graphic 5, both shared use solution and cycle lane solution would be suitable solutions for this case. The inclination forward to one or another would be influence by other factors. As the thesis considers shared-use solutions, only this option will be analyzed. The bicycle lane option is considered in section B.4.4 in Handbook 017.

Figure 42: Second condition of Road with two lanes driving (Statens Vegvesen, 2008)

SUGGESTED SOLUTIONS

- FIRST SOLUTION

Advisory lanes are a good alternative of cycle lanes, since they separate bicycles from the motor traffic, giving more safety to cyclists and also create a shared condition without reducing any space to the roadway. Because this condition has the same cross section than the conditions before, both advisory lanes scenarios should be considered. In the Norwegian Handbook 017 is registered the same speed and volume situation with cycle lanes as a bicycle facility with 1,25 meters what will make easily the choice but in this case, enough width will not provide to the roadway. **Vertical signs** will signalize the street.

- SECOND SOLUTION

If the 50 km/h road has a traffic volume less than 4.000 vehicles per day, a shared traffic solution, as described in section "Two Lanes. SECOND CASE, FIRST SITUATION" could be also used clearly indicate the presence of cyclists, both by sharrow markings and by vertical signs.

THIRD CASE

The final two-lane roadway section has speed limit of **50 km/h** and the volume of vehicles per day between **8.000-15.000,** and thus, according to the cycle lane conditions of the Norwegian design guideline rules 017, this existing road will be not appropriate for a shared-use bicycle facility being a Cycle Lane the suitable solution. For this reason, the section shown in Figure 43 will be not further analyzed.

Figure 43: Third condition of Road with two lanes driving (Statens Vegvesen, 2008)

III. <u>With on-street parking on both sides</u>

For roadway sections with on-street parking supplied on both sides of the road, the given roadway section in Figure 44 applies for two different situations are given regarding speed limit and the amount of vehicles per day. The total width of the street is **6 meters** for the roadway plus **3,5 meters** of parking lanes, equal to 9,5 meters total.

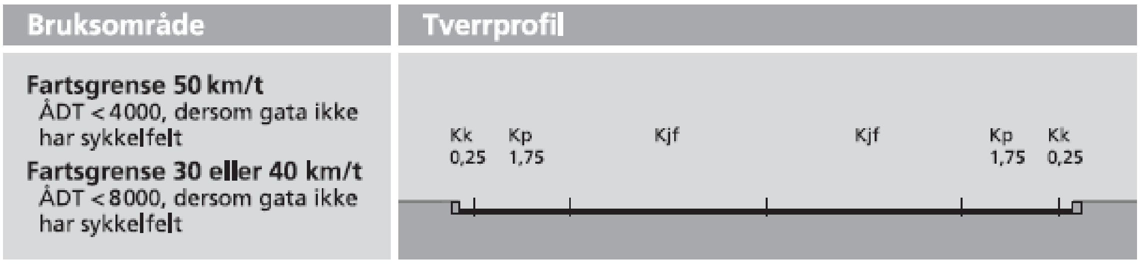


Figure 44: Road with two lanes driving and on-street parking in both sides. (Statens Vegvesen, 2008)

FIRST SITUATION

It is done for a speed of **50km/h** and traffic volume less than **4.000 vehicles** per day.

SECOND SITUATION

The second condition for on-street parking is when a lower speed limit is used, **30-40 km/h**; but the amount of motor vehicles per day is higher than the previous option, less than **8.000**.

SUGGESTED SOLUTIONS

- SOLUTION

For both the first and the second conditions, the solution provided will be the same. Previous research from the USA (Cambridge, Massachusetts, Portland, Oregon), suggest that painting **Sharrows** on the road is a good option for roads with parking. In these cases, because of the possibility of **"dooring"** due to the on-street parking, sharrow markings will be placed at a certain distance from the curb. In addition, the sharrow markings make drivers aware of the presence of cyclists, and, will guide cyclists in order to help them avoid possible dooring. Motorist can overtake cyclists and the distance from the curb to the middle of the sharrow will be determined according to the characteristics of the road.

Figure 45 shows the sharrow solution for a parallel parking street in both sides of the roadway. Distance X is the distance from the curb to the middle of the sharrow, and it will be necessary to discover through experiments as the case of Cambridge (Hunter, et al., 2011). In Cambridge the distance from the curb is 3,4 meters but current research, shows that a safe condition/environment can be provided if the distance is reduced to 3,1 meters.

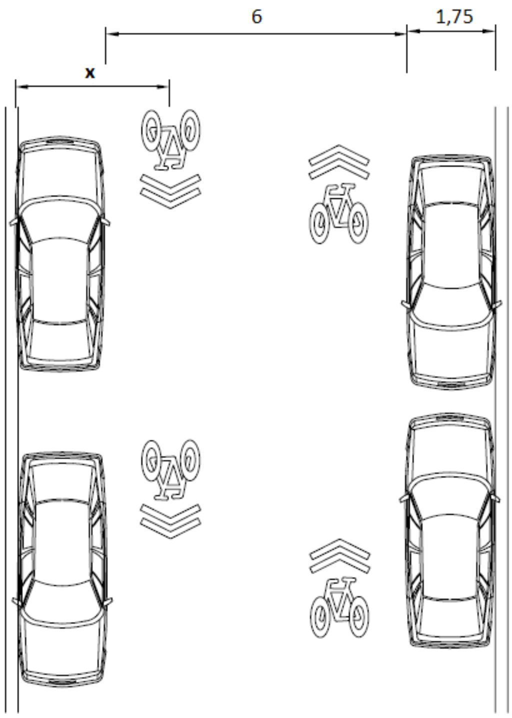


Figure 45: Sharrow solution with parking on both sides of the road

3.3. Trondheim

GENERAL INFORMATION

While the shared use bicycle solutions developed in this thesis are applicable all over Norway, the proposed solutions are examined further in the city of Trondheim.

Trondheim is a city and municipality in Sør-Trøndelag county, Norway with a population of 179,123 inhabitants and a density of 539 inh/km^2. It is the third most populous municipality in Norway, although the fourth largest urban area.

Trondheim is one of the major cities in Norway with the largest bike share. Bike share in is about 8%, according RVU 2009/2010 (Trondheim Kommune, 2013), but this share is expected to double by 2025 given the goals of the National Transport Plan (Statens Vegvesen, 2003). The northern climate of the country makes harder to encourage the use of bikes during the winter, where temperatures sometimes reach -20 degrees and snow and ice on the roadway is common. That makes the percentage of cycling higher during the period from May to October.

Due to the area and density of Trondheim, 70% of people need less than an hour to bike/ride from town square to where they live. In addition, 30% of all car trips are less than three kilometers. These data are very important because make the incentive for riding to increase easily as same as replacing trips made by car with bike trips.

The studies and surveys have been made by Environment package for transport in Trondheim (Trondheim kommune, Sør- Trøndelag fylkeskommune og Statens vegvesen, 2013) that encourages bike share connecting it as a fast and healthy mode of transport. They will use over 1.5 billion over the next few years to build and upgrade the main facilities for cycling in the city, improving the maintenance in winter.

Future Cities is collaboration between the government and the 13 largest cities in Norway (where Trondheim is), to reduce greenhouse gases emissions and make cities better places to live in (Aarvig & Rjånes, 2013). They propose future cities built close than cities in the present to walk and cycle instead of using the car: fewer cars and roads and more bike paths and parks. In this way, city will be more beautiful and people little healthier.

STUDIED ARED- STREETS ANALYZED

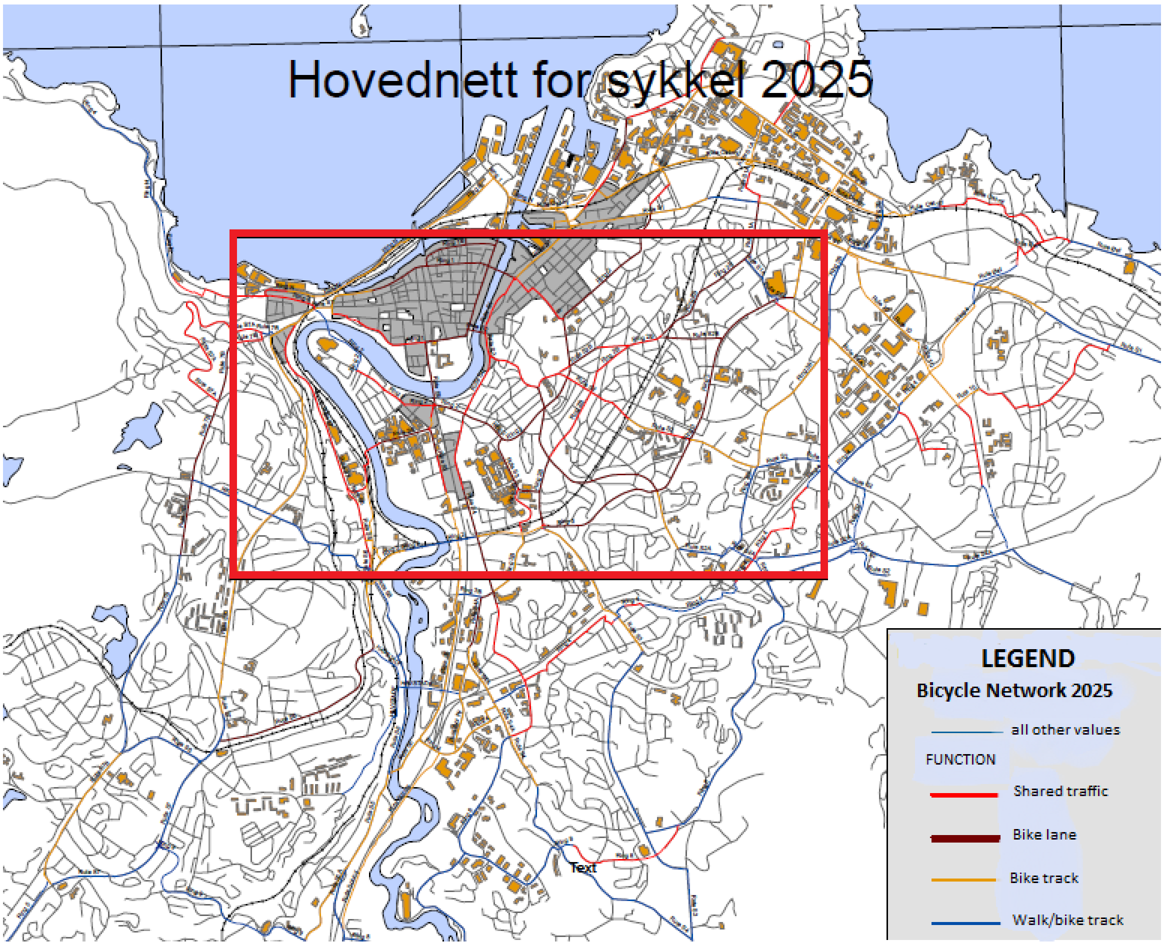


Figure 46: Area of the streets to study (Statens Vegvesen, 2013)

Figure 46 above shows the bicycle network projected to 2025 in Trondheim. The red color squared painted on the map represent the area in which will be studied different solutions and conditions of shared bicycle use for the city of Trondheim. Different suggestions will be applied and studied over seven streets interesting for the Norwegian Road Administration in order to provide a suitable shared-traffic (cars and bicycles) solution and encourage bike shared in the city. Theses streets are signalized in Figure 47 below.

In order to provide feasible possible solutions for the different roads studied in Trondheim, to analyze the different on-street factors is necessary. Width of the street, vehicles flow (included heavy vehicles), speed limit, on-street parking and current designations for bikes or restrictions for motor vehicles, if the street is one-way or two-ways direction and/or if any traffic calming has been already applied, are the factors this thesis considers important to provide an appropriate solution.

Vehicles volume (including the percentage of heavy vehicles on the road, where heavy vehicles are all these vehicles with a length more than 6,5 meters) and speed limit of the street data have been supplied by the Norwegian Road Administration (Statens Vegvesen, 2013).

From data supplied, it was noted that all the streets in the study have traffic flow less than 3.000 vehicles per day and 30 km/h as a speed limit. Mostly of all the streets have a traffic flow volume less than 1.000 vehicles per day that located the street in a pleasant and quiet environment. With regards to the other factors, site visits were necessary to have a first-hand view of the streets as well as to measure the width of the streets.

Figure 47 below shows the different streets painted with a red line following their length. These streets are further described below.

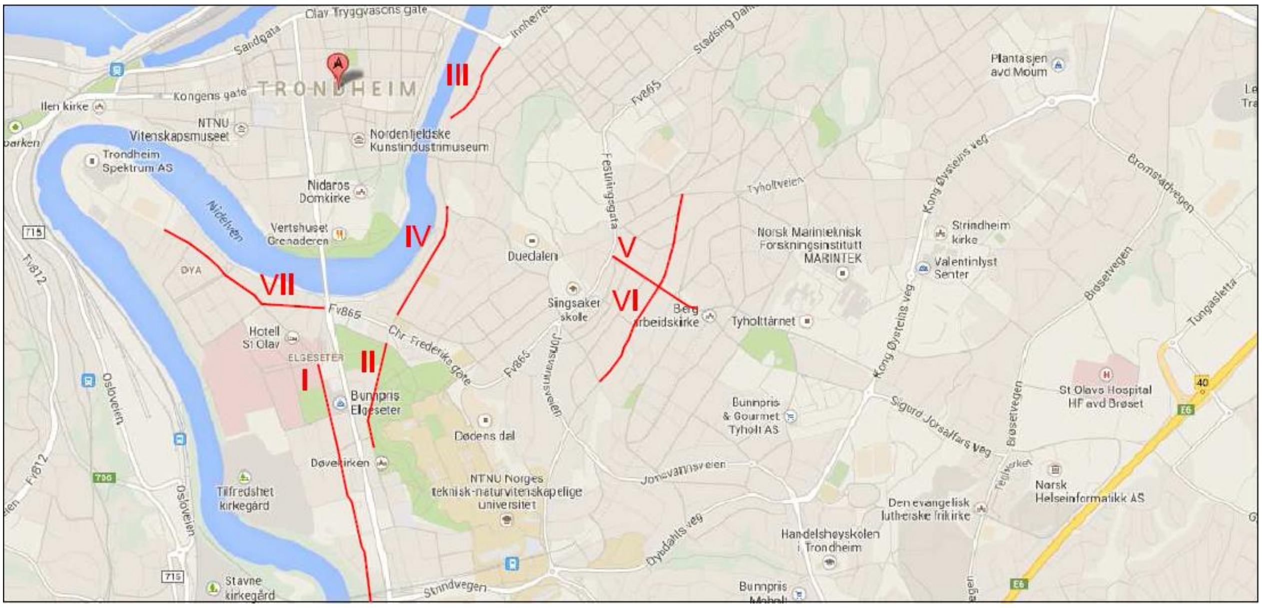


Figure 47: Studied Streets in Trondheim for a shared use solution

I. Udbyes gate between Olav Kyrres gate and Abels gate
II. Klæbuveien between Magnus den Godes gate and Snorres gate
III. Nedre Bakklandet between south end of Nygata and Bakkegata
IV. Vollabakken between Christian Fredriks gate and Lillegårdsbakken
V. Blusuvolsbakken between Tyholtveien and Nordahl Bruns veg
VI. Strindvegen between Jonsvannsveien and Tyholtveien
VII. Klostergata between Håkon Jarls gate and Krogness gate

I. *Udbyes gate between Olav Kyrres gate and Abels gate*

CURRENT SITUATION

This street will be analyzed in two different parts due the change of roadway section it has from the road Einar T. gate to Abels gate as the Figure 48 below shows. The characteristics of both roadway sections are represented on Table 5. To provide continuity in the shared use bicycle facility, same solution for both roadway sections will be suggested.

Also, the change of roadway section will be a point of discussing. The roadway space changes from 8 meters width (whole room of the road) to 5,75 meters width because on-street parking in one side of the road. Since in this last roadway section, bicyclist can take 2,8 meters width (one direction). At point of Einar t.gate, the street is wider: 4 meters for one direction. The change of section influences in the choice of the solution.

Table 5: Characteristics of roadway section studied from Udbyes gate

Roadway section	**Olva Kyrres gate to Einar T. gate**	**Einar T. gate to Abels gate**
Roadway width*	8 meters	5,75 (roadway)+ 1,75 (parking)= 7, 5 meters≈ 8 meters
AADT	300-1.000 (9-30 heavy vehicles)	300-1.000 (9-30 heavy vehicles)
Speed limit	30 km/h	30 km/h
On-street parking	Not parking	One side
Vertical signs	30 Zone	30 Zone
Number of lanes	Two-ways street. Not centerline	Two-ways street. Not center line
Speed reducer	Bumps	-

Figure 48: Udbyes gate, from Olav Kyrres gate to Einar T. gate (left picture) and from Einar T. gate to Abels gate (right picture); (Google , 2013)

*****To analyze the possible solution, the width of the street has been considered the same wide.

SUGGESTED SOLUTIONS

- FIRST SUGGESTION

Due the low traffic volume and the speed limit of the street (30 zone), it seems that this road only collect residential traffic. The environment of the street is pleasant and very quiet. For this reason, it is not needed any strong shared use facility. Nevertheless, in a shared bicycle use, it is important the awaraness of drivers about cyclists on the road. For this reason, bicycle facility provided could be signalizing the street through **vertical signs** for a shared use condition at the junctions points with other streets (currently there is one bicycle sign at the beginning of the street from Olav Kyrres gate.

The change of roadway section due to the presence of on-street parking will not suppose any problem to resolve for this shared use condition.

- SECOND SUGGESTION

On-pavement markings, **Sharrows** on both sides of the road are a feasible solution as well. With this facility, drivers will be aware of bicyclists in all their way and cyclists will be guide in their travel lane to avoid the possible "dooring effect" in zones where on-street parking is provided.

As the pavement is painting with sharrows markings, the problem of roadway section change due to the on-street parking, could be solved with on-pavement arrows that indicate the change of position of the travel lane and the arrows will be followed by sharrows markings, as it is seen in Figure 49.

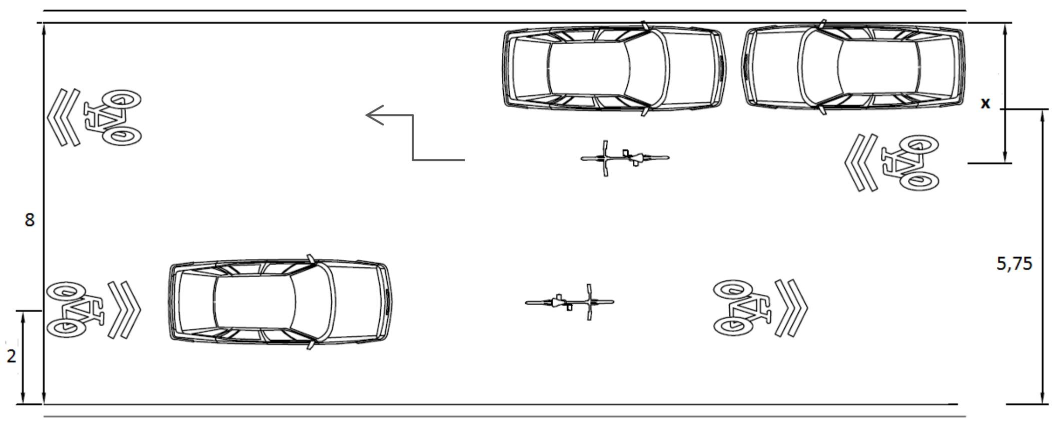


Figure 49: Sharrow solution in Udbyes gata. Transition from on-street parking roadway section to roadway section without parking

OTHER MEASURES SUGGESTED

Not obeying the speed limit law of the street can be a problem on this road. The width of the street (in the 8 meters roadway section) does not help drivers to drive at 30km/h and less if the traffic volume of the street is very low. To have sufficient space and driving alone make drivers confident to drive faster. Because the roadway section change problem, providing on-street parking as traffic calming measure in the same side of the road as the other lane parking was is a good solution. This roadway section has already applied bumps as traffic calming solution.

II. Klæbuveien between Magnus den Godes gate and Snorres gate

CURRENT SITUATION

This street is designed for a 50km/h speed limit according to the NPRA data, but it is designated as a 30 km/h Zone by a sign in the studied roadway section. Within this thesis, it is assumed that the street has a speed limit of 30km/h. On the south end of the street segment is a cycle lane facility, with which the shared traffic solution must transition in to. Table 6 shows the characteristics of this roadway section and a picture of it is seen in Figure 50.

Table 6: Characteristics of the roadway section studied from Klæbuveien gate

Roadway section	**Between Magnus den Godes gate and Snorres gate**
Roadway width	7 meters
AADT	400 (8 heavy vehicles)
Speed limit	30 km/h
On-street parking	Not. It is a different level from the roadway
Vertical signs	30 Zone and Bicycle Sign
Number of lanes	Two-ways street

Figure 50: Roadway section studied from Klæbuveien gate, (Google , 2013)

SUGGEST SOLUTIONS

- FIRST SUGGESTION

As in the street I before, the traffic flow volume is very low (in this case II is lower than the street I) that ensures it is residential traffic. For this reason shared use condition without any special on-pavement marking is a good solution to provide, but with **vertical signs posted** at all the possible junctions. Currently, at the beginning of the street as it is watched on Figure 50, there is a vertical bike sign.

- SECOND SUGGESTION

The structure of the street is very similar to the mixed traffic condition of Dublin city. For this reason, the same solution they have provided within this type of streets is a good alternative: On-pavement markings, **Sharrows** in the middle of the lane to give priority to cyclists but allowing overtaking because of the quiet and pleasant street environment. Figure 7 shows the solution in Dublin. This roadway section is also similar to the proposal first profile Two Lanes two of existing roads in Norway.

- THIRD SUGGESTION

Due to the very low AADT in this street, to paint a **bike symbol** in the middle of the roadway can be an appropriate solution. The function will be the same as Sharrows but this solution allows painting fewer symbols on the road (however they are bigger). It is allowed to overtake cyclists but the symbols will make motorists aware of the shared condition and they will not run of the lane (AADT low, wide width). A vertical shared condition symbol (car + bike) could be required at the beginning of the street because people can understand this solution is only for bikes and not a shared bicycle solution. The bicycle marking will be painted with the tilt in both directions as Figure 51 shows.

Figure 51: Bicycle symbols in the middle of the roadway

- FORTH SUGGESTION

If an on-pavement marking facility wants to be provided in addition to the verticals signs, the possibility of **painting two red lines** in both sides of the road should be analyzed: the condition of the current pavement is poor, so it does not worth to paint sharrows each certain distance and also, the traffic flow is very low and not too big measures are required. One red line in both sides of the road is a good manner to aware drivers they are sharing the whole space with cyclists. Figure 52 illustrated this solution.

Figure 52: One red line in both sides of the road: warming effect

The current pavement does not invite drivers to go faster. For this reason, not traffic calming measures are suggested.

III. <u>Nedre Bakklandet between Bakkegata and the south end of Nygata</u>

CURRENT SITUATION

Nedre Bakklandet Street will be analyzed in two parts because its characteristics experience a total change at the junction with the north of Nygata and it can be visualized on Figure 53. For this reason, it will be suggested two different types of solutions for the street, one for the left picture (Nedre Bakklandet between Bakkegata and the north of Nygatta) and another for the right picture (Nedre Bakklandet between the north and the south of Nygatta).

Table 7 shows the different characteristics for the two roadway sections.

Table 7: Characteristics of Nedre Bakklandet road

Roadway section	Bakkegata to the north of Nygatta	From the north to the south end of Nygatta
Roadway width	4,8 (roadway)+ 3,5 (parking)= 8,3 meters	3 meters
AADT	1.000 (30 heavy vehicles)	< 1.000 *
Speed limit	30 km/h	30 km/h
On-street parking	Yes. On both sides	No. Parking on different level (sidewalk)
Vertical signs	Not signals for bikes	Only “to park is forbidden”
Number of lanes	Two-ways street	Two-ways street

*According to NPRA data the traffic flow in Nedre Blakklandet street studied is 1.000 vehicles per day. But for this roadway section, traffic flow is assumed to be less than 1.000 vehicles per day: cross of motor vehicles is forbidden for both directions, from the joint point of Nedre Bakklandet and the south end of Nygata in direction to Bakkegata and from this joint point in direction to Brubakken. For this reason, traffic in this roadway section should be only **residential traffic** with AADT < 1.000 vehicles per day. In addition it is assumed not heavy vehicles on the street. Figure 53 shows the Street in the left picture.

Figure 53: Nedre bakklandet from Bakkegata to the north of Nygatta (left), and from north of Nygatta to south end of Nygatta (right), (Google , 2013)

FROM BAKKEGATA TO THE NORTH OF NYGATTA

SUGGESTED SOLUTIONS

The solution is very similar, referred to road width, traffic flow and speed limit to the Dublin case for Shared condition on narrow streets. In this roadway section, a “danger factor”: on-street parking as Figure 53 shows on both sides is added.

- FIRST SOLUTION

Along this roadway section, sharrows are a feasible solution. Sharrows can be marked on the pavement a certain distance from the curb (x on Figure 54) ; as shared use bicycle solutions in Cambridge or shared use bicycle solutions in Portland examples, in an effort to help cyclist avoid both adjacent traffic and “dooring” vehicles. In the same way, drivers will be more aware of cyclists at time of leaving the parking gap and accidents will be avoided. Overtaking is permitted, assuming there is sufficient street width. The roadway width (excluding parking) is 4,8 meters that is not wide enough for two lanes. For this reason overtaking cyclists is allowed when there are no oncoming vehicles. Because this street has very low traffic flow, this solution can be feasible. If it was not the case, this option will be almost impossible because there will be a long line of cars queuing behind cyclists. Not centerline will be provided due to the lack of space for two roadway lanes. The suggested solution is represented in Figure 54.

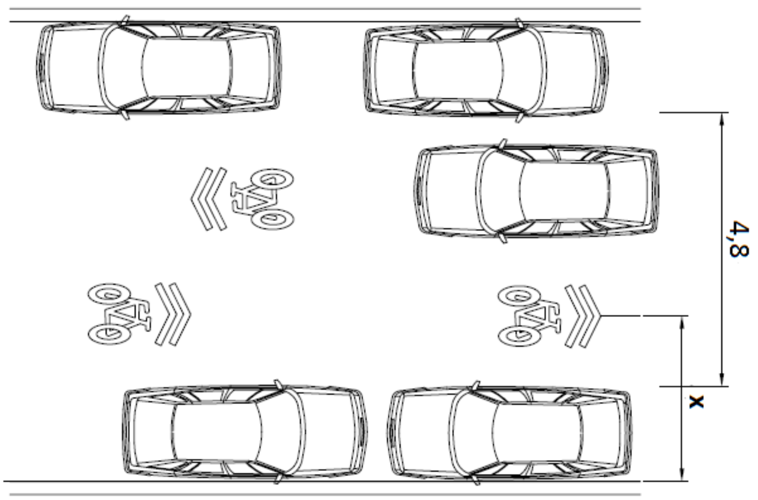


Figure 54: Sharrow solution on-street parking in Nedre Bakklandet

- SECOND SOLUTION

Another feasible solution could be “Shared use with **none markings** on the pavement” but as parking is presented, the option explained previously, could be a better solution.

FROM NORTH OF NEDRE BAKKLANDET TO SOUTH END OF NYGATA

SUGGESTED SOLUTIONS

- FIRST SOLUTION

A measure that could be added to the first solution suggested is to paint the road **with one red line** (as II Klæbuveien between Magnus den Godes gate and Snorres gate) in both sides of the roadway, one line on each edge) as seen in Figure 55. On-pavement markings make drivers more conscious of the presence of cyclists for what is not needed to paint the whole width of the street.

Figure 55: Red lines. Second solution suggested for Nedre bakklandet from north of Nygatta to south end of Nygatta

- SECOND SOLUTION

Due the low traffic volume and the residential use assumed, the narrow width of the road and the type of pavement and the short roadway section it is, motor vehicles will not drive at high speed, even they will not reach the 30 km/h speed limit of the road. For this reason, a **shared use condition** is proposed for this roadway section and it will be signalized at the beginning of the street by **vertical signs**. Bicyclists will ride in both directions of the street (as same as motor traffic) sharing the room with motor vehicles who, due the characteristics of the street (characteristics that do not invite drivers to drive fast) and the shared condition signal imposed, are expected to drive slowly and to give priority to cyclists.

Sidewalks are almost at the same level than roadway and help vehicles to retire from the roadway if there is not sufficient space. Any signal of “forbidden overtaking” will be provided but it is expected drivers do not overtake cyclists if the condition is not appropriate for that.

The shared use condition at low speed (it is expected motor vehicles drive at lower speed than the speed limit) remind the **Woonerf** situation. This shared use condition will not be imposed on the street but the situation done could be similar to it.

IV. *Vollabakken between Christian Fredriks gate and Lillegårdsbakken*

CURRENT SITUATION

Norwegian Road Administration is on the way of drafting a plan to build red bike lanes in this street. It will be studied if this is the best solution, or maybe could be another solution is feasible as well.

The roadway experiences an uphill in its way to Christian Fredriks gate at the approached intersection that it can be visualized on Figure 56.

Table 8 below shows the characteristics of the studied street.

Table 8: Characteristics of roadway section studied from Vollabakken

Roadway section	**Between Christian Fredriks gate and Lillegårdsbakken**
Roadway width	7- 7,2 meters. 5 meters where parking is provided
AADT	2.000 (40 heavy vehicles)
Speed limit	30 km/h
On-street parking	Some parking restrictions: Some roadway sections in one side of the street. Not parking in other roadway sections
Vertical signs	Not bicycle sign
Number of lanes	Two-ways street
Speed reducer	Bumps located close to the uphill section

Figure 56:Vollabakken gate, Trondheim (Google , 2013)

SUGGESTED SOLUTION

Same issue about change of section is presented in this road, but on-street parking is provided in same sections of the road: some parking restrictions. The problem comes at time of suggesting continuity shared use solution because the width of the street will be 2 meters wider in some roadway sections and 2 meters narrower in others in an alternating manner. This issue needs to be kept in mind to supply a good solution.

The suggested solution is a mixture of two shared use bicycle facility types:

From Lillegårdsbakken to Christian Fredriks gate the road experiences an uphill direction, so a **red bike lane** of 1,25 meters is a suitable solution to be provided. The reason is the possible cyclists´ instability and wobble at upping the street .Also, the change of roadway section is not produced on this side of the road for what continuity is reached with the bike lane. To make the solution a shared use condition, the red line will be painted as broken red line: **advisory lanes.**

In the opposite direction the width changes because the on-street parking. Sharrows is a good option to be provided. In the roadway sections with on-street parking, **sharrows** will be painted a certain distance from the curb, acting as Cambridge´s solution. In roadway sections without any on-street parking, Dublin situation will be represented with the sharrow marking in the middle of the lane.

Perhaps the bigger disadvantage is that continuity is not supplied within this solution. At change of roadway section, the change of sharrows location must be applied because the room given for each roadway lane also varies and parking would be located covering almost the sharrow or sharrow would be placed almost in the middle of the road. For a total comprehensive condition, on-pavement arrows that indicate the change of roadway section and the change of travel lane could be an appropriate solution as it was suggested for the road Udbyes gate between Olav Kyrres gate and Abels gate previously analyzed. The situation is represented in Figure 57.

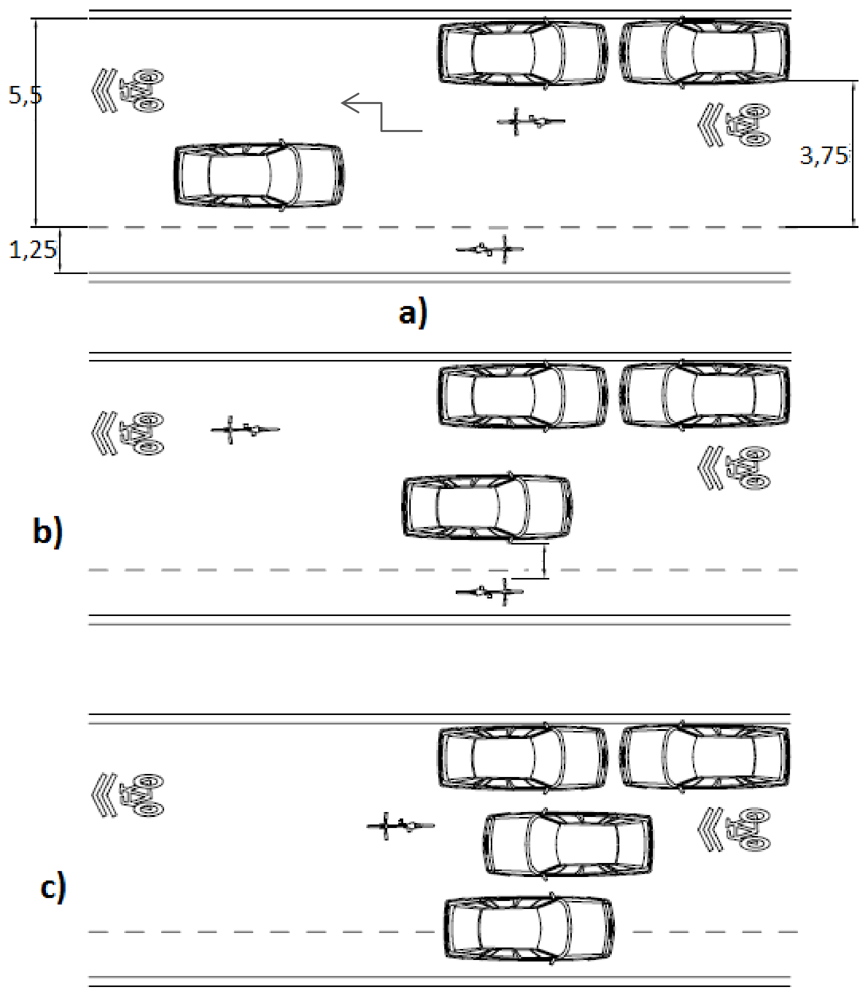


Figure 57: Advisory lane and sharrows solution for Vollabakken gate

It is obvious there is sufficient space for this solution in roadway sections with none on-street parking (7 meters) represented on (a) Figure 57 but, will be enough space where on-street parking condition occurs? Since the advisory lane is place instead a bike lane, that provides more space to motor vehicles in case of the not presence of bicyclists (c). Overtaking is allowed always there is enough space to do that. In the downhill direction (on-parking streets) free parked car gaps can help for a vehicle to wait if there are oncoming bicyclists and vehicles.

In Figure 57 there are three situations represented. In a) a cyclist changes the travel lane from on-street parking to none on-street parking situation. In b) is seen how there is enough space for a motor vehicle to pass side-by-side in the on-street parking situation. In c) a motor vehicles has to pass the advisory lane because another vehicle oncoming.

OTHERS MEASURES SUGGESTED

In case the solution suggested was not the appropriate, other measures in relation with on-street parking should be studied. Thinking about the possibility of removing the parking or providing parking in whole length of the street can be an interesting point.

Good information to know is that an off-street parking is located adjacent to the street. It can be analyzed if this parking has enough capacity for more motor vehicles or if the adjacent streets can collect the possible parked vehicles.

V. Blusuvolsbakken between Tyholtveien and Nordahl Bruns veg

CURRENT SITUATION

Due the characteristics represented of the street on Table 9, it can be considered a residential street or an access road to a main road. In Figure 58 is shown a picture of the street.

The street changes the direction three times what will be further studied below with the possible solutions.

Table 9: Characteristics of Blusuvolsbakken gate

Roadway section	**Between between Tyholtveien and Nordahl Bruns veg**
Roadway width	4,95 meters
AADT	1.000 (30 heavy vehicles)
Speed limit	30 km/h
On-street parking	Not parking
Vertical signs	30 Zone
Number of lanes	Two- ways street in one roadway section One- way street with different directions in others

Figure 58: Blusuvolsbakken gate, Trondheim (Google , 2013)

SUGGESTED SOLUTION

As the street changes the direction in three different segments, different proposals will be suggested for each segment, but always supplying a good connection between all of them: functionality, homogeneity and legibility needs to be reached.

- FIRST SOLUTION

TWO-WAY DIRECTIONS: FROM EIDSVOLLS GATE TO STRINDVEGEN

The characteristics of the street referrer to a pleasant and quiet residential environment and suit with the FIRST CASE of the profile for Two Lanes road previously explained in 3.2.

For this reason the solution proposed for this segment of the street is the same proposed for the FIRST CASE of Two Lanes profile in the section 3.2: **Sharrow** marking in the middle of the road in both traffic directions. Although the width of the street is narrower than the width registered in that profile, it is sufficient for two-ways street, and more in this road, as low traffic flow. The solution follows Dublin shared road solution for narrow streets.

Overtaken is allowed, always that it is safe for bicyclists.

ONE-WAY DIRECTION: FROM STRINDVEGEN TO SKULE BARDSONS GATE

Contraflow lane facility will be provided on the street. According to the Norwegian handbook 017 and the traffic and speed conditions, the width of the cycle lane will be 1,25 meters leaving 3,70 meters for the one traffic roadway width. Thus it is done in this road, a situation in which bicyclist-car-bicyclist (opposite direction) can drive side-by-side respecting the distance recommended between them. Overtaking is allowed in the shared lane condition and sharrows can be provided on it to remind vehicles the shared condition. The situation can be seen in Figure 59.

ONE-WAY DIRECTION: FROM SKULE BARDSONS GATE TO NORDAHL BRUNS VEG

Due the characteristics of the street does not change, it will be suggested the same solution than SECOND SEGMENT OF THE STREET but in the opposite direction because the traffic direction allowed changes. Figure 59 shows the situation.

The third segment of the street is connected with a pedestrian & bicycle segment of the street.

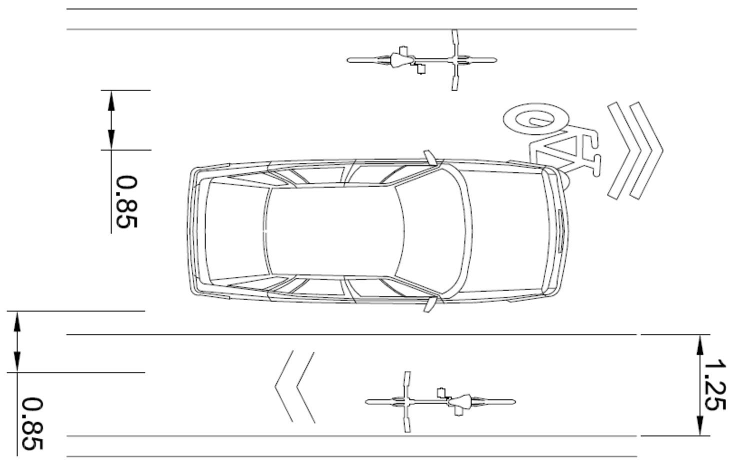


Figure 59: Contraflow solution for Blusuvolsbakken roadway section studied

- SECOND SOLUTION

Second solution suggested for this street is the same as FIRST SOLUTION but only with the vertical signs signalizing the bicycle condition of the road. As Blusuvolsbakken between Tyholtveien and Nordahl Bruns veg is a pacific road, bicyclists' contraflow will be possible if it is clearly signalized with a vertical sign.

OTHERS MEASURES SUGGESTED

There are signals to forbid parking on the road, but sometimes cars park on it (maybe they are residential cars). More parked restrictions could be applied whether there were parked vehicles on the contraflow lane roadway section. In general the street is very narrow to provide on-street parking. Perhaps it would be necessary to apply more parking restrictions along the road.

But it is not too easy to change the restrictions or to apply new rules within a street: experiments to prove that is the best option are needed.

VI. Strindvegen between Jonsvannsveien and Tyholtveien

CURRENT SITUATION

This road is perpendicular to the before analyzed street Blusuvolsbakken between Tyholtveien and Nordahl Bruns veg thus the solution must have a good connection with it.

For a good representation of its characteristics the street is divided in three parts in the Table 10 because it changes in parking restrictions and in width. Figure 60 and Figure 61 represent some sections of the roadway.

It will be suggested a unique solution in order to provide continuity to the facility.

Table 10: Characteristics of Strindvegen, Trondheim. Google maps view

Roadway section	**from Tyhotveien to Reidulvs**	**from Reidulvs to Blusvollsbakken**	**from Blusvollsbakken to Jonsvannsveien**
Roadway width	4,75 meters	4,95 meters	4,5- 5 meters
AADT	600 (12 heavy vehicles)	600 (12 heavy vehicles)	600 (12 heavy vehicles)
Speed limit	30 km/h	30 km/h	30 km/h
On-street parking	Yes. On one side	Allowed after 16.00 pm	Some parking restrictions
Vertical signs	30 Zone	NO	NO
Number of lanes	Two-ways street	Two-ways street	Two-ways street

Figure 60: Strindvegen, from Tyhotveien to Reidulvs (left picture) and from Reidulvs to Blusvollsbakken (right picture) (Google , 2013)

Figure 61: Strindvegen from Blusvollsbakken to Jonsvannsveien, Trondheim (Google , 2013)

SUGGESTED SOLUTION

- FIRST SOLUTION

As it is represented on the Table 10, the traffic flow is light and it is assumed that almost all the volume of vehicles is residential traffic. The speed limit of the street is 30 km/h but due the narrow street and the parking allowed in some sections of the roadway, the posted speed may be less than that limit. It is created then, a pleasant environment in which cyclists can ride without danger. For this reason, it is suggested a **shared use condition**, without any on-pavement markings considering that the random on-street parking will not let any on-street marking provide continuity along the length of the road.

- SECOND SOLUTION

Painting a **bicycle symbol in the middle** of the road will emphasize the shared use bicycle facility signposting provided by the vertical signs. Thus drivers will be more aware of presence of bicyclists on the road. This solution is like one of the proposals for Klæbuveien between Magnus den Godes gate and Snorres gate: Bicycle symbols will look at both directions as shows Figure 62.

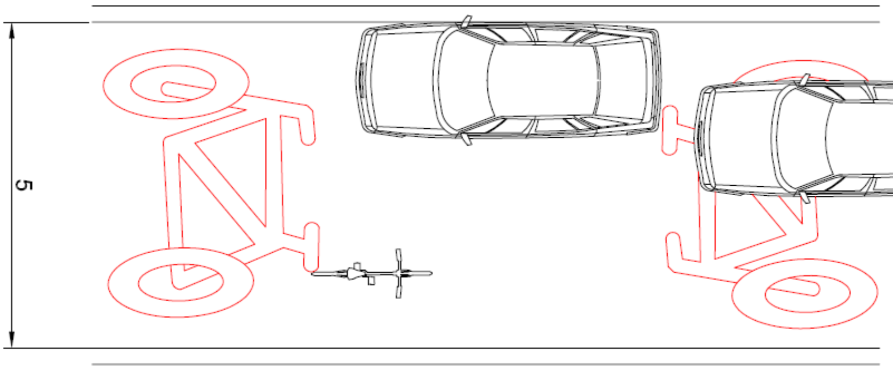


Figure 62: Bicycle symbol in the middle of the roadway in Strindvegen as shared use

In the Figure 62 is seen how a car waits behind a parked car while a cyclists is passing. As the traffic in the street is low, this solution is suitable because there is not going to produce any queue.

VII. Klostergata between Krogness gate and Håkon Jarls gate

CURRENT SITUATION

This street is study in two different roadway sections due its complete change of characteristics. In the Table 11 below three roadway sections are represented in order to provide better information about the road. The width of the roadway would be the only relevant factor and it does not change in the two first roadway sections. For this reason, it will be provided two facility types. The first facility will be provided for the section of road between krogness gate and Ragnhilds gate, shown in the Figure 63 and the second facility from Ragnhilds gate to Elgeseter gate shown in the Figure 64.

Table 11: Characteristics of Klostergata between Krogness gate and Håkon Jarls gate

Roadway section	**from Krogness gate to Gudrunsgate**	**from Gudrunsgate to Ragnhilds gate**	**From Ragnhilds gate to Håkon Jarls gate**
Roadway width	5 (roadway)+ 4,25 (parking)= 9,25 m	5,35 meters	4,85 (roadway)+ 4 (parking)= 8,85 m
AADT	2.500 (73 heavy vehicles)	3.000 (90 heavy vehicles)	600 (18 heavy vehicles)
Speed limit	30 km/h	30 km/h	30 km/h
On-street parking	Backing parking in one side	NO	In both sides
Vertical signs	NO	NO	NO
Number of lanes	Two-ways street	Two-ways street	Two-ways street
Speed Reducer	Bumps	Bumps and raised pedestrians´ crossings	NO

Figure 63: Klostergata from krogness gate to Ragnhilds gate (Google , 2013)

Figure 64: from Ragnhilds gate to Håkon Jarls gate, Trondheim (Google , 2013)

KLOSTERGATA FROM KROGNESS GATE TO RADNHILDS GATE

SUGGESTED SOLUTION

On-pavement marking is suggested as a solution for this street due the higher traffic volume and the presence of heavy vehicles respecting the other roads studied.

Also, speed reducers have been supplied on the street before what emphasizes “the possible unsafe condition”.

- FIRST SOLUTION

Sharrows in the middle of the lane as in Dublin case for narrow streets. This solution has been suggested on the road Blusuvolsbakken between Tyholtveien and Nordahl Bruns veg in its first segment analyzed where width and speed characteristics are very similar.

The higher flow in this street and the presence of heavy vehicles accentuate an important difference respecting the others streets. For this reason, to suggest another solution in order to provide a safer condition for cyclists is thought.

- SECOND SOLUTION

Advisory Lanes that provides a safer condition to cyclists could be a feasible solution due the presence of motor vehicles. This solution was suggested for SECOND CASE of Two Lanes existing Norwegian roads.

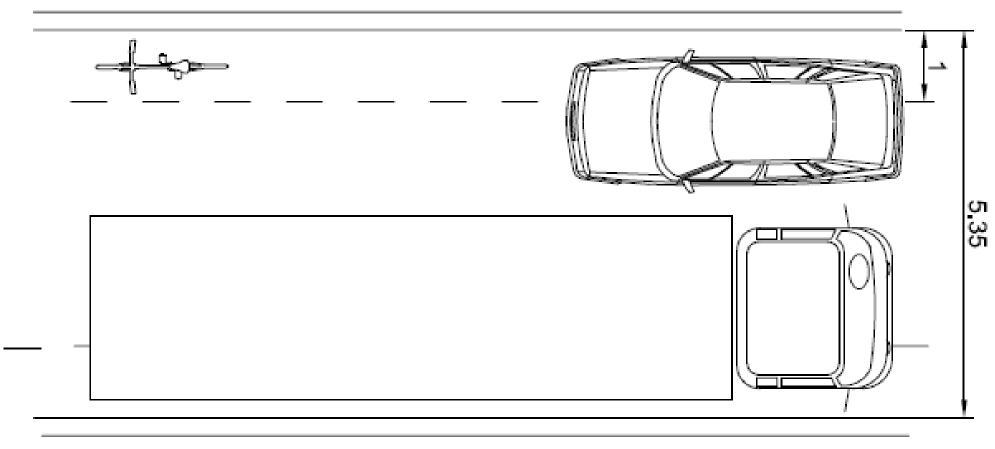


Figure 65: Klostergata advisory lanes solution from krogness gate to Ragnhilds gate

The big disadvantage is the too narrow width of the street for this solution that will not leave more than 3 meters for two directions of roadway and the advisory lanes will be used almost all time as roadway. Figure 65 shows a situation in which a truck and a car cross one another in presence of bicyclists: car waits until the truck pass to take the roadway lane and leave the advisory lane. The most unfavorable situation will be in which two trucks cross each other. The problem in this case would not come from the shared use condition suggested as advisory lanes yield all the width to the roadway but from the width of the street.

In other cities where this facility was provided like Dublin, the Netherlands or Vienna, the width of the roadway is around 8 meters. However in case of not presence of cyclists, vehicles can take the whole width of the street.

As it was noted in SECOND CASE of Two Lanes of the Norwegian existing roads, the width of advisory lanes will be an issue to study.

KLOSTERGATA FROM RADNHILDS GATE TO ELGESETER GATE

SUGGESTED SOLUTION

This roadway section is almost identical to the roadway section of Nedre Bakklandet road From Bakkegata to the north of Nygatta. For this reason, the suggested solution will be the same as it: **Sharrows** on the pavement. In addition, a contraflow lane is provided in a perpendicular road to this roadway section. Marking sharrows on the pavement will help to the awareness of drivers about cyclists when they turn to the right to a one-way road for traffic.

3.4. Summary of Results

The different solutions suggested for the existing Norwegian roads (valid for all the roads in Norway) are summarized below in Table 12; and the suggested solution for the seven streets studied in Trondheim, in Table 13 and Table 14. Table 13 shows the street where the solutions have been suggested for the whole length of the road, and Table 14 shows these roads in which a separate analysis of some roadway sections has been necessary.

Table 12: Summary of the suggested solutions for the existing streets in Norway

<table>
<tr><th>CHARACTERISTICS TYPE OF STREET</th><th>LIMIT SPEED</th><th>AADT</th><th>WIDTH OF THE ROAD</th><th>SUGGESTED SOLUTIONS</th><th>ON-PAVEMENT MARKING OPTIONS</th><th>SIGNS</th></tr>
<tr><td rowspan="5">One Lane
one way street</td><td rowspan="5">30 Km/h</td><td rowspan="5">< 300, no heavy vehicles</td><td rowspan="5">3,5 meters</td><td rowspan="2">Contraflow</td><td>Marked
1,25 meters contraflow lane:
Broken withe lines
Sharrows in traffic direction</td><td rowspan="18">Vertical signs at the beginning and at the end of the street to inform motorists about the shared condition
Way finding should be included within a bike route to provide a good and appropriate way for bicyclist</td></tr>
<tr><td>Unmarked</td></tr>
<tr><td>Shared road condition</td><td>No on-pavement marking</td></tr>
<tr><td>Bicycle street</td><td>Bike symbol in the whole width of the street</td></tr>
<tr><td>Woonerf</td><td>-</td></tr>
<tr><td rowspan="11">Two Lanes</td><td rowspan="3">30-40 km/h</td><td rowspan="3">0-4.000, <100 heavy vehicles</td><td rowspan="3">5,5 meters</td><td>Shared road solution</td><td>Sharrows painted in the middle of the lane</td></tr>
<tr><td>Shared road solution</td><td>No on-pavement marking</td></tr>
<tr><td>Woonerf</td><td>-</td></tr>
<tr><td rowspan="3">30-40 km/h</td><td rowspan="3">0-4.000, > 100 heavy vehicles</td><td rowspan="8">6 meters</td><td>Shared road solution</td><td>Sharrows painted in the middle of the lane</td></tr>
<tr><td rowspan="2">Advisory lanes</td><td>Broken withe lines 1,25 m each bicyclists lane</td></tr>
<tr><td>Broken withe lines 1,0 m each bicyclists lane</td></tr>
<tr><td rowspan="2">30-40 km/h</td><td>4.000 - 8.000</td><td>Shared road solution</td><td>Sharrows painted in the middle of the lane</td></tr>
<tr><td>8.000 - 15.000</td><td rowspan="2">Advisory lanes</td><td rowspan="2">broken withe lines 1,25 or 1 m</td></tr>
<tr><td rowspan="2">50 km/h</td><td>0 - 8.000</td></tr>
<tr><td>0-4.000</td><td>Shared road solution</td><td>Sharrows painted in the middle of the lane</td></tr>
<tr><td>50 km/h</td><td>8.000-15.000</td><td colspan="2">CYCLE LANES- NOT STUDIED IN THE THESIS</td></tr>
<tr><td rowspan="2">With on-street parking on both sides</td><td>50 km/h</td><td>> 4.000</td><td rowspan="2">6 meters roadway</td><td rowspan="2">Shared road solution</td><td rowspan="2">Sharrow painted a certain distance from the cub</td></tr>
<tr><td>30 -40 km/h</td><td>< 8.000</td></tr>
</table>

Table 13: Summary of the suggested solutions for the streets proposed in Trondheim

CHARACT STREET	LIMIT SPEED	AADT	WIDTH ROADWAY (m)	ON-STREET PARKING	SIGN	SPEED RED.	SUGGES. SOLUTION	ON-PAVEMENT MARKING	OTHER MEASURES SUGGESTED	SIGNS SUGGESTED
I	30 km/h	300-1.000 9-30 heavy vehicle	8 - 5,75	NO - YES	30 Zone	Bumps	**Shared use condition**	**No** on-pavement markings **Sharrows in the middle of the lane**: no parking **Sharrows a certain distance from the curb**: parking	**On-pavement arrow to mark the change of roadway section** Possible **traffic calming**: **On-street parking** in the no parking roadway section: width is wide and very low flow: vehicles can run	Vertical sign at the beginning and at the end of the road and in all the junctions to signalize the shared condition **Way finding signs** must be added to a bicycle network
II	30 km/h	400 8 heavy vehicle	7	NO	30 Zone Bicycle sign	NO	**Shared use condition**	**No** on-pavement markings **Sharrows in the middle** of the lane **Bike symbol in the middle** of the roadway **One red line** on each side of the roadway	-	
IV	30 km/h	2.000 40 heavy vehicle	7 - 5 m	NO-YES Some parking restrictions	NO	Bumps	**Advisory lanes in on side + Shared use condition**	**Broken red lines** in Advisory lane (1,25 m wide) **Sharrows a certain distance** from the curb in parking roadway sections and in the middle of the lane when not parking in shared use condition	**An arrow** is provided in the side of change of roadway section **to mark that change** **To remove or providing on-street marking** to have same roadway section in the whole length of the street	
VI	30 km/h	600 12 heavy vehicle	4,75 - 5	One side a section, allowed after 16.00 pm in another and some parking restrictions in others	30 Zone in some section	NO	**Shared use condition**	**No** on-pavement markings **Bike symbol in the middle** of the roadway	-	

Table 14: Summary of the suggested solutions for the streets proposed in Trondheim

CHARACT STREET	ROADWAY SECTION	LIMIT SPEED	AADT	WIDTH ROAD (m)	ON STREET PARKING	SIGN	SPEED RED.	SUGGESTED SOLUTIONS	ON-PAVEMENT MARKING	OTHER MEASURES SUGGESTED	SIGNS
III	**Bakkegata to the north of Nygatta**	30 km/h	1.000 30 heavy vehicle	4,8	YES. Both sides	NO	NO	**Shared Road condition**	**Sharrows** painted **a certain distance** from the curb	-	**Vertical signs** at the beginning and at the end of the street to ensure users of the road they know bicyclists are expected there **Way finding signs** must be added to a bicycle network
									No on-pavement markings		
	North of Nygatta to south end of Nygata		< 1.000	3	NO	To park is not allowed	NO	**Shared Road condition**	**One red line** on each side of the roadway		
									No on-pavement markings		
V	**Two ways directions**	30 km/h	1.000 30 heavy vehicle	5	NO	30 Zone	NO	**Shared Road condition**	**Sharrows** painted **in the middle** of the lane	Street too narrow, more parking restrictions?	
									No on-pavement markings		
	One way direction							**Contraflow solution (one way segment)**	**Contraflow** lane, withe line **Sharrow** on the shared lane	More parked restrictions could be applied whether there were parked vehicles on the contraflow lane roadway section	
									No on-pavement markings		
VII	**KLOSTERGATA FROM KROGNESS GATE TO RADNHILDS GATE**	30 km/h	2.500-3.000 75-90 heavy vehicle	5- 5,75	Backing parking in one road section. NO in the rest of the road	NO	Bumps and raised pedestrians´ crossings	**Shared road condition**	**Sharrow** marking **in the middle** of the lane for two directions	-	
								Advisory lanes in both sides	**White broken lines** in both sides of the road (1 - 1,25 m) the width should be studied		
	KLOSTERGATA FROM RADNHILDS GATE TO ELGESETER GATE		600 18 heavy vehicle	4,85	YES. Both sides		NO	**Shared road condition**	**Sharrows a certain distance** from the curb		

As Table 12 shows the solutions for the existing Norwegian roads are:

- Contraflow lanes, shared road condition without on-pavement markings, bicycle street and Woonerf for one lane streets.
- Shared road solution with and without on-pavement markings on the road, advisory lanes if the speed and flow conditions require them and woonerf for two lanes streets.
- Shared road solution with on-pavement markings for on-street parking roads.

The solutions for the streets in Trondheim shown in Table 13 and Table 14 are:

- Contraflow lanes for one-way streets.
- Shared use condition without on-pavement markings for streets with traffic flow less than 1.000 vehicles per day.
- Shared use condition with on-pavement markings (sharrows, bike symbol in the middle of the roadway and red lines) for streets with traffic flow less than 1.000 vehicles per day but also for one street with 2.5000 vehicles per day and presence of heavy vehicles.
- Advisory lanes where the traffic flow situation require it: higher traffic volume (until 3.000 vehicles per day) or presence of heavy vehicles.
- Shared use condition with sharrows a certain distance from the curb in on-street parking streets.

Vertical signs located at the beginning and at the end of the street to inform the type of shared use bicycle facility adapted on the road are provided in all of the streets.

Way findings should be included within a city to provide a good bicycle network because the most appropriate way to follow will be signalized to cyclists. This a good measure to included low traffic and low speed streets around the city in which none shared use condition have been applied.

4. Discussion

4.1. Important aspects for a feasible shared use condition

Safety is one of the most important factors which people consider when deciding whether to move by bicycle. For this reason, all the shared use solutions applied within a street should result in safe condition for all street users. In section 2.2 III, the principles of sustainable safety according to the city of Dublin are explained. They include functionality, homogeneity, legibility, forgivingness and self-awareness and all of them have the safety factor as final target. These principles should be reached in all the bicycle facilities provided. A good and pleasant environment occurs in shared facilities where both motor vehicles and cyclists understand their limitations, the space of the street where riding/driving, and the target of the facility.

Following the principles of sustainable safety, shared facility concepts should be kept in mind at time of design.

Principles for cycling facilities suggested in the Norwegian handbook 233 (Stantens Vegvesen, 2003) should be followed when a cycling facility is suggested on a given road. These principles result in a cycle network which is comprehensive, unified, simple, attractive and safe. Road markings and signage allow for the well-functioning of the facility, the solution is well understood and well use for all the users together, and forming a good street in which ride/drive.

While not covered in detail in this thesis, another important point of discussion are the **transitions** between different types of bicycle facilities **(system changes)**. Sometimes these transitions are not clearly identified and misunderstandings can occur. One of the most typical situations is the transition from cycle path to shared condition where bicyclists move from a segregated situation to then cycle with motor vehicles. Posted signs to provide good information about the routes are required. To suggest the appropriate solution for KLOSTERGATA FROM RADNHILDS GATE TO ELGESETER GATE roadway section, the transition between the possible solution and the contraflow lane facility already applied in one of the perpendicular streets has been taken into account. The signs used in Norway were shown previously in Figure 33.

4.2. Suggested solutions for Trondheim

Trondheim´s streets for which shared use bicycle facilities have been suggested are streets with low traffic volumes and speed limits of 30 km/h. The highest AADT registered in these streets is 3.000 vehicles per day, coinciding with the only street with presence of heavy vehicles, which adds a “danger factor” for a shared use condition.

Due the volume and speed limit characteristics, and the on-street parking already provided on some of the streets, similarities between these roads and the road types I; II FIRST CASE; II SECOND CASE, FIRST SITUATION and III SECOND SITUATION from the existing Norwegian roads analyzed.

According with the similarities in speed limit and volume, the suggested solutions for the streets in Trondheim are very similar to the given solutions for street types in Norway, but they are adapting to the current street situation/ characteristics of the real street.

The roads analyzed in Trondheim are too narrow to provide a good/feasible shared use bicycle solution if they are compared to the solutions provided in the other studied countries (the only solution provided for a similar width is shared use condition with sharrows in the middle of the lane for Dublin situation for narrows streets). Facilities are suggested within a street given the speed limit, traffic flow and others characteristics of the street for a given width, but in some cases more room on the road would result in a better functioning of the facility: this is the case of

KLOSTERGATA FROM KROGNESS GATE TO RADNHILDS GATE roadway section for which **advisory lanes** have been proposed due the traffic flow of the road, not even leaving 3 meters for the roadway section. If the flow traffic characteristics were lower, a

shared use facility without on-pavement marking can be feasible for the narrow roads because drivers do not feel free to drive faster and a pleasant shared condition occurs.

In some streets, a new solution not seen in the cities studied has been suggested: **one red line** in both sides of the road. The facility signalizes a shared condition in which benefits of the street are shared and; without needed of **sharrows**, motorists can be aware of the sharing situation. This solution, as with the **bicycle marking** on the road occupying all the width (same function as the red lines) should be studied in more depth to examine its feasibility.

Overall, the shared use solutions suggested for the different streets are: shared use facility with sharrows in the middle of the lane (without on-street parking), share use facility when parking is provided thus sharrows will placed a certain distance from the curb, shared use facility without any on-pavement marking for the most quiet and pleasant streets, contraflow solution for one-way roads and advisory lanes when the traffic flow is higher or with the presence of heavy vehicles. Some new shared condition facilities with red lines or a marked bike symbol in the middle of the road have also been included as mentioned previously.

However, not all the solutions suggested are totally appropriate for the analyzed streets. As Table 12, Table 13 and Table 14 show, various solutions for the same roadway section have been provided in order to analyze them in more depth and reach the most suitable option. Table 15 and Table 16 show the possible advantages and disadvantages the solutions suggested for the streets in Trondheim have, given the characteristics of the road (solutions shown in Table 13 and Table 14 respectively. Characteristics of the street are not represented in these tables.

Table 15: Advantages and disadvantages of the suggested solutions for the streets in Trondheim

ROAD	SUGGES. SOLUTIONS	ON-PAVEMENT MARKING	ADVANTAGES	DISADVANTAGES
I	**Shared use condition**	NO	Economic No car restrictions	Possible dooring effect in on-street parking sections More difficult awareness about cyclists without on-pavement markings. It is a street so wide thus motorist do not expect cyclists
	Sharrows	Sharrows in the middle of the lane: no parking Sharrows a certain distance from the curb: parking Arrow to mark the transition between both	Sharrows guide cyclists to not drive too close to parked vehicles. Vehicles expect cyclists on the road No car restrictions	Can be unnecessary due to the traffic volume and/or if the street is not frequented by cyclists
II	**Shared use condition**: Share benefits of the road	NO	Economic No car restrictions Feasible because of the low traffic	Shared use condition is not in the mind of vehicles all time
		Sharrows in the middle of the lane	No car restrictions Vehicles are more aware of the presence of cyclists	Maybe it is not necessary due the low traffic
		Bike symbol in the middle of the roadway		Maybe cars understand bicyclists have priority: wrong message Maybe markings are not needed
		One red line on each side of the roadway	No car restrictions Vehicles are more aware of the presence of cyclists Appropriate: not markings but vehicles are aware	New measure: Impact can not be fully understood, but the sign at the beginning of the street mark the shared condition
IV	**Advisory lanes in on side + Shared use condition**	Broken red lines in Advisory lane (1,25 m) Sharrows a certain distance from the curb (parking sections) and in the middle of the lane when (not parking)	Shared space in all the road width Non car restrictions Cyclists have their own space for the uphill direction and it is space for vehicles if it is needed and safe. Prevent possible dooring with sharrows Good to mark the street: higher flow	-
VI	**Shared use condition:** Share benefits of the road	No on-pavement markings	Economic: shared condition Not restrictions for cars Continuity in the whole length of the street (some parking restrictions --> parking may cover the on-street marking)	More difficult awareness about cyclists without on-pavement markings
		Bike symbol in the middle of the roadway	Make aware motorist of the presence of bicyclists (on-road-in situ) Not restrictions for cars	Maybe it is not necessary (low traffic) Cars can understand wrong the message of the facility (bicycle priority instead of shared condition) and feel greatly impacted by the “new conditions of the street”

Table 16: Advantages and disadvantages of the suggested solutions for the streets in Trondheim

ROAD	ROADWAY SECTION	SUGGEST. SOLUT.	ON-PAVEMENT MARKING	ADVANTAGES	DISADVANTAGES
III	Bakkegata to the north of Nygatta	**Shared Road condition**: shared benefits of the road	Sharrows painted a certain distance from the curb	Make drivers aware of the presence of cyclists and guide cyclists to avoid the possible dooring effect Non restrictions for cars	Economic
			No on-pavement markings	Economic No restrictions for cars	Drivers can be unaware of cyclists Dooring effect can occur because cyclist can feel intimidate by motor vehicles and drive too close to parked vehicles
	North of Nygatta to south end of Nygata	**Shared Road condition:** shared benefits of the road	One red line on each side of the roadway	Make drivers conscious of the presence of cyclists without painting sharrows No car restrictions	Maybe it is not needed. Very narrow street, very low traffic. It is not expected motor vehicles run
			No on-pavement markings	No painting a cobble road (AADT very low and very narrow width) No restrictions for cars	More difficult awareness about cyclists without on-pavement markings
V	Blusuvolsbakken gate from Eidsvolls Gate to Strindvege	**Shared Road condition**	Sharrows painted in the middle of the lane	Aware motorists of the presence of cyclists No restrictions for motorist: sharing the same benefits	Low traffic volume and very short segment: residential traffic. Maybe sharrows are not necessary
			No on-pavement markings	Economic No restrictions for cars	More difficult awareness about cyclists without on-pavement markings
	Blusuvolsbakken gate from Strindvege to Nordahl Bruns Veg	**Contraflow solution (one way segment)**	Contraflow lane. Withe line Sharrow on the shared lane	Two directions for cyclists No restrictions for cars: enough space for contraflow lane and overtaking cyclists-motor vehicle-cyclist side-by-side	Can be not necessary due to the low traffic and width of the street (narrow: vehicles will not run)
			No on-pavement markings	Two directions for cyclists No restrictions for cars Not painting the road can be appropriate when traffic volume is low, Economic	If cyclists are not expected on the road (can be an education problem), the contraflow direction can be dangerous for them without signals
VII	Klostergata from Krogness Gate to Radnhilds Gate	**Shared road condition**	Sharrow marking in the middle of the lane	More awareness of cyclists Guide cyclists, benefits of sharing the street No restrictions for cars	Cyclists may feel unsafe due the presence of motor vehicles. Also, the width of the street is too narrow
		Advisory lanes in both sides	White broken lines in both sides of the road (1 - 1,25 m)	Provide their own space for cyclists and the same space is provided to the roadway if it is necessary and safe for cyclists	Width of the street is too narrow to provide this facility: heavy vehicles occupy the road width Queues (traffic flow is higher than other streets) if cyclist demand is high: vehicles have to wait for a safe situation
	Klostergata from Radnhilds Gate to Elgeseter Gate	**Shared road condition**	Sharrows a certain distance from the curb	Avoid possible dooring and guide cyclists Awareness of cyclists. No restrictions for cars Benefits of road are sharing	-

Other measures proposed in the solutions are not as easy to apply because they change the characteristics of the road. These measures are traffic calming solutions which would change the width of the street removing or adding on-street parking for an equal roadway width along the road or speed reducers.

For a good and suitable bicycle network, **Way finding signs** are included within all the solutions to provide a good route for cyclists. Way finding encourages the population to take the bike as a mode transport to go around because it provides safe and good ways for cyclists and connect safer and low traffic streets in which shared condition has not been already applied to the bicycle network.

4.3. Factors that affect the effectiveness of a cycling solution

On-pavement markings are solutions provided in almost all the streets analyzed, but in Norway, markings on the streets are not totally suitable because of the northern weather. In winter the pavement is often totally covered by snow and ice, thus on-pavement marking is a bad solution because markings are not seen and the layers of snow and ice remove the markings with time.

For the winter reason, and because vertical signs should be present to inform motorist the type of street they are operating on, **bike vertical signs** is used for **all the solutions** suggested. The shared bicycle facility more important to provide signage is contraflow condition because drivers do not expect cyclists riding in the opposite direction.

Policies of the city and government support both at the national and municipally level are very important factors to develop a solid cycling base within a city, increasing the percentage of people cycling. A good example is the case of the Netherlands, Denmark and Germany (Netherlands, Denmark and Germany: Widespread bike use) that have achieved the highest cycling level in the world in spite of having high rates of car ownership. Norway and, especially Trondheim are on the way of making safer cities: Norwegian Public Administration has written a National Cycling Strategy as a result of the government´s concern. It is a strategy for safer, greener and on no fatalities, which aims to increase bicycling as mode of transport in Norway. The government is in collaboration with the 13 largest cities in Norway (one of them is Trondheim) to build denser cities where cars are not necessary.

For cycling policy/strategy to work, it is also necessary that the conditions of the city are appropriate for cycling. Hard winter (surfaces covered by snow and/or ice) and hilly areas (like Norway is) are factors against the increased cycling use. That is one of the reasons that explain why in the Netherlands or Denmark more people are bicycling than in Norway.

5. How We Assess?

5.1. Evaluation of the effectiveness of a new measure

The analysis of different solutions for a specific problem, ending with the final choice, is not enough to introduce a new measure within a road or define new regulations within a strategic transportation plan. For this reason, once the discussed solutions have been reached, it is necessary to test if the solution is totally appropriate for the problem and/or if it will work as expected.

There are several previous research efforts that discuss how transportation administrations around the world have evaluated the effectiveness of a new measure and determined its advantages and disadvantages to know if it is the most appropriate facility/solution. Evaluation of shared lane markings in Cambridge (Hunter, et al., 2011)and Evaluation of Shared lane markings for cyclists in Melbourne (Daff, 2013) are discussed and summarized below in Table 17 (Cambridge) and Table 18 (Melbourne).

I. Cambridge, Massachussetts: Evaluation of Shared lane markings

In Cambridge, Massachusetts an experiment on the effectiveness of marked roads in a shared traffic street was concluded. The study made a before (no marking) and after (sharrows placed 10ft-3,05 meters from the curb) evaluation to compare how motorists and cyclists operated on a street with parallel parking in Cambridge. The evaluation, which was part of a broad FHWA study on sharrows, was intended to determinate whether an alternative of the 11ft (3,4 meters) spacing recommended in the 2009 version of the *Manual of Uniform Traffic Control Devices* (US. Department of Transportation - Federal Highway Administration, 2009) would be effective. The study wanted to determine this narrower spacing (10 feet versus 11 feet) was.

The experiment was conducted on Massachusetts Avenue on a four lane street with parallel parking on both sides of the road. The AADT was 29.000 vehicles per day and the speed limit 30mph (48km/h). The number of peak hour bicycle riders was between 150 and 200. Roadway width and lanes width data was identified (Figure 66), such as the distance from the sharrow to the curb.

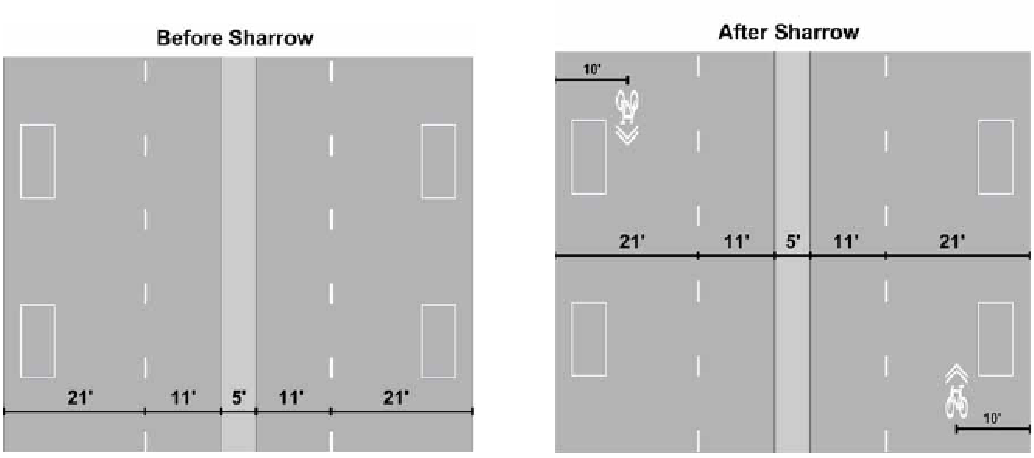


Figure 66: Width of the roadway section before (left picture) and after (right picture) adapting sharrows (Hunter, et al., 2011)

The experimental design involved collecting data from bicycles and motor vehicles in the traffic stream before and after the installation of the sharrows: local data collectors videotaped bicycles and motor vehicles travelling along Massachusetts Avenue before and after placement of the sharrows.

A camera was set up in line with the outside edge of a parked motor vehicle to provide a clear view of oncoming bicycles and motor vehicles. Zoom was used to follow the bicycles and videotaping was done at weekdays at various times of the day. Approximately 200 images were taken from the videotaping for both the inbound and the outbound directions. The distances taken before and after the sharrow condition were: bicycle to parked motor vehicle with a following motor vehicle; bicycle to parked motor vehicle with no following motor vehicle; bicycle to passing motor vehicle; and motor vehicle in the travel lane to parked motor vehicle with no bicycles present. The distance from the curb to the tires of parked vehicles (both the front and the rear tires) was measured as well.

Interesting situations or status for both motor vehicles and bicycles were coded with direction of travel: if the vehicle was following or passing the bicyclist, if the overtaking maneuver was safely done, vehicle stays on the lane or moving to the adjacent lane; if the bicycle rode on the sharrow, bicyclist position, existed or not dooring, whether the bicyclists took control of the lane preventing overpassing or the occurrence of avoided maneuvers and conflicts between bicyclists and motor vehicles.

Chi-squared tests were performed in order to examine the distributions of variables before and after placement of the sharrows. Analysis of variance model were used the effect of spacing and other performance measures (including site characteristics, treatment…)

Results pertaining to several variables were derived from the coding of the bicycles and vehicles and the interaction between both of them, and the spacing images extracted from the videotapes.

The relation between the number of observations and the average of all the spacing variables was analyzed before and after sharrows. The percentage of observations within a special variable was counted as well.

Data obtained before and after sharrows were compared to understand advantages and disadvantages of both situations. The scope of the experiment was to evaluate if the measure analyzed would solve the problem in which the research was conducted.

Overall, the installation of sharrows at 10ft (3,04 m) from the curb produced a safe situation: the space between motor vehicles from the travel lane and parked vehicles without presence of bicyclists increased, which tends to increase the safety of cyclists. The distance from riding cyclists to a parked vehicle increased, decreasing the percentage of cyclists riding within the potential door zone in presence of parked vehicles and vehicles following them. Data was different for the outbound direction than for the inbound direction that can be due to the difference in spacing variables.

Table 17 summarizes this information.

II. <u>Melbourne, Australia: Evaluation of Shared Lane Markings for cyclists</u>

In Melbourne (Australia), a before and after study methodology was used to examine the effects of sharrows on road users in three streets in the inner suburbs of the city, sufficiently representative of local streets. All the streets were flat and had a footpath on at least one side. The three streets are: Ewing Street, Scotchmer Street, and Wingrove Street represented in Figure 67, Figure 68 and Figure 69 with their width measurements.

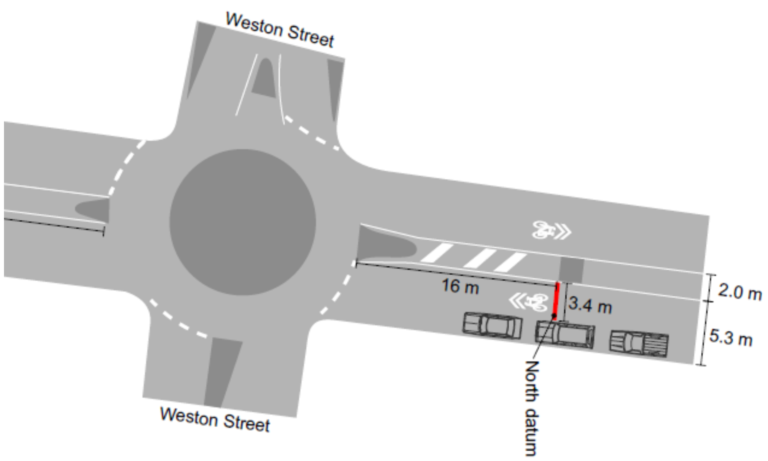


Figure 67: Placement of sharrow in Ewing Street (Daff, 2013)

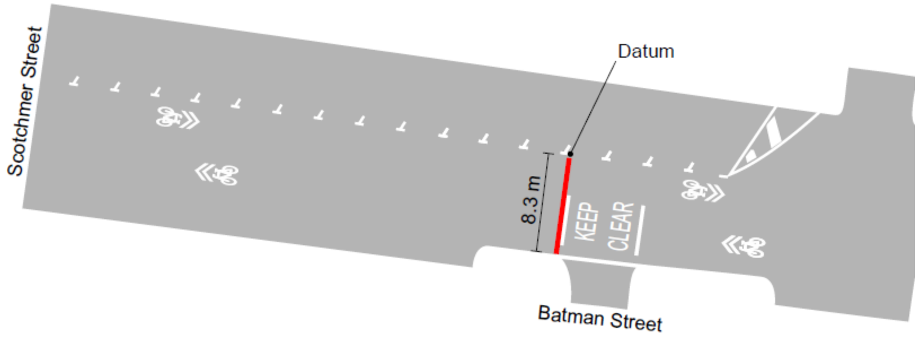


Figure 68: Scotchmer Street with Sharrows placed (Daff, 2013)

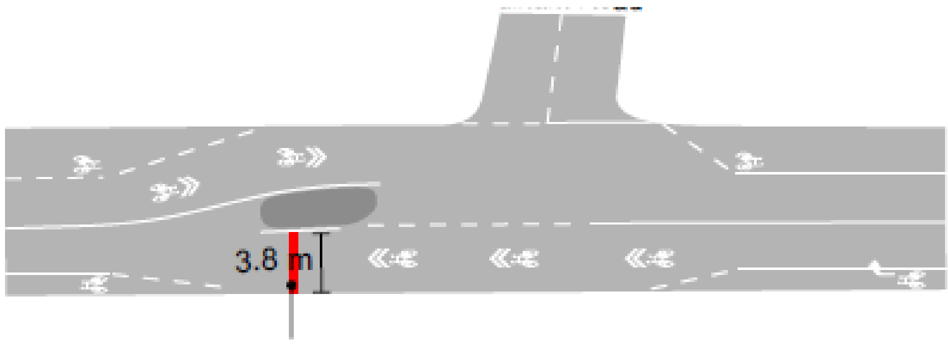


Figure 69 Wingrove Street after sharrows (Daff, 2013)

The three streets were 40-50 km/h speed limit with AADT of 5.000 vehicles per day for two of the three streets and 10.000 vehicles per day for the other. Number of cyclists was 200 per day in each street.

Observational data was collected in the study before the sharrows were installed and these observations were repeated after the sharrows were installed. Video recording at two sites on each street identified cyclist lateral tracking positions, interactions between motorists and cyclists and intercept interviews with cyclists.

The objectives of the study was focus on if cyclists acted differently with the presence of sharrows, if cyclists understood the purpose of sharrows and if they felt safer when sharrows were on the road, and on how was the likelihood of intimidatory interactions between motorists and cyclists.

The results show that sharrows can be effective at some sites (Scotchmer Street, Ewing Street) but entirely ineffective at others (Wingrove Street).

Overall, after the application of sharrows the percentage of cyclists on the road increased. However the increased levels of intimidatory driving by motorists indicated that did not always legitimize cyclists on the roadway.

Difference in speeds between the roads was noted, 50 km/h in Ewing Street and Wingrove Street versus 40 km/h in Scotchmer Street, which raised the question about the appropriate speed of motor vehicles for a shared use condition, because at higher speeds, the facility makes the situation less safe. The most violent situations occurred in Wingrove Street, were besides the speed, another factors studied took part.

The effects the sharrows had on road user behavior was that it was the tendency of cyclists to ride farther out into the traffic lane, but that varied depending of the traffic situation and the road geometry; more aggressive response behaviors by some motorists; the direction of cyclists more predictable with sharrows and overall not great changes due to the lateral distance to parked vehicles were observed.

Table 18 summarizes this information.

Table 17: Evaluation of Shared lane markings in Cambridge, Massachusetts

UNITED STATES AMERICA												
FACTORS/ CITY	**INHAB/ DENSITY**	**% MOTOR TRAFFIC**	**% BIKE**	**MEASUREMENT PROVIDED**	**SITUATION IN THE CITY**	**STREET MARKED**	**AADT ROAD**	**LIMIT SPEED**	**WIDTH OF STREET**	**PARKED VEHICLES**	**EXPERIMENT**	**AFTER EXPERIMENT**
CAMBRIDGE (Massachusetts) EXPERIMENT	108.900 inh 2675 inh/km^2	40,50%	3,90%	**Sharrows on street: EXPERIMENT.** Shared road within on-street parked (parallel parking-both sides)	Massachusetts Avenue- four lanes divided street. The street is a busy transit corridor.	YES. Sharrow= bicycle + arrow marked on the street a certainly distance from the curb.	29.000 vehicles/day in the whole Avenue--> 7250 vehicles per lane	48 km/h	69 ft (5ft of median) = 19,7 meter both sides. ONE SIDE: 32ft = 9,85 meters	Yes. Parked vehicles in one or both sides of the street (parallel parking). Sharrow improve the distance of cyclist from it and the space the cyclist takes.	Before-after evaluation of sharrow paced at 10ft spacing from the curb to help prevent dooring crashes with parked motor vehicles against the 11 ft recommended in MUTCD	10ft spacing is enough for improving the situation: dooring improved; distance from the parked vehicles to motorist increased what meant more space for bicyclist, avoidance maneuver decreased, bicycles passing more separate from parked vehicles.

Table 18: Evaluation of Shared lane marking for cyclists in Melbourne, Australia

AUSTRALIA													
FACTORS/ CITY	**INHAB/ DENSITY**	**% MOTOR VEHICLE**	**% BIKE**	**SITUATION IN THE CITY**	**MEASUREMENT STREET MARKED**	**AADT ROAD**	**LIMIT SPEED**	**WIDTH OF THE ROAD**	**CENTRE MEDIAN**	**PARKED VEHICLE**	**INTERSECTIONS**	**GENERAL OBSERVATIONS**	**DISCUSSION**
MELBOURNE (before and after STUDY to examine the effect of SHARROW)	4246000 inh. 1768 inh/km^2	76,70%	1,20 %	**Ewing Street** (Local Street)	**Sharrow** The street has already chevron 2 meter	5000 veh/day	50 km/h	12,6 meters	Intermittent median	Parallel both sides	Roundabout	Cyclists tend to track farther out into the traffic lane: cyclist claim the lane Most lateral tracking. Reduction in riders into the dooring zone Motorists intimidate more to cyclist and follow more impatiently. Sometimes aggressively behaviors Cyclist maintain more predictable direction	How safe can be sharrows? Type of street: volume and limit speed can make sharrow less safe instead safer. Speed difference between cyclist and motorists is one factor that support the aggressive behavior of motorists
				Wingrove street (Local Street)	**Sharrow** Traffic calming: island	5000 veh/day	50km/h	13,3 meters	Slow points islands	Parallel one side and no-parking in the other	Street between intersections		
				Scotchmer Street (Local Street)	**Sharrow** centers 1.3-1.5 meters from parking **Traffic Calming**: 40km/h markings on the road pavement	10000 veh/day	40km/h	10 meters	No median o centre line	Angle one side, parallel other side	Street between intersections		

6. Conclusions

This thesis was motivated by the lack of appropriate bicycle facilities in Norway, including but not limited to the city of Trondheim. Specially, this thesis explored bicycle facility solutions for those streets where a separated cycle solution cannot be provided. These roads are narrow roads where there is not enough room to provide cycle lanes, or roads with low to-moderate speed limits and traffic volumes, so that the need or separation between motor vehicles and bicycles decreases. A good shared environment between motor vehicles and cyclists in streets without a separated lane for them allows cyclists to feel safe without adversely impacting motorists with the shared solution. The thesis focuses on suggesting suitable, feasible, and comfortable shared use bicycle facilities that comply to the existing bicycle regulations and street designations of Norway. Safety is a key component considered in all the suggestions.

Shared use bicycle solutions on narrow streets in others countries from Europe and US were examined. Information on bicycle facilities from countries/cities such as the Netherlands, Münster, Dublin, Ferrara, Ghent, Murcia, Alicante, Vienna, Cambridge and Portland was used to develop appropriate solutions given the existing Norwegian streets standards found in the Norwegian Handbook 017.

Additionally seven streets in Trondheim (suggested by the Norwegian Public Road Administration) were studied in greater detail. Based on the general solutions recommended, specific, appropriate shared use solution were developed given the conditions and characteristics of each road. Width, speed limit and traffic volume were the main factors considered but others factors such as on-street parking, speed reducers, or any restriction were considered as well.

The solutions suggested for both the existing roads registered in the Norwegian handbook and the studied streets in Trondheim include the following shared bicycle facility solutions, all adapted to the required conditions of each road:

- Contraflow lanes for one-way streets
- Advisory lanes
- Shared use solutions both marked (sharrows) and unmarked condition.
- Woonerfs

The shared use bicycle facility solutions suggested provide a facility in which quality of service for both vehicles and cyclists are reached. Vehicles and cyclists shared the space of the street, also sharing benefits of the road.

Some of the roads analyzed in Trondheim are too narrow to provide a good/feasible shared use bicycle solution from those suggested above, according to the speed limit and traffic flow conditions. If the speed limit and the traffic volume are low for a very narrow road, the most feasible solution would be shared use bicycle condition without on-pavement markings.

For a feasible and suitable shared use facility, other measures are provided along with the facility itself to ensure motorist awareness and inform all the road-users of the shared use bicycle properties of the road. Signage also informs cyclists of the most appropriate way to reach a destination. This includes vertical signs and way findings.

6.1. Future work

After analyzing the possible solutions and suggesting the most appropriate shared use bicycle facility, the next step within this research would be to apply the suggested solutions and assess their use. For that, data observation before and after the solution is provided will be necessary and the roadway situation will be compared and examined for the most concern conditions and relationships between motor vehicles and cyclists. Surveys and interviews to cyclists and motorists about the new shared use condition will be helpful as well. This will allow for a clearer picture of how these facilities can be used within Norway.

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