COMPARISON OF BICYCLE TRANSPORTATION SYSTEMS IN EL PASO AND PRAGUE

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Dedication

I dedicate this work to my family, friends and adviser who supported me, encouraged me, and gave me inspiration and motivation during my studies.

I would like to dedicate this thesis to Vania Mora, who have always provided me with unyielding support and encouraged me to improve myself every day.

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COMPARISON OF BICYCLE TRANSPORTATION SYSTEMS IN EL PASO AND PRAGUE

by

JOSE C HERNANDEZ, Bc.

THESIS

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This thesis is an output of the Transatlantic Dual Masters Degree Program in Transportation Science and Logistics Systems, a joint project between Czech Technical University, Czech Republic, The University of Texas at El Paso, USA and University of Žilina, Slovak Republic.

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I declare that this Master's thesis is my own work and that I list all references in compliance with ethical guidelines on elaboration of Master's thesis.

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Guides for elaboration

During the elaboration of the master's thesis follow the outline below:

- Chapter 1: Introduction
- Chapter 2: Literature Review
- Chapter 3: Rules and Regulations of Bicycle Transportation
- Chapter 4: Geometric Design of Bicycle Facilities
- Chapter 5: Bicycle Infrastructure and Usage
- Chapter 6: Simulation of Operations of Bicycle Facilities
- Chapter 7: Conclusions

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Abstract

Dopravní infrastruktura je klíčovou komponentou pro bezpečnost cyklistické dopravy. Každým rokem dochází ke stovkám nehod cyklistů způsobených absencí či špatně navrženou infrastrukturou. Kvalitní a bezpečná infrastruktura cyklistické dopravy je také nezbytná pro další rozvoj cyklistiky a její propagace jako ekologické alternativy k jiným druhům dopravy. Cílem této diplomové práce je srovnání přístupu k návrhu a realizaci infrastruktury cyklistické dopravy ve Spojených státech a v České republice. Práce se nejprve věnuje historii cyklistické dopravy a její terminologii, posléze analyzuje stav legislativy, návrhových parametrů, souběh cyklistické dopravy s ostatními druhy dopravy a reálný stav dopravní infrastruktury v obou zemích. Následuje modelování vybraných úseků v programu VISSIM a návrh možných zlepšení pro tyto úseky. Během modelování byly zjištěny slabiny koncepcí infrastruktury cyklistické dopravy v USA i ČR, v závěru práce jsou proto shrnuta doporučení pro jejich odstranění v rámci navazujícího výzkumu.

infrastruktura cyklistické dopravy, smíšený provoz, VISSIM, bezpečnost cyklistické dopravy, návrhové parametry

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Chapter 1: Introduction

1.1 Background

The usage of bicycle as a transportation mode has had a big growth in the recent years due to its significant benefits such as reduction in traffic and better health that people get with the exercise. The importance of this transportation mode is the result of the increase of motorized vehicles in roads, traffic accidents, driver's stress, CO_2 production, among other factors. Bicycle has direct influence in reducing these negative numbers.

As a result, the agencies, organizations and government are noting the importance of transportation systems for bicycles. In the United States (U.S.) and EU, bicycle is one of the priorities in transportation design. The design of bicycle transportation infrastructure is based on the vehicle, pedestrians and bicyclist needs.

This thesis is about the design and implementation of the bicycle transportation systems in two-countries, the U.S. and the Czech Republic (CZ). The cities studied are Prague and El Paso, Texas. In this document, the comparison of the bicycle infrastructure design process and implementation in these two cities is the main focus, to draw experience for the two cities to improve the transportation systems for bicycles.

1.2 Objectives

The objective of this research is to compare the transportation infrastructure for bicycles in U.S. (specifically El Paso, Texas) and EU. (specifically Prague, Czech Republic). Selected traffic designs will be replicated with the use of VISSIM software, with the purpose of evaluating if VISSIM is capable of replicating the rules and regulations.

1.3 Outline of Thesis

Chapter 1 of this thesis introduces the bicycle transportation system and the need to study its implementation. The literature review in Chapter 2 details about the history of bicycle transportation, and its sustainability. Chapter 3 presents the rules and regulations of bicycle transportation in each city studied. Chapter 4 is about the geometric design. It includes design criteria and guidelines used by the public agencies. The existing bicycle infrastructure and usage are covered in Chapter 5, which describe the bicycle lane network and more important transportation facts. Chapter 6 covers the use of VISSIM to evaluate specific traffic designs selected in a bicycle network. Finally, Chapter 7 makes conclusions arising from this research, the research contribution with recommendation for future studies.

Chapter 2: Literature Review

2.1 History of Bicycle Transportation

Bicycle was called "Velocipede" since its appearance in 1700s. Bicycle was described by Jacques Osanam as "the theoretical advantages of a human-powered carriage in which one can drive oneself wherever one phases, without horses" (Herlihy, 2004). Velocipede had a big affluence in Paris, France before its popularity cross the Atlantic to the American continent. The exponential grow did not appear until 1869 where the velocipede popularity conquered the globe and it has become part of human's daily life. **Figure 2.1 and 2.2** show some of the firsts bicycles in history, when bicycle was a luxury.

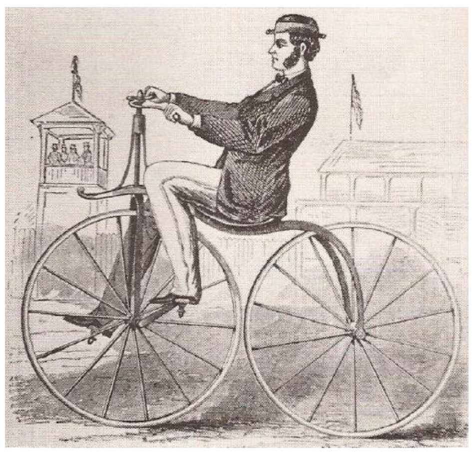


Figure 2.1: Velocipede.
Source: (Calif, 1983)

In the 18th and 19th centuries, there were many modifications to velocipede. Changes in functionality, size, and design were the most notable changes; every region had their design characteristics. The most notorious improvement for velocipede was made for Monod in 1869. This improvement is considered almost-perfect because it made the light, strong and easy to control and operate. The name bicycle appears in 1968 in The New York Daily News.

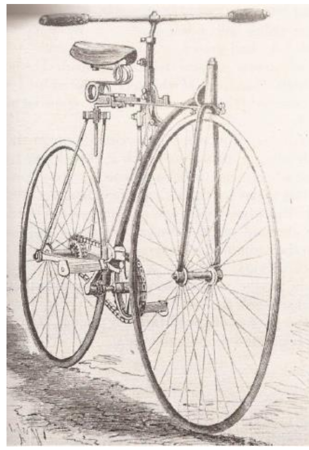


Figure 2.2: Chain bicycle.
Source: (Calif, 1983)

Accordingly to Calif (1983), throughout the history, bicycle had many changes and applications. The bicycle was adapted to many different uses. In **Figure 2.3,** bicycle adapted for ice and war are showed. The main application has been transportation. Moreover bicycle was a resource in wars as 1st world war in XX century.

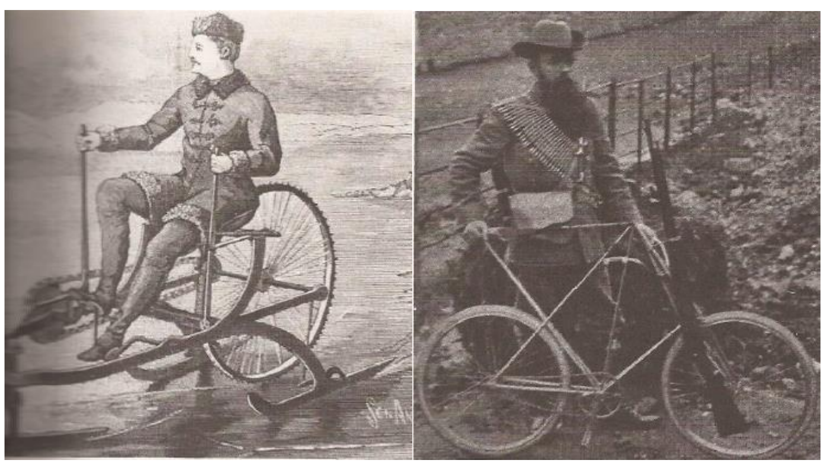


Figure 2.3: Examples of bicycle uses (ice and war).
Source: (Calif, 1983)

The first important bicycle facility was “Pasadena Cycleway” in 1900 that connects Pasadena and Los Angeles in California, constructed with a cost of $187,500. It was 18 miles long between these two cities with a toll of 10 cent per trip.

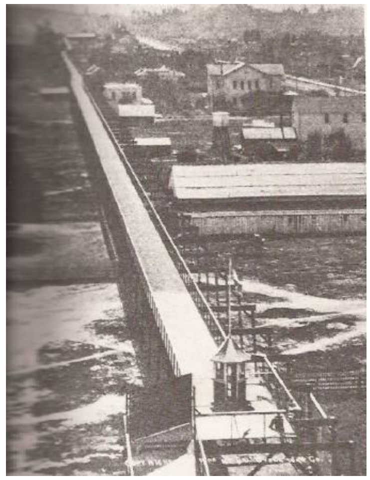


Figure 2.4: Pasadena Cycleway.
Source: (Calif, 1983)

Bicycle transportation is the answer to many concerns that are related to motorized transportation. Traffic congestion, energy consumption and pollution emissions are few of these problems. Bicycle has been considered as an appropriate mode for many trips. These trips are mostly in urban and suburban areas, where they do not exceed two miles in length. The existing and potential bicycle infrastructure should be integrated into the actual and future transportation planning process. This way the safety, convenience and demand of this mode can increase.

As the bicycle use increases, the needs of bicyclist started to be notable. Needs like access to public places, rack for parking and storage, bicycle exclusive lanes, help to promote the use of this non-motorized transportation mode and therefore are the most important. Incorporating bicycle into the transportation systems also has benefits for other transportation users. Motorized vehicles have wider and paved shoulders. With this the sight distance is improved for motorists and provides a buffer between traffic lanes and sidewalks. Pedestrians have more space to be protected against high speed traffic. These and other benefits are the result of implementing a bicycle infrastructure project. The community building codes, safety education, parking facilities, land use policies, roadway maintenance and other policies are responsible for the implementation of bicycle transportation systems.

2.1.1 Types of Bicycle Trips

Classify bicyclists and bicycle trips have been a complicated issue because there are many factors to taking into account. But without any doubt, there is not a single classification for all bicyclists or bicycle trips. In other words, a bicyclist can fit the characteristics of more than one classification. The most important factors are rider's physical ability, trip purpose and comfort level. But in many cases engineers switch these classification criteria accordingly theirs needs. For example, a person may use a bicycle for fitness training in the morning, later use the same bicycle to go to work or buy something in a grocery store. These ways this person uses the bicycle for the two trips may be classified as home base work trip (HBW) and home base other (HBO) respectively. As a result, transportation engineers classify bicycle trips according to trip purpose, utilitarian (nondiscretionary) and recreation (discretionary).

Utilitarian trips are trips that are involved in meeting the daily needs of people. In the most usual cases these are trips to work, school, shopping (and their return trips). One of the characteristics of these trips is that they can be replaced with other transportation modes which satisfy the traveler's needs. Some reasons that influence the mode choice for this kind of trips are the shortage of a vehicle, availability of driver license, accessibility of public transportation or cost.

On the other hand, recreational trips are generated by exercise or leisure motivation. There is a huge range of age among recreational bicyclists, since child to senior use bicycle for recreational purposes. Moreover, the characteristics of the ride can have many variations. Speed is an important one; as the speed can vary from 0 to 50 miles per hour (mph). It depends of the fitness level of the rider. The most difficult design criterion for transportation designers is the length of the ride. In general, children generate trips with their neighborhood of around 1 or 2 miles, but professional bicyclists can ride up to 100 miles in length. In recreational trips, there is also mountain biking. This type of trip includes a combination of wild natural surface and paved surface. In this thesis, mountain biking on natural surface will not be discussed, while on paved surface will be considered as part of recreational or utilitarian trips.

The American Association of State Highway and Transportation Officials (AASHTO) has guidelines for different types of bicycle facility design accordingly uses and needs. The design principle is similar to the design for motor vehicles. The difference between bicycle network for recreational trips and utilitarian trips is very little. This is the main complication in the design. The main distinction about this two uses are; (i) the people who use bicycle for utilitarian trips in most cases are looking for short, fast and less physical demanding routes; (ii) on the other hand, people who use bicycle for recreational trips use all kind of routes, for example a professional bicyclist in many cases uses the more demanding route, and this means the route with more changes in elevation, longer than other routes and high speed can be development with enough safety. But in many cases the needs for these two types of trips are the same. **Table 2.1** shows the similar and contrast characteristics of utilitarian and recreational trips. These are general trip characteristics. There do not represent any specific age, type of bicycle, level of physical condition among other factors.

Table 2.1: Recreational Trips vs. Utilitarian Trips.

Recreational Trips	Utilitarian Trips
Directness of route not as important as visual interest, shade, protection from wind	Directness of route and connected, continuous facilities more important than visual interest, etc.
Loop trips may be preferred to backtracking; start and end points are often the same	Trips generally travel from residential to schools, shopping or work areas and back
Trips may range from under a mile to over 50 miles	Trips generally are 1-5 miles in length
Short-term bicycle parking is needed at recreational sites, parks, trailheads and other recreational activity centers	Short-term and long-term bicycle parking is needed at stores, transit stations, schools, workplaces
Varied topography may be desired, depending on the fitness and skill level of the bicyclist	Flat topography is desired
May be riding in a group	Often ride alone
May drive with their bicycles to the starting point of a ride	Use bicycle as primary transportation mode for the trip; may transfer to public transportation; may or may not have access to a car for the trip
Typically occur on the weekend or on weekdays before morning commute hours or after evening commute hours	Some trips occur during morning and evening commute hours (commute to school and work), but in general bicycle commute trips may occur at any hour of the day

Source: (AASHTO, 2010)

2.2 Bicycle Transportation and Sustainability

2.2.1 Level of User Skill and Comfort

To classify the level of user and comfort, AASTHO divides them into two categories: (i) experienced and confident users; and (ii) casual and less confident users. Experienced and confident users include people of all ages who use bicycles for utilitarian and recreational trips. Their main characteristic is that they have enough experience with riding bicycle in mixed traffic. Usually, this type of bicyclists uses the most direct route for their utilitarian trips. For recreational trip they use any route without taking account the traffic and topographic conditions. On the other hand, there are casual and less confident users. This classification involves a majority of the population with a wide range of characteristics. Persons who use dedicated bicycle facilities or low traffic streets are in this group. For these users bicycle is the transportation mode for multiple purposes. These can be recreational or utilitarian, with children, other cyclists, or just ride alone. To complement the scope of the AASTHO classification, **Table 2.2** shows the classification in more extensive way.

Table 2.2: Casual/Less Confident vs. Experienced/Confident Riders.

Experienced/Confident Riders	Casual/Less Confident Riders
Most are comfortable riding with vehicles on streets, and are able to negotiate streets like a motor vehicle, including using the full width of a narrow travel lane when appropriate and using left-turn lanes.	Prefer shared use paths, bike boulevards, or bike lanes along low-volume, low-speed streets.
While comfortable on most streets, some prefer on-street bike lanes, paved shoulders or shared use paths when available.	May have difficulty gauging traffic and may be unfamiliar with rules of the road as they pertain to bicyclists: may walk bike across intersections.
Prefer a more direct route.	May use less direct route to avoid arterials with heavy traffic volumes.
Avoid riding on sidewalks. Ride with the flow of traffic on streets.	If no on-street facility is available, may ride on sidewalks.
May ride at speeds up to 20 mph on flat ground, up to 45 mph on steep descents.	May ride at speeds around 8 to 12 mph.
May cycle longer distances.	Cycle shorter distances: 2 to 5 miles is a typical trip distance.

Source: (AASHTO, 2010)

2.2.2 Transportation Planning Process

Transportation infrastructure for bicycle is implemented via different design methods, developed by experience and by research. These designs are implemented in rural and urban areas. The most common design documents are described in the following parts of this sub-section.

Firstly, bicycle master plans are prepared by state Departments of Transportation (DOTs) in continuous treatment with counties and Metropolitan Planning Organizations (MPOs). The master plans focus on policy issues, network planning and design. These plans are in short and long-term to maintain and improve the functionality.

Transportation impact and traffic studies are other processes used for bicycle transportation planning and design. These studies evaluate transportation modes including pedestrian, bicycle and vehicles for environmental sustainability. In conjunction with The National Environmental Policy Act (NEPA) and other federal environmental agencies the study evaluates the impact of the growth of the different transportation modes on the community.

In Comprehensive Transportation Plan, there is a bicycling section that should include long-term planning, safety plans for highway, and the future demand study. The bicycle design process and public characteristics are same as for motor vehicle. In public meetings, the opinion of persons who uses all modes should be taken into account to improve the actual transportation system. In some cases the bicycle part of the transportation master plan is a separated chapter and considered as a comprehensive transportation plan for bicycle.

The designs of both neighborhood and transportation corridor facilities have rules for bicycle access and intersection with streets and highways. Safety should be an important factor to incorporate into the design. The safety, comfort and level of service are the main factors to attract people to use bicycle as a transportation mode. After that, the authority should keep these facilities in proper condition to maintain the use.

2.2.3 Bicycle into the Transportation Infrastructure Network

A transportation network is the coexistence of different transportation modes. The users of a transportation network consist of motorized vehicles, pedestrians and bicycles. The design of the transportation system including these modes has a process to follow. This process seeks the equilibrium between all modes according to the actual needs and the future demand. The process to incorporate bicycle into the actual system has different stages.

The first decision about bicycle transportation infrastructure is to determine the places that need it. The idea is that the bicycle network should be everywhere, except on highways where it is prohibited for safety reason. The most important factors to consider according to AASTHO (2010) are:

- Traffic volumes
- Traffic speed
- Safety (barriers and spacing)
- Productive zones
- Direction and connection routes
- Aesthetics
- Density of bikeways
- Cost feasibility
- Number of trucks
- Number of intersection

These factors have different values or scores for the designers. In cases of cost or aesthetics the values are negatives, but the sum of the values of each category gives an overall qualification for the route. The route with the highest overall value is the most desirable to be implemented.

Other factors that influence bicycle system implementation are projects that take advantage of right of way. Some examples of these situations are:

- The bikeway is designated in a construction/reconstruction or maintenance zone. It means that work is schedule at that time and implementation of bikeway may be part of the bigger project.
- The implementation of bikeway by private sector company requirements.
- Implementation in major capital projects for example freeways, rail projects, bridges or other major project.
- Implementation of shared-use paths (shared by pedestrians and bicycles) in conjunction with governmental services (water, electric supply, and natural gas).

- Vacant land. A good example of this is the old public rail roads that are useless. This type of land is good for shared-use path.

There are many different designs ifor bicycle transportation according to the needs and future potential development projects. These designs varied as a result of some factors such as location, traffic volume, and user characteristics. The common designs accordingly AASHTO (2010) are represented in the **Table 2.3** where their characteristics are compared.

Table 2.3: General Considerations for Different Bikeway Types.

Type of bikeway	Best use	Motor vehicle design speed	Traffic volume	Classification or intended use	Other considerations
Shared use path: independent corridor	Linear corridors in greenways, or along waterways, highways, active or abandoned rail lines, utility rights-of-way, unused rights-of-way. May be a short connection, such as a pathway connector between two cul-de-sacs, or a longer connection.	n/a	n/a	Provides a separated path for non-motorized users	Analyze intersections to anticipate and mitigate conflicts between path and roadway users. Design path with all users in mind, wide enough to accommodate expected usage. On-road alternatives may be desired for advanced riders who desire a more direct facility that accommodates higher speeds

Source: (AASHTO, 2010)

Table 2.3: General Considerations for Different Bikeway Types (continued).

Type of bikeway	Best use	Motor vehicle design speed	Traffic volume	Classification or intended use	Other considerations
Paved shoulders	Rural highways that connect town centers and other major attractors	Variable. Typical posted rural highway speeds (generally 40-55 mph)	Variable.	Rural roadways; inter-city highways	Provides more shoulder width for roadway stability. Shoulder width should be dependent on characteristics of the adjacent motor vehicle traffic, i.e. wider shoulders on higher-speed roads
Bike lanes	Major roads that provide direct, convenient, quick access to major land uses. Also can be used on collector roads and busy urban streets with slower speeds	Generally, any road where the design speed is more than 25 mph	Variable. Speed differential is generally a more important factor in the decision to provide bike lanes than traffic volumes	Arterials and collectors intended for major motor vehicle traffic movements	Where motor vehicles are allowed to park adjacent to bike lane, ensure width of bike lane sufficient to reduce probability of conflicts due to opening vehicle doors and other hazards. Analyze intersections to reduce bicyclist/motor vehicle conflicts. Sometimes bike lanes are left "undesignated" (i.e. bicycle symbol and signs are not used) in urban areas as an interim measure
Bike boulevard	Local roads with low volumes and speeds, offering an alternative to, but running parallel to, major roads. Still should offer convenient access to land use destinations	Use where the speed differential between motorists and bicyclists is typically 15 mph or less. Generally, posted limits of 25 mph or less	Generally less than 3,000 vehicles per day	Residential roadways	Typically only an option for gridded street networks. Avoid requiring bicyclists to make frequent stops. Use signs, diverters, and other treatments so that motor vehicle traffic is not attracted from arterials to bike boulevards

Source: (AASHTO, 2010)

Table 2.3: General Considerations for Different Bikeway Types (continued).

Type of bikeway	Best use	Motor vehicle design speed	Traffic volume	Classification or intended use	Other considerations
Shared lanes (wide outside lanes)	Major roads where bike lanes are not selected due to space constraints or other limitations	Variable. Use as the speed differential between bicyclist and motorists increases. Generally any road where the design speed is more than 25 mph	Generally more than 3,000 vehicles per day	Arterials and collectors intended for major motor vehicle traffic movements	Explore opportunities to provide parallel facilities for less confident bicyclists
Shared lanes (shared lane markings)	Space constrained roads with narrow travel lanes, or road segments upon which bike lanes are not selected due to space constraints or other limitations	Variable. Use where the speed limit is 35 mph or less	Variable. Useful where there is high turnover in on-street parking to prevent crashes with open car doors	Collectors or minor arterials	May be used in conjunction with wide outside lanes. Explore opportunities to provide parallel facilities for less confident bicyclists. Where motor vehicles allowed to park along shared lanes, ensure marking placement reduces potential conflicts with opening car doors
Shared roadways (no special provisions)	Minor roads with low speeds and volumes, where bicycles can share the road with no special provisions	Speed differential between motorists and bicyclists is typically 15 mph or less. Generally, speed limits of 30 mph or less	Generally less than 1,000 vehicles per day.	Neighborhood or local streets	Can provide an alternative to busier streets in a gridded street network. On a non-grid network, may be circuitous or discontinuous

Source: (AASHTO, 2010)

2.2.4 Analysis for Bicycle Infrastructure

There are many traffic analysis techniques to support the design of bicycle facilities. These techniques base their analysis in bicycle volume, quality of service, safety or cost-benefit. According to the results of these analyses, transportation planners and engineers have enough information to make better design decisions. For this reason these procedures are very important to bicycle facility planning and design.

The bicycle count in an established bicycle route is important to the understanding, planning and operation of the design. This way the designer can predict the current use and potential increase in users, predict the interaction with motor vehicles and pedestrians, analyses the demographic data and design for future expansion.

Quality of service (bicycle level of service) evaluates the condition for bicycle traffic. The forecast for future service condition also is a factor to consider in predicting the life of the design. The Level of Service (LOS) involves the documentation of current conditions, identification of the bikeway/roadways sections, creation of bicycle maps, and determination of the impact of bicycle on projects. These have the common purpose of prioritizing and programming bicycle preferences and improvements. The evaluation of the LOS is delimited with grades from A through F, where A as the best grade.

Safety is an important measure analyzed by the designers, but getting a reliable data represent a real challenge. This is a result of many factors. Firstly, many crashes that do not involve motor vehicles are not reported. This means that in most cases where only bicycles are involved there is insufficient data for safety analysis. This is because bicycle only crashes generally result in only minor injuries. The other factor is the interaction between motor vehicles, pedestrians and cyclists. Designers analyze the geometry and evaluate the safety for bicyclists. In a combined evaluation of these factors the safety of a bicycle route is designated and compared with other routes.

Demand analysis is used by designers to predict where the bicycle transportation system should be located. Geographic Information Systems (GIS) is used to perform detailed analysis of the data. This analysis is based on demographic information in an area so as to estimate how many thavels are expected to use this transportation mode.

Finally, in the cost-benefit analysis, a series of studies are performed to verify where the optimum route is. The optimum route is the one which has the lowest cost or highest benefits. To lower the cost of bicycle facility improvement project it can be part of a bigger transportation or utility infrastructure project. The benefit can be for the potential industrial zone, shopping zone or school zone in reduction in traffic, emission and noise. The benefit can be immediately or in the long-term.

2.3 Bicycle Terminology

2.3.1 El Paso, TX Terminology

This section explains the commonly used terms in bicycle planning and facility design.

- *Bikeway*: Trail, path, part of a street or surface terrain (surfaced or smooth) with signs, marks or way which in some manner show that it is designated specifically for bicycles or are to be shared with other transportation modes. The most common are bicycle lanes, trails, bicycle routes, shared lanes or shared-use paths.
- *Bicycle Lane:* Part or portion of roadway whit single directional flow. Usually it should have pavements mark to establish preferential or exclusive bike use. Signage supplements bike lanes to notice the lane existence.
- *Bicycle Route*: System of bikeways which connect different locations accordingly demands of users. These systems may be a combination of various types of bikeways. Bike route is designated with signs, marks that are shown in maps. Along bike routes

directional, distance and other useful information may be provider to ensure the bicyclist conform.

- *Shared Lane*: Roadway which is open to bicycle and motor vehicles without assigned space for each, both vehicles should use this lane with same preferences. In some cases signs may be used to control the traffic connivance.
- *Shared –Use Path*: Path which is open to bicyclist, runners, pedestrians and other non-motorized vehicle. This path should be separated from the motor vehicle lane. Usually shared-use path allows two way directions with directional lane wider than bike lane.
- *Bicycle Network*: Network of bikeways with an authority on charge. This system may be composed by bicycle lanes, bicycle routes, shares paths and facilities for users.

2.3.2 Prague, CZ Terminology

- B + R: Bike and ride, usually this bicycle infrastructure is connected with the public transportation, the main objective of this avoid or decrease the use of particular motor vehicles.
- Motor-less zone / communication (bezmotorová zóna / komunikace): Pedestrians are the main purpose of this zone, but the entrance for motor-less vehicles (bicycles) is permitted, usually used in sidewalks.
- Bus cycle lane (bus+cyklopruh): Lane reserved for busses and bicycles, in many cases taxis are included too.
- Cycle-picto (Piktogramový koridor pro cyklisty): The marked trail recommending of bicycles.
- Cycle lane (Cyklistický pruh): Lane dedicated just for bicycles.
- Bicycle path (Cyklistická stezka): This is denominated bicycleway footpath because permit transit of pedestrians and bicyclist. This path has its modified signs for cyclists.

- Cycle route (Cyklistická trasa): This cycle route has directional transport flow of bicycles, but do not determine relationship to motor vehicles.
- Stop box (Předsazená stopčára): Space in fort of the line at intersection determinate to the bicyclist wait for the green light and start the movement first.

Chapter 3: Rules and Regulations of Bicycle Transportation

3.1 Rules of Regulations of U.S., Texas and El Paso

In U.S., one of the most important factors that discourage the use of bicycle is safety. Riding in mixed traffic is a challenge for new bicyclist. In recent years, several agencies in U.S. (for examples Departments of Transportation, Metropolitan Planning Organizations, police departments) have been trying to improve the safe interactions between different transportation modes. In U.S., there are rules and laws for bicycle at the national level, but different states have adopted their own regulation for this transportation mode.

3.1.1 El Paso, U.S. Bicycle Rules of Regulation and Law

Law enforcement plays an essential role in bicycle transportation system to reduce the unsafe interaction with motor vehicles. The implementation of these regulations improves the riding environmental for bicyclist and reduces bicycle involved crashes. Some of the more important regulations in U.S. for bicycle transportation are:

- *195.115 Reducing barriers for pedestrian and bicycle access to schools.*

City and county governing bodies shall work with school district personnel to identify barriers and hazards to children walking or bicycling to and from school.

The cities, counties and districts may develop a plan for the funding of improvements designed to reduce the barriers and hazards identified.

- *366.112 Bicycle lane and path advisory committee; members, terms, duties and powers; meetings.*

(1) There is created in the Department of Transportation an advisory committee to be appointed by the Governor to advise the department regarding the regulation of bicycle traffic and the establishment of bicycle lanes and paths. The committee shall consist of eight members including an employee of a unit of local government employed in land use planning, a representative of a recognized environmental group, a person engaged in the business of selling or repairing bicycles, a member designated by the Regional Recreation Trails Advisory Council, and at least one member under the age of 21 at the time of appointment.

- *366.514 Use of highway fund for footpaths and bicycle trails.*

(1) Out of the funds received by the Department of Transportation or by any county or city from the State Highway Fund reasonable amounts shall be expended as necessary to provide footpaths and bicycle trails, including curb cuts or ramps as part of the project. Footpaths and bicycle trails, including curb cuts or ramps as part of the project, shall be provided wherever a highway, road or street is being constructed, reconstructed or relocated. Funds received from the State Highway Fund may also be expended to maintain footpaths and trails and to provide footpaths and trails along other highways, roads and streets and in parks and recreation areas.

- *802.325 Bicycle safety program; contents; fees.*

(1) The Department of Transportation, in consultation with the Transportation Safety Committee shall establish a bicycle safety program that complies with this section to the extent moneys are available for such program. The program established may include the following:

(a) Bicycle safety promotion and public education.

(b) Advice and assistance for bicycle safety programs operated by government or nongovernment organizations.

(c) Classroom instruction and actual riding instruction necessary to teach safe and proper operation of bicycles.

(d) Bicycle education and information that assist police agencies in the enforcement of bicycle laws.

(e) Other education or safety programs the department determines will help promote the safe operation of bicycles, promote safe and lawful riding habits and assist in accident prevention.

(f) The department may charge a fee for services provided under the program.

Any fee charged by the department under this paragraph shall be established by rule and shall not be in an amount that will discourage persons from participating in safety programs offered by the department under this section.

- *810.150 Drain construction; compliance with bicycle safety requirements; guidelines.*

(1)Street drains, sewer drains, storm drains and other similar openings in a roadbed over which traffic must pass that are in any portion of a public way, highway, road, street, footpath or bicycle trail that is available for use by bicycle traffic shall be designed and installed, including any modification of existing drains, with grates or covers so that bicycle traffic may pass over the drains safely and without obstruction or interference.

- *811.050 Failure to yield to rider on bicycle lane; penalty.*

(1) A person commits the offense of failure of a motor vehicle operator to yield to a rider on a bicycle lane if the person is operating a motor vehicle and the person does not yield the right of way to a person operating a bicycle, electric assisted bicycle, electric personal assistive mobility device, moped, motor assisted scooter or motorized wheelchair upon a bicycle lane.

(2) This section does not require a person operating a moped to yield the right of way to a bicycle or a motor assisted scooter if the moped is operated on a bicycle lane in the manner permitted under the law.

(3) The offense described in this section, failure of a motor vehicle operator to yield to a rider on a bicycle lane, is a Class B traffic violation.

- *811.065 Unsafe passing of a person operating a bicycle.*

(1) A driver of a motor vehicle commits the offense of unsafe passing of a person operating a bicycle if the driver violates any of the following requirements:

(a) The driver of a motor vehicle may only pass a person operating a bicycle by driving to the left of the bicycle at a safe distance and returning to the lane of travel once the motor vehicle is safely clear of the overtaken bicycle. For the purposes of this paragraph, a 'safe distance' means a distance that is sufficient to prevent contact with the person operating the bicycle if the person were to fall into the driver's lane of traffic. This paragraph does not apply to a driver operating a motor vehicle:

(A) In a lane that is separate from and adjacent to a designated bicycle lane;

(B) At a speed not greater than 35 miles per hour; or

(C) When the driver is passing a person operating a bicycle on the person's right side and the person operating the bicycle is turning left.

(b) The driver of a motor vehicle may drive to the left of the center of a roadway to pass a person operating a bicycle proceeding in the same direction only if the roadway to the left of the center is unobstructed for a sufficient distance to permit the driver to pass the person operating the bicycle safely and avoid interference with oncoming traffic..

(c) The driver of a motor vehicle that passes a person operating a bicycle shall return to an authorized lane of traffic as soon as practicable.

(2) Passing a person operating a bicycle in a no passing zone in violation of ORS 811.420 constitutes prima facie evidence of commission of the offense described in this section, unsafe passing of a person operating a bicycle, if the passing results in injury to or the death of the person operating the bicycle.

(3) The offense described in this section, unsafe passing of a person operating a bicycle, is a Class B traffic violation.

- *814.400 Application of vehicle laws to bicycles.*

(1) Every person riding a bicycle upon a public way is subject to the provisions applicable to and has the same rights and duties as the driver of any other vehicle concerning operating on highways, vehicle equipment and abandoned vehicles, except:

(a) Those provisions which by their very nature can have no application.

(b) When otherwise specifically provided under the vehicle code.

- *814.450 Unlawful load on bicycle; penalty.*

(1)A person commits the offense of having an unlawful load on a bicycle if the person is operating a bicycle and the person carries a package, bundle or article which prevents the person from keeping at least one hand upon the handlebar and having full control at all times.

3.1.2 El Paso, Texas Bicycle Rules of Regulation and Law

In U.S. each state has its own regulation for bicycling. El Paso is under the Texas bicycle regulations. The bicycle regulations depend on the rules of other transportation systems, environmental and existing facilities. These regulations are called “rules of the road’ and are based on the Texas Transportation Code statues. Some of the more important regulations in Texas are:

Texas Transportation Code

- *Sec. 545.107. Method of Giving Hand and Arm Signals*

An operator who is permitted to give a hand and arm signal shall give the signal from the left side of the vehicle as follows:

- to make a left turn signal, extend hand and arm horizontally;
- to make a right turn signal, extend hand and arm upward, except that a bicycle operator may signal from the right side of the vehicle with the hand and arm extended horizontally; and
- to stop or decrease speed, extend hand and arm downward.

- *Sec. 551.101. Rights and Duties*

(a) A person operating a bicycle has the rights and duties applicable to a driver operating a vehicle under this subtitle, unless:

a provision of this chapter alters a right or duty; or

a right or duty applicable to a driver operating a vehicle cannot by its nature apply to a person operating a bicycle.

(b) A parent of a child or a guardian of a ward may not knowingly permit the child or ward to violate this subtitle.

- *Sec. 551.102. General Operation*

(a) A person operating a bicycle shall ride only on or astride a permanent and regular seat attached to the bicycle.

(b) A person may not use a bicycle to carry more persons than the bicycle is designed or equipped to carry.

(c) A person operating a bicycle may not use the bicycle to carry an object that prevents the person from operating the bicycle with at least one hand on the handlebars of the bicycle.

(d) A person operating a bicycle, coaster, sled, or toy vehicle or using roller skates may not attach either the person or the bicycle, coaster, sled, toy vehicle, or roller skates to a streetcar or vehicle on a roadway.

- *551.103. Operation on Roadway*

(a) Except as provided by Subsection (b), a person operating a bicycle on a roadway who is moving slower than the other traffic on the roadway shall ride as near as practicable to the right curb or edge of the roadway, unless:

(1) the person is passing another vehicle moving in the same direction;

(2) the person is preparing to turn left at an intersection or onto a private road or driveway;

(3) a condition on or of the roadway, including a fixed or moving object, parked or moving vehicle, pedestrian, animal, or surface hazard prevents the person from safely riding next to the right curb or edge of the roadway; or

(4) the person is operating a bicycle in an outside lane that is:

(A) less than 14 feet in width and does not have a designated bicycle lane adjacent to that lane; or

(B) too narrow for a bicycle and a motor vehicle to safely travel side by side.

(b) A person operating a bicycle on a one-way roadway with two or more marked traffic lanes may ride as near as practicable to the left curb or edge of the roadway.

(c) Persons operating bicycles on a roadway may ride two abreast. Persons riding two abreast on a laned roadway shall ride in a single lane. Persons riding two abreast may not impede the normal and reasonable flow of traffic on the roadway. Persons may not ride more than two abreast unless they are riding on a part of a roadway set aside for the exclusive operation of bicycles.

(d) Repealed by Acts 2001, 77th Leg., ch. 1085, § 13, eff. Sept. 1, 2001.

Acts 1995, 74th Leg., ch. 165, § 1, eff. Sept. 1, 1995.

Amended by Acts 2001, 77th Leg., ch. 1085, §§ 10, 13, eff. Sept. 1, 2001.

- *Sec. 551.104. Safety Equipment*

(a) A person may not operate a bicycle unless the bicycle is equipped with a brake capable of making a braked wheel skid on dry, level, clean pavement.

(b) A person may not operate a bicycle at nighttime unless the bicycle is equipped with:

(1). A lamp on the front of the bicycle that emits a white light visible from a distance of a least 500 feet in front of the bicycle; and

(2). on the rear of the bicyle:

(A) A red reflector that is:

(i) of a type approved by the department; and

(ii) visible when directly in front of lawful upper beams of motor vehicle headlamps from all distances from 50 to 300 feet to the rear of the bicycle; or

(B) lamp that emits a red light visible from a distance of 500 feet to the rear of the bicycle.

(C) In addition to the reflector required by Subsection (b), a person operating a bicycle at nighttime may use a lamp on the rear of the bicycle that emits a red light visible from a distance of 500 feet to the rear of the bicycle.

- *Sec. 551.105. Competitive Racing*

(a) In this section, "bicycle" means a non-motorized vehicle propelled by human power.

(b) A sponsoring organization may hold a competitive bicycle race on a public road only with the approval of the appropriate local law enforcement agencies.

(c) The local law enforcement agencies and the sponsoring organization may agree on safety regulations governing the movement of bicycles during a competitive race or during training for a competitive race, including the permission for bicycle operators to ride abreast.

Texas Driver’s Handbook is a book used to instruct drivers the driving laws and regulations in Texas. The Texas Department of Public Safety is in charge of the publication and updates of this handbook. The following regulations are in a section for bicyclist in this handbook:

Do:

1. A bicyclist should always obey all traffic laws, signs, and signals. Never ride opposite the flow of traffic. Stop at all stop signs and stop at red lights.
2. A person operating a bicycle on a one-way road with two or more marked traffic lanes may ride as near as possible to the left curb or edge of the road.
3. Individuals who are riding two abreast shall not impede the normal reasonable flow of traffic on the road. Individuals riding two abreast on a “laned” road must ride in a single lane.
4. Bicyclists may ride on the shoulder of the road.
5. Bicyclists may signal a right turn using either their left arm pointing up or their right arm pointed horizontally.
6. A person operating a bicycle on a road moving slower than the other traffic shall ride as near as possible to the right curb or edge of the road unless:
   a) The person is overtaking and passing another vehicle proceeding in the same direction;
   b) The person is preparing for a left turn at an intersection or onto a private road or driveway;
   c) There are unsafe conditions in the road such as fixed or moving objects, parked or moving vehicles, pedestrians, animals, potholes, or debris; or
   d) The person operating a bicycle in an outside lane that is:

- Less than 14 feet in width and doesn’t have a designated bicycle lane adjacent to that lane; or
- The lane is too narrow for a bicycle and a motor vehicle to safely travel side by side.

Don’t:

1. No bicycle shall be used to carry more than the number of individuals it is designated or equipped for.
2. No person riding a bicycle shall attach the same or himself to a streetcar or vehicle upon a road.
3. No person operating a bicycle shall carry any package, bundle, or article which prevents him/her from keeping at least one hand on the handlebars.
4. Only ride upon or astride a permanent and regular seat.

Bicycles Must Be Properly Equipped

1. Every bicycle shall be equipped with a brake which will enable the operator to make the braked wheels skid on dry, level, clean pavement.
2. Hearing-impaired bicycle riders may display a safety flag.
3. Every bicycle in use at nighttime shall be equipped with:
   a) A lamp on the front which emits a white light visible at a distance of at least 500 feet to the front of the bicycle;
   b) A red, DPS-approved reflector on the rear must be visible from distances of 50 feet to 300 feet. (A red light on the rear visible from a distance of 500 feet may be used in addition to the red reflector.)

Bicycle Safety Guidelines

1. It is highly suggested bicycle riders wear an approved bicycle helmet.
2. When riding on pedestrian facilities, reduce speed and exercise caution.
3. Do not weave in and out of parked cars.

4. Move off the street to stop, park, or make repairs to your bicycle.
5. A bicyclist should select a route according to the person's own bicycling skill and experience.
6. It is not required by law but bicycles should be equipped with a mirror.

Accordingly the Texas Transportation code and Texas Driver's Handbook bicycle in a vehicle, as a result person who rides on a bicycle has the same rights and obligations that motor vehicle. This includes penalties for violating or ignores traffic laws. The violation of these laws affects the driver record; do not matter if the person rides on bicycle or motor vehicle.

3.1.3 Vehicle Design

Safety is one of the most important considerations for bicycle transportation system to improve in the bicycle facilities. Safety is very important bicyclist. Seeking the safe interaction between bicyclist and motor vehicle drivers is the main purpose of the implementation of law and the design of facilities.

Adults are the more stable and safer riders than children and seniors. An adult has the ability change the velocity and apply brakes faster than children and seniors. They can predict the traffic flow and behavior of the motorized vehicles better and take an action to prevent an accident. Adults have the knowledge of traffic rules because they are already familiar with riding in mixed traffic. Meanwhile, seniors usually ride in a slower speed but have longer reaction time. Finally children have the highest risk, as they have slower reaction time to adverse a risky situation, and they do not understand the danger and consequences.

Designers for bicycle transportation facilities have to consider many factors that may affect the integrity of the bicyclist. The variety of bicycle style and size create the need of standards for facility design. In U.S., AASTHO has design dimension for bicyclist and other non-motorized users (AASHTO 2010). **Figure 3.1** shows the critical dimension for adult bicyclists. These dimensions are based on the most critical case, taking into account speed, wind, rain and topographic changes. According to these dimensions, the designer can develop a bicycle facility in different situations like curb, tunnels, and parked cars streets.

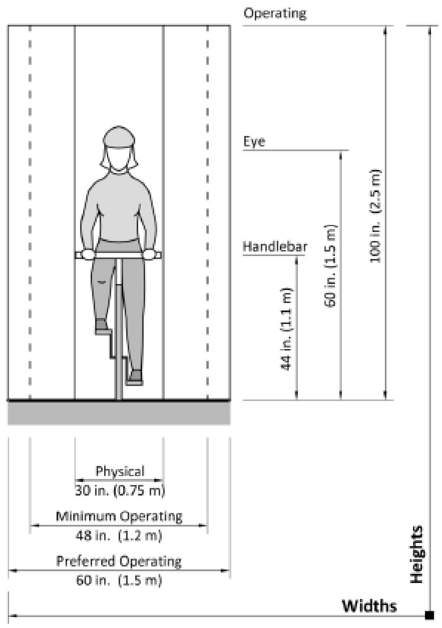


Figure 3.1: Bicyclist Operating Space.
Source: (AASHTO, 2010)

In **Figure 3.2,** the most common dimensions for typical bicycles and accessories are showed.

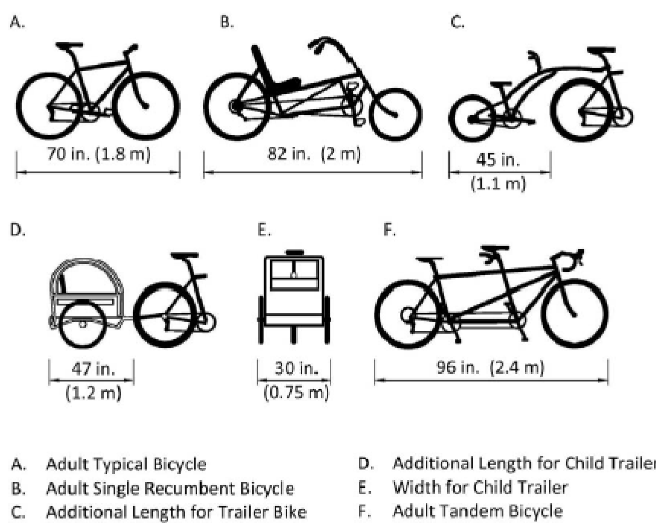


Figure 3.2: Typical Bicycle Dimensions.
Source: (AASHTO, 2010)

Table 3.1 shows the general key performance criteria established by AASHTO.

Table 3.1: Key Performance Criteria.

Bicyclist Type	Feature	Value	
		US Customary	Metric
Typical upright adult bicyclist	Speed, paved level terrain	8-15 mph	13-24 km/h
	Speed, downhill	20-30 plus mph	32-50 plus km/h
	Speed, uphill	5-12 mph	8-19 km/h
	Perception reaction time	1.0-2.5 s	1.0-2.5 s
	Acceleration rate	1.5-5.0 ft/s 2	0.5-1.5 m/s 2
	Coefficient of friction for braking, dry level pavement	0.32	0.32
	Coefficient of friction for braking, wet level pavement	0.16	0.16
	Deceleration rate (dry level pavement)	8.0-10.0 ft/s 2	2.4-3.0 m/s 2
	Deceleration rate for wet conditions (50-80% reduction in efficiency)	2.0-5.0 ft/s 2	0.6-1.5 m/s 2
Recumbent bicyclist	Speed, level terrain	11-18 mph	18-29 km/h
	Acceleration rate	3.0-6.0 ft/s 2	1.0-1.8 m/s 2
	Deceleration rate	10.0-13.0 ft/s 2	3.0-4.0 m/s 2

Source: (AASHTO, 2010)

3.1.4 Riding Bicycle in Mixed Traffic

Riding in mixing traffic is one of the most important issues for people that use the bicycle as transportation mode. Ridding in mixed the traffic implies that the bicyclist must follow the traffic laws as other motor vehicles.

The safest way to ride a bicycle in traffic mix is going with the traffic flow in the same direction. This way the bicyclists have close to five times fewer accidents with other vehicles, (Foster 1985). The actions of the bicyclist are more predictable for motor vehicle drives if the bicyclist follow the traffic flow direction. This way the motor vehicle drivers consider the bicycle as another vehicle on the road. In **Figure 3.3,** the driver of the blue car is not aware of the bicyclist because the bicyclist is travelling on his/her right, in the opposing flow direction. Moreover, the time-to-collision is reduced if the bicycle rides on the other side (right hand side) of the street. By keeping the bicyclist in the right hand side of the roadway, the motor vehicle's driver has three times the reaction time.

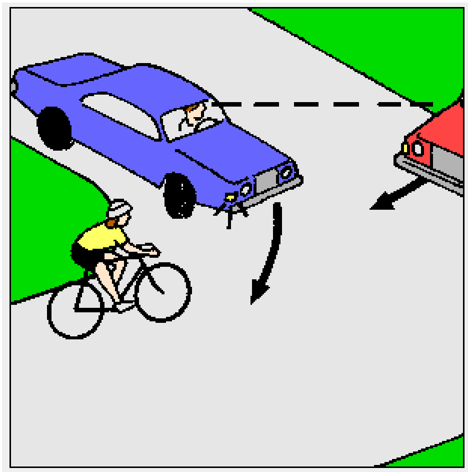


Figure 3.3: Intersection collision, the most common type caused by wrong-way riding.
Source: (Allen, 2010)

The most common cause of accidents that involve just bicycles is hazards in the front of the bicycle. Bicyclists have to train their eyes to scan the road ahead, blind spots and the traffic. Bicyclist should ride far enough from the edge of curb or travel to avoid the risk from blind spots from parked cars. Moreover, the parked cars can be potential risk for the bicyclist, as open door is a frequent and unpredictable obstacles.

Roads where there are parked cars or other kind of visible obstruction around 3 feet width from the sidewalk is a potential risk for bicycle. As the bicycle approaches the intersection, motorized vehicles that are integrated with the traffic flow will not be able to see the bicyclist. In this case the bicyclist should be even farther from the edge of the road. The **Figure 3.4** shows the correct and incorrect technique to avoid this situation.

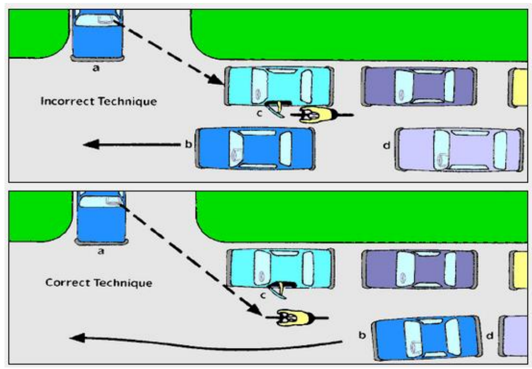


Figure 3.4: Riding in a safe distance from roadside hazard increase the bicyclist safety.
Source: (Allen, 2010)

One of the most common errors in bicyclist is riding in and out between parked vehicles. As Shown in **Figure 3.5**, when the bicyclist rides in between the space between two parked vehicles the vehicles that is approaching from behind losses the visibility of the bicyclist until the bicyclist merges back to the travel lane.

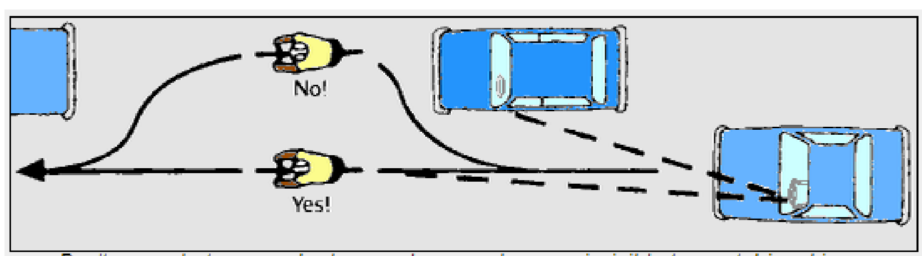


Figure 3.5: Do not weave between parked cars, bicyclist becomes invisible to overtaking drivers.
Source: (Allen, 2010)

Right turn with extra wide lanes is the cause of many accidents between a motorized vehicle and a bicycle in U.S. **Figure 3.6** shows the correct and incorrect right turns. The safer way for the bicyclist to turn right is to keep straight until the edge of intersection is reached, then the turn can be made in a safe way. On the other hand if the bicyclist keeps riding too close to the curb, the vehicle at the moment of the turn may hit the bicyclist.

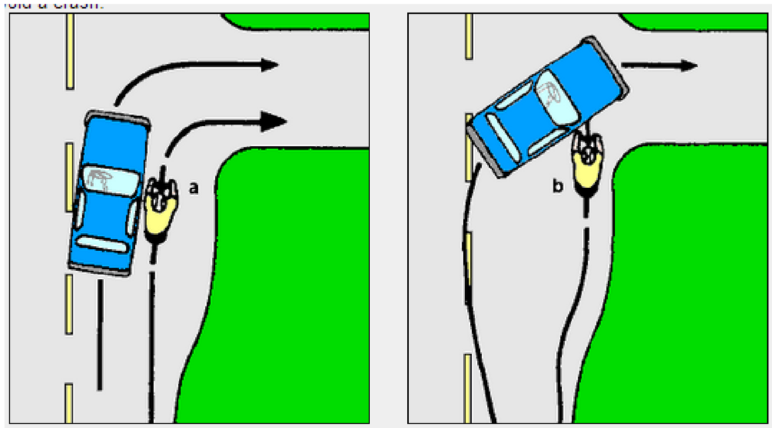


Figure 3.6: Correct and incorrect way to turn right next to motor vehicles
Source: (Allen, 2010)

Safety in a two-lane undivided highway (one lane per direction) without a wide shoulder is a very important issue. This type of road mostly has low traffic volume. The problem occurs when a vehicle is attempting to overtake another vehicle. During part of the overtaking maneuver, the overtaking vehicle occupies the opposing lane. As shown in **Figure 3.7**, an approaching bicyclist is facing the overtaking vehicle, both in the same lane but traveling in the opposite directions, which is a potential head on collision.

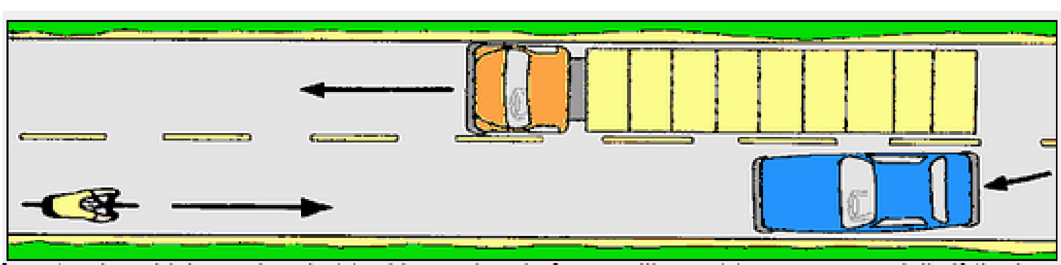


Figure 3.7: Passing cars are a potential danger for bicyclist in narrow two lane roads.
Source: (Allen, 2010)

In many cases, safety of the bicyclist in mixed traffic is related to the relative speed between the bicycle and motorized vehicles. Usually motorized vehicles are faster than bicycles, but in some cases like downhill or in congested traffic bicycle speed is near or higher than motor vehicles. In these cases, the recommendation is for the bicycle to stay in the middle of the right lane (as in **Figure 3.8**). In this way bicycle represent another vehicle and is more visible. If the bicyclist keeps to the right side of the motorized vehicle in higher speed, it is more difficult for the bicyclist to maintain the control of the bicycle. **Figure 3.8** represents the recommended bicyclist behavior in high speed section.

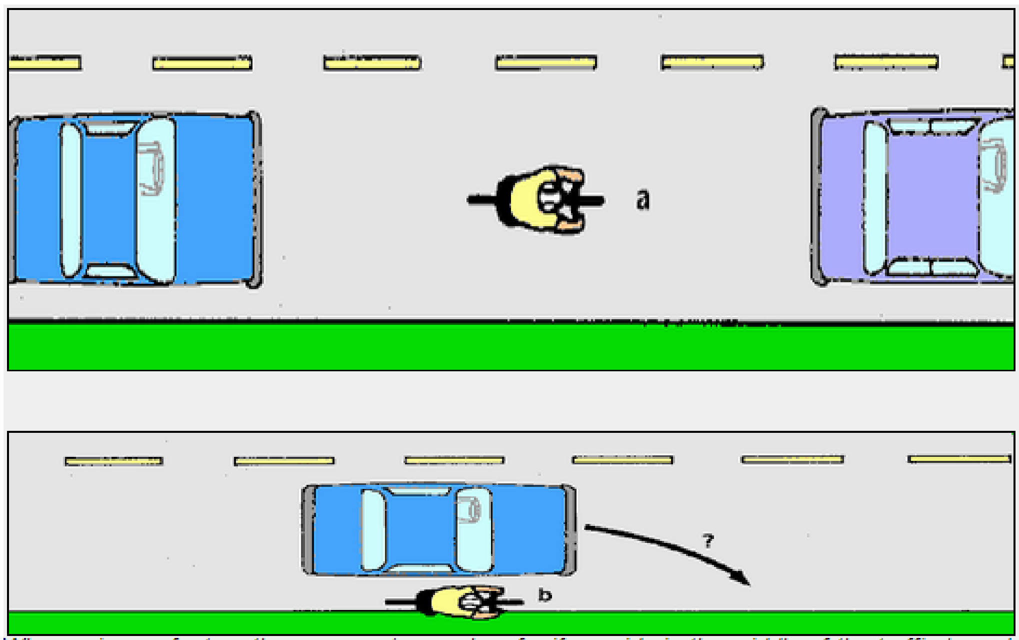


Figure 3.8: High speed riding on mix traffic
Source: (Allen, 2010)

One of the most controversial issues about riding bicycle in mixed traffic is turning left at an intersection. Many crashes that involve bicycles are the result of ignorance of the correct procedures by motor vehicle drivers to drive next to a bicyclist and the incorrect left turns by bicyclists. There are two valid options to make left turns: (i) “motor vehicle style” - when the bicyclist makes left turn from the left side of the right half of the approach or from the right-most left turn lane, (ii) “pedestrian style” - when bicyclist travels in the right-most through lane across the intersection, stops at the corner in the crosswalk, then makes a 90 degree turn **Figure 3.9** shows graphically the two proper ways for a bicycle to turn left at an intersection.

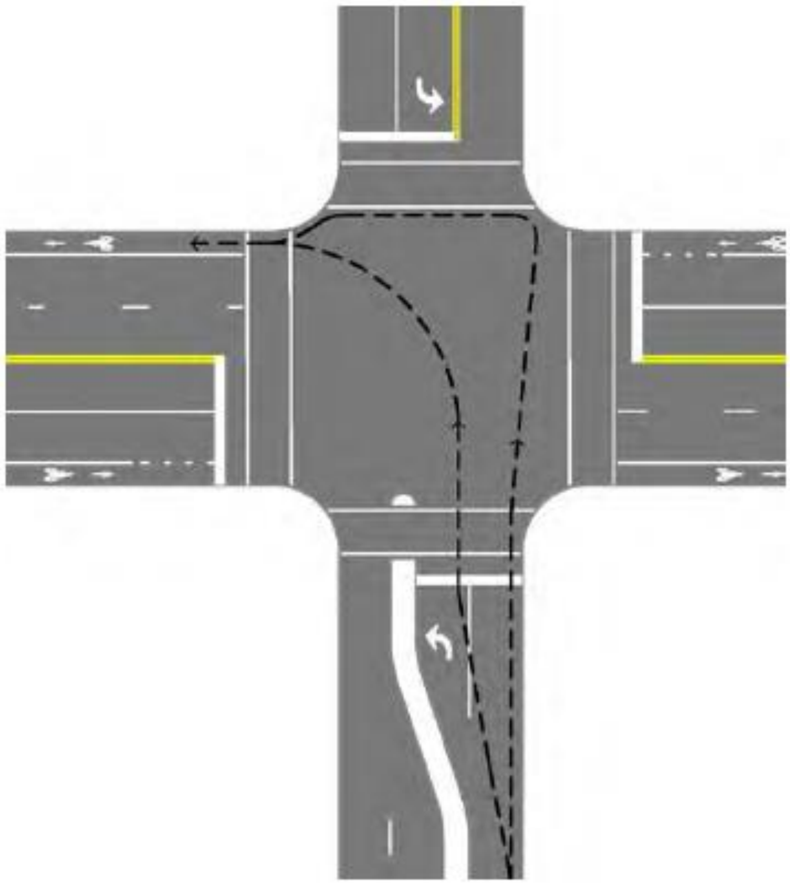


Figure 3.9: A Bicyclist's Two Options for Turning Left at an Intersection
Source: (AASHTO, 2010)

3.2 Rules of Regulations of EU, Czech Republic and Prague

Safety is a factor can modify the amount of bicyclists on roads. For this reason, agencies in the Czech Republic have been working in safety related issues (Ministerstvo dopravy a spojů, Český Publisher Normalizační Institut). One of the important action to enforce bicycle safety is the laws and regulations between bicycles and the other transportation modes.

3.2.1 Prague, Czech Republic Bicycle Rules of Regulation and Law

One of the most effective way to improve safety of bicyclist on the roads is the creation of rules and regulations that regulate the behavior of bicyclists and motor vehicle drivers. In the Portál hlavního města Prahy (portal of Prague, 2006) there are basic rules of operation of bicycle accordingly to Czech Law (no. 361/2000 coll.), the most significant are:

§ 3 Basic Condition for participation in road

(1) Road traffic will not participate in person, which would be due to age or reduced physical or mental capacity could jeopardize the safety of the operation. This does not apply if the person himself or another person has taken such measures that endanger the safety of road no. (2) to drive or ride on animal can only entity that is enough physically and mentally to driving or riding on an animal and to the extent needed controls driving or riding on an animal and regulations on road traffic.

§ 4 Obligations of participants

When participating in road**,** everybody is obliged a) behave considerately and discipline to act to endanger life, health or property of others or his own that does not harm the environment or endanger the life of animals, their behavior is obliged to adapt especially construction and technical traffic road conditions, weather conditions, traffic situation on the road, their abilities and their state of health, b) follow the rules of road traffic governed by this Act, the police instructions, guidelines persons authorized to drive on the road and stopping vehicles and guidance of persons on whom it provides specific legal prescription issued to ensure the safety and flow of traffic on the road, c) follow the light, or even accompanying acoustic signals, traffic signs, transport facilities and equipment for traffic information.

§ 23 Entering on the road

(1) When entering from a location outside the road on the road the driver must give right of way to vehicles or drivers for animals traveling on a road or organized body of pedestrians or wizards driven animals and animals going out on the road. This also applies when entering purpose of the road or the trail for cyclists or pedestrians or residential zone to another road.

§ 53 Walking

(1) A pedestrian must use primarily sidewalk or pedestrian paths. Pedestrian, who bears the subject, which could endanger the operation of the sidewalk, enjoys the right shoulder or right edge of the road. (2) The parties to the road than pedestrians must sidewalk or pedestrian paths taken, unless this Act stipulates otherwise. (3) Where there is no sidewalk or if it is infeasible, go to the left side of the road, and where there is no shoulder or if it is infeasible, go as close as possible at the left side of the road. Pedestrians are allowed to walk on the shoulder or at the edge of the road more than two abreast. In reduced visibility, increased traffic on roads or in dangerous and confusing sections may go by pedestrians only for him. (4) If the established trail for cyclists and pedestrians road sign marked "trail for pedestrians and cyclists" (C9), not Walker endanger a cyclist traveling along the trail. (5) If the established route for pedestrians and cyclists marked traffic sign "Trail for walkers and cyclists", which is separated lane for pedestrians and bicycle lanes (C10), is obliged to use the pedestrian only lane marked for pedestrians. Lane marked for pedestrian cyclists can enjoy only when circumvention, entering and leaving the trail for pedestrians and cyclists; must not endanger cyclists ride in the lane marked for cyclists. (6) A person moving through a manual or motorized wheelchair not on the sidewalk or path for pedestrians endanger other pedestrians. If he cannot use the sidewalk, may enjoy the right shoulder or right edge of the road. (7) The person leading bicycle or moped

may use the sidewalk, just do not endanger other pedestrians; otherwise they shall enjoy the right shoulder or right edge of the road.(8) A person moving skiing, rollerblading or similar sports equipment not on the sidewalk or path for pedestrians endanger other pedestrians.

§ 57 bicycling

(1) If the established lane for cyclists, bicycleway or if it is at the junction with controlled traffic lane for cyclists established and defined space for cyclists, cyclist is required to enjoy.

(2) On the road with a bicycle ride on the right side of the road; if they are not threatened or impeded by pedestrians, they may go to the right side of the road. Driving around in terms of road means and scooter.

(3) Cyclists may ride only one at a time.

(4) If the subject moves slowly or when the vehicle stands behind the right edge of the road, the cyclist traveling in the same direction the vehicle to overtake or go round the right hand side along the right edge of the roadway or shoulder of the road if it is the right of the vehicle enough space; It is required to take extra care.

(5) If the established trail for cyclists and pedestrians road sign marked "trail for pedestrians and cyclists", not cyclist endanger pedestrians walking on the trail.

(6) If the established trail for cyclists and pedestrians road sign marked "trail for pedestrians and cyclists", which is separated lane for pedestrians and bicycle lanes, cyclist is obliged to use only lane marked for cyclists. Lane marked for pedestrian cyclist can enjoy only in passing, overtaking, turning, turning and braking on the approach to the path for pedestrians and cyclists; must not endanger pedestrians going in the lane marked for pedestrians.

(7) Lanes for cyclists or bicycle path can also enjoy a person moving on skis or rollerblades or similar sports equipment. In doing so, the person is obliged to follow the rules under paragraphs 3, 5 and 6 and light signals according to § 73rd.

(8) Before entering the crossing for cyclists, the cyclist must make sure that if can cross the road without endangering themselves and other road users on the road, the cyclist may pass over the road only if given the distance and speed of approaching vehicles will not force their driver to change direction or speed of travel. On crossing for cyclists to ride on the right.

§58

(1) A cyclist under the age of 18 years is required for drive use a helmet type approved under a special law and have it mounted and properly attached to the head.

(2) A child under 10 years is allowed on the road, local road and public utility road to ride a bicycle under the supervision of a person over 15 years; it does not apply to ride on the sidewalk, bike path and in the residential and pedestrian zone.

(3) To single bicycle is not allowed to ride in two; however, if the bicycle is equipped with a seat for transporting children and fixed footrest, may a person older than 15 years carry a person under the age of 7 years.

(4) A bicyclist may not ride without holding the handlebars, stick with another vehicle, and keep driving the second bike, hand truck, dog or other animal and carry objects that would hinder bicycle steering or endanger other road users on roads. When driving must have a cyclist feet on pedals.

(5) A bicyclist is required in poor visibility while driving have lit the lamp with a white light shining forward and rear lamp with light red or flashing red light. If the roadway is sufficiently and continuously illuminated, the cyclist can be substituted for white headlight flashlight with flashing light.

(6) The bicycle may be connected trailer which is not wider than 800 mm, it has at the rear two red reflectors triangular shape located closest to the lateral contours of the truck and is associated with a bicycle fixed coupling device. Covers If the trailer or its cargo in

poor visibility rear position light red bicycle trailer must be fitted at the rear left red glare-free light.

Ministerstvo dopravy a spojů (Ministry of Transport and Communications) has important law and regulation for bicyclist on the road, some of the most important are:

Bicycles must be equipped with:

a) Two independent effective brakes with control braking effect; Bicycles for children of preschool age freewheel hub equipped with a coaster brake need not be fitted with front brake.
b) The free ends of the handlebar tube must be securely plugged (plugs, handles, etc.).
c) Termination control levers brake and the handlebar risers must have either edge wrapped energy-dissipating material, or (when used with solid materials) have edges with a radius of curvature less than 3.2 mm; derailleur lever, thumb screws, clamps the wheel hubs, brackets, and the mudguard must be either wrapped edge energy-dissipating material, or (if used rigid materials) must have edges with a radius of less than 3.2 mm in one plane and the second plane perpendicular to it at least 2 mm.
d) Nut wheel hubs, if not winged, quick or in combination with end cover charge, must be closed.
e) Red rear reflector , the reflector can be combined with a red rear lamp or replaced with reflective materials similar characteristics; reflecting surface shall not be less than 2000 mm^2 , with an inscribed quadrilateral must have one side at least 40 mm, the device must be firmly placed in the median longitudinal plane of the bicycle or on the left side closest to her at the height of 250 to 900 mm above the ground plane ; illuminating surface must be perpendicular to the road surface within a tolerance of +/- 15° and perpendicular to the median longitudinal plane of the bicycle with a tolerance of +/- 5°; reflective materials replacing rear reflector can be placed on clothing or footwear cyclists.

f) White front reflector , the reflector can be replaced with reflective materials with similar characteristics; reflector must be placed in the median longitudinal plane of the surface of the tire of the front wheel stationary bikes; reflecting surface shall not be less than 2000 mm^2 , with an inscribed quadrilateral must have one side at least 40 mm illuminating surface must be perpendicular to the plane of the road with a tolerance of +/- 15° and perpendicular to the longitudinal center plane of the bicycle with a tolerance of + / - 5°; reflective materials to replace the reflector can be placed on clothing or footwear cyclists.

g) Reflective orange on both sides of pedals, the retro-reflectors can be replaced with light-reflecting materials placed in shoes or in their vicinity.

h) On the rays front or rear wheel or both wheels of at least one side reflector orange on each side of the wheel; reflecting surface shall not be less than 2000 mm^2, with an inscribed quadrilateral must have one side at least 20 mm, the retro-reflectors can be replaced with reflective material on the sides of the wheel or on the sides of the tire casing or at the ends of the bumpers and side parts of the garment cyclists.

Bicycles for driving in poor visibility must be fitted with the following lighting and light-signaling devices:

a) Searchlight shining white light forward; headlamp must be aligned and adjusted continuously so that the reference axis of the light flux intersect the ground plane at a distance of 20 m far from the lamp, and that this adjustment could spontaneously or unintentional interference with the driver change, if the roadway is sufficiently and continuously lit, the lamp can be replaced lamp white color with flashing light

b) Rear lamp red, the conditions for the location of this lamp are identical to those for positioning and fixing of rear reflectors under paragraph 1. e); rear red lamp may be combined with a rear red reflector under paragraph 1. e); rear red lamp can be replaced with the lamp flashing red light.

c) A source of electricity if it is a source of the supply of energy, its capacity must ensure intensity of the lights referred to in points a) and b) for at least 1.5 hours without interruption.

1. Light gear bicycle is not considered equipment within the meaning of § 32 of Act no. 361/2000 Coll.
2. If the bicycle is equipped with a seat for the transportation of the child, the seat must be firmly secured and equipped with strong supports for the child's feet. The seat and the support must be provided and located so as to prevent injury to the child when driving or endangering the safety of driving. If the bicycle is equipped with luggage rack, the rack must be properly and securely attached and shall not affect driving safety.
3. Tires and rims shall not exhibit cracks, cracks and other obvious distortion which would clearly interfere with safe driving.
4. Bicycles put on the market after 1 January 2003 must have an easily accessible location frame durably marked clearly legible serial number or be equipped with it reliably replaces them. For reliable serial number replacing equipment in this case is considered, for example, and electronic media such information, which will be firmly connected to the bicycle frame.
5. Bicycles put on the market after 1 January 2003, unless they are equipped in accordance with Art. 2 of this Annex, ie. For driving in poor visibility, must be provided with clear and prominent warning in the instructions that the wheels are not in the state of equipment eligible to traffic in reduced visibility.
6. Bicycling can be additionally equipped with an auxiliary motor, if:
   a) Will continue to preserve the original character of the bike (according to Art. 1, 2).
   b) Auxiliary motor will adequately fulfill the conditions of § 19 of the Act.

c) Its power does not exceed 1 kW.

d) In the case of the internal combustion engine will have an engine capacity roller (s) greater than 50 cm3.

e) The maximum design speed of not more than 25 km/h.

f) Installation of the propulsion system (engine, fuel tank and battery) on the bike will not require intervention on its supporting parts.

g) If the vehicle meets all the above requirements shall be deemed for the purposes of this ordinance continues a bicycle.

7. For the purposes of this Decree shall be understood to include bicycle and tricycle, as well as multi-seat bicycles (example tandems) and other such vehicles propelled by human power, and also intended for use on the road, such as. Scooters.

3.2.1 Vehicle Design and Safety

In Prague there are many factors to take into consideration when designing an adequate bicycle infrastructure to ensure bicycle safety. In Czech Republic, the dimension of bicyclists is one of the first consideration. This is according to the many styles and sizes of bicycles and bicyclists. **Figure 3.10** shows the dimension for bicyclists. The free height for bicyclist is 2.5 m, meanwhile the widths can vary from 1.0 m (at less than 6% of gradient) to 1.5 m in critical dimensions. The designers can move between these values depending on the conditions of the road. Some factors that can affect the width are gradient, curb, surface material, amount of traffic, among other factors.

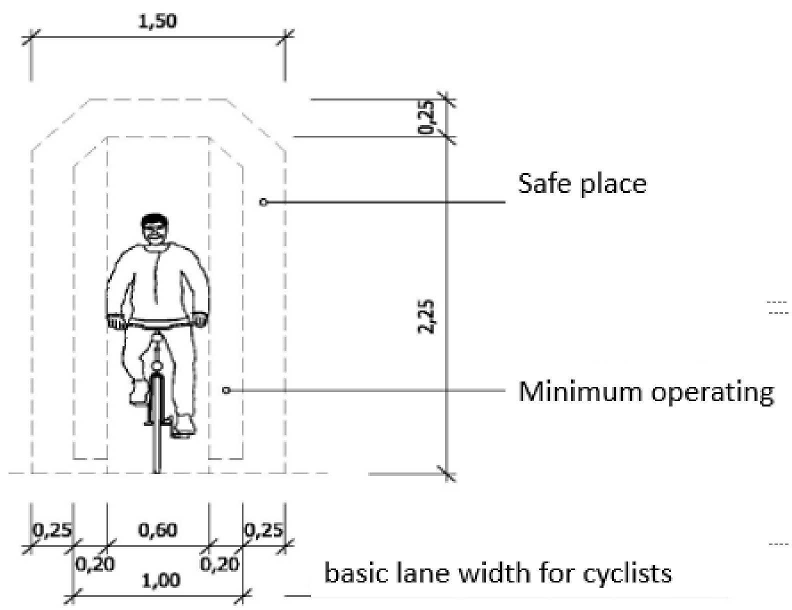


Figure 3.10: Bicyclist Operating Space.
Source: (EDIP)

Table 3.2 shows the general key performance criteria established for bicycle infrastructure design.

Table 3.2: Design speed, internal radio and External expansion for design.

Design Speed	Internal radio	External expansion
10 km/h	2,50 m	0,50 m
15 km/h	4,50 m	0,50 m
20 km/h	8,00 m	0,50 m
25 km/h	14,00 m	0,25 m
30 km/h	22,00 m	-

Source: (EDIP)

3.2.2 Riding Bicycle in Mixed Traffic

In roads where bicycles and motor vehicles have to share the lanes, one of the main conflicts are in overtaking cases. Overtaking is permitted in lanes with width of more than 3.75 m. However, in lanes with width less than 3.0 m, passing is prohibited. In cases where overtaking involving a bus, the lane should have a minimum width of 4.25 m.

If the bicycle lane is on the right side of the right motor vehicles lanes, the minimum width of the bicycle lane is 1.0 m and there should be 0.25 m that separates the bicycle lane and the sidewalk and 0.25 m that separate bicycle lane and the motor vehicle lanes. **Figure 3.11** shows the real representation of the bicycle lane.

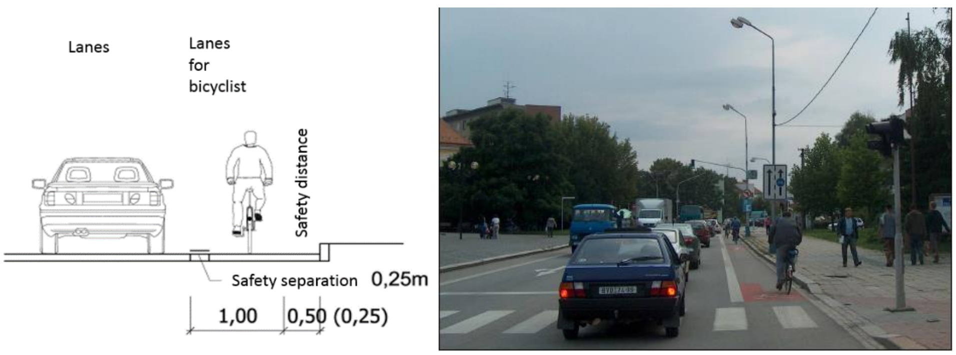


Figure 3.11: Typical bicycle lane in Prague.
Source: (EDIP)

In some cases, the bicycle lane is shared with bus (tram) stops. **Figure 3.12** shows a shared lane between bicycles and buses. In this case when a bus is occupying the bus stop, bicyclists have two options to proceed:

- Move into the next motor vehicle lane with caution and keep on the right side of the lane.
- Stop and wait for the bus to continue its movement.

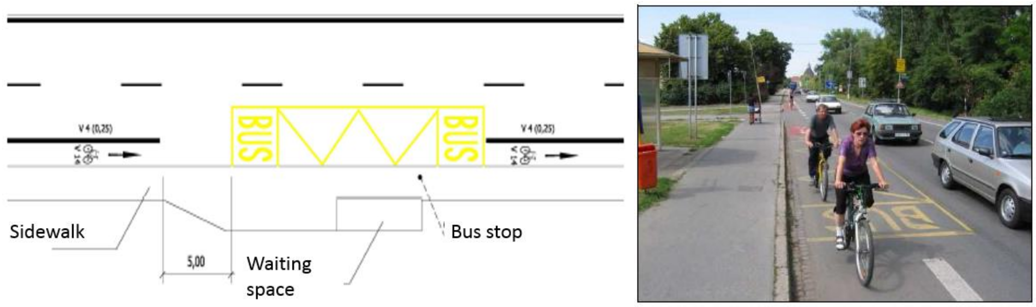


Figure 3.12: Bus+cyklopruh (bus+cycle lane).
Source: (EDIP)

Another issue with bus stops is when the stops are next to the bicycle lane on the right side. In this case, the bus in the bus stop should yield to bicyclist. **Figure 3.13** shows the real case.

Figure 3.13: Bicycle lane with bus stop at right side.
Source: (EDIP)

In Prague, in many cases the bicycle lanes are combined with pedestrian sidewalk. This is common in streets with high traffic volume. In this case the width of the bicycle lane is 1.0 mwhen the bicycle flow is bidirectional, the width increases to 2.0 m (1.0 m per direction). In both cases the lane should have a clearance of 0.25 m on both sides. **Figure 3.14** is a real representation for the combined bicycle/pedestrian shared path.

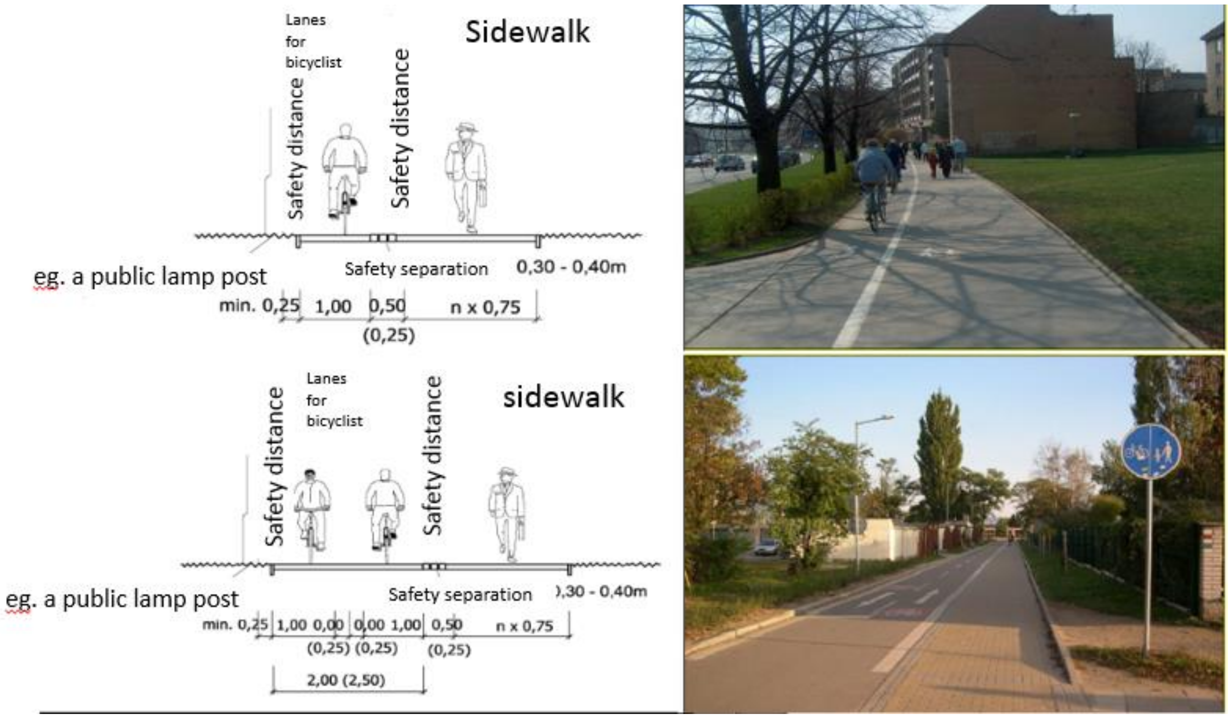


Figure 3.14: Bicyclist-pedestrians relationship.
Source: (EDIP)

Stop box is a space designated for bicycles that are waiting for a green light at an intersection, this way the bicyclist is waiting in front of the motor vehicle traffic. Stop box has two main purposes, the first one is for bicyclist to avoid inhaling CO_2 emissions from cars and the second one is to reduce the risk of crashes cars. **Figure 3.15** shows a real stop box.

Figure 3.15: Bicycle box stop.
Source: (Praha, 2010)

One of the most important and controversial issues for bicyclist is left turn at intersection. This specific case has many problems between motor vehicles and bicyclists. In Czech Republic, there are two safe ways to turn left without a bicycle path. In the first one, the bicycle has to move into the left most lane and turn like motor vehicles. In the second way, the bicyclist should go straight and wait for the perpendicular light to cross with the traffic flow in the cross street. **Figure 3.16** shows both movements.

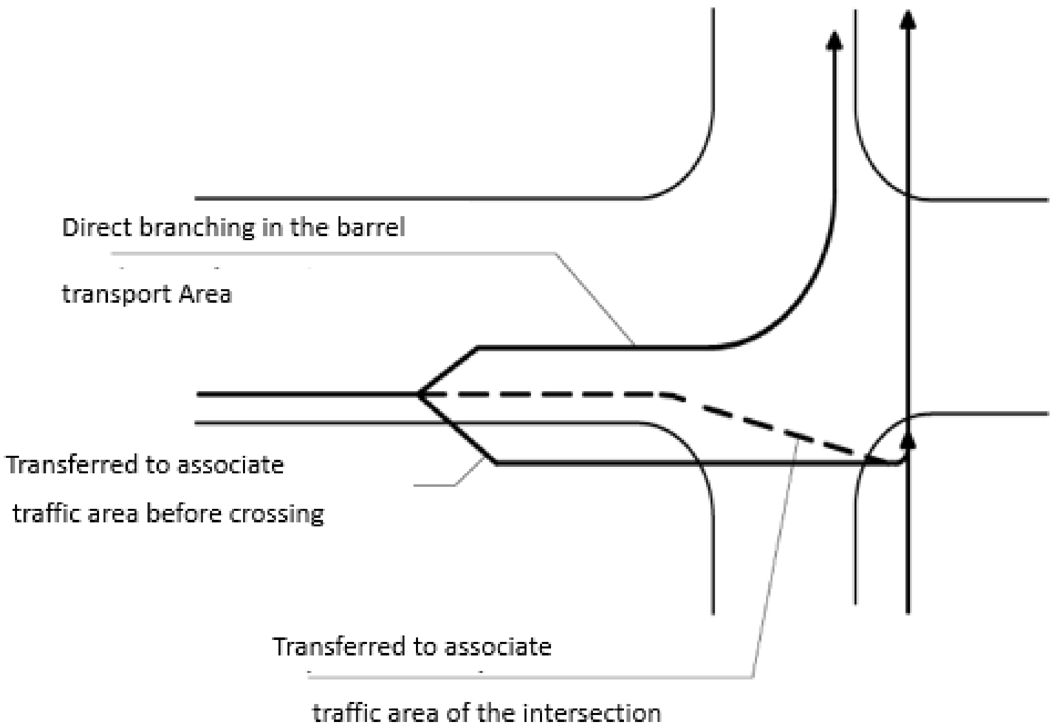


Figure 3.16: A Bicyclist's Two Options for Turning Left at an Intersection.
Source: (EDIP)

Český Publisher Normalizační Institut (ČSN), (Czech Standards Institute, in English) has some rules for bicyclists that ride on road with motor vehicles:

- Bicyclist should ride on the right side of the right lane or on the right shoulder of the street in the direction of the motor vehicles traffic flow.
- At an intersection, bicyclists should reduce the speed at 20 m upstream of the intersection and give hand signal before making a turn.
- In bridges, tunnels, or highways if there is no bicycle lane, bicyclist should ride with the pedestrians at the sidewalk.
- When crossing train tracks, bicyclist should pass in an angle of 60 to 90 degrees to avoid potential fall, and always yield to the passing train.

3.3 Comparison

In El Paso as Prague many governmental agencies and departments support the restoration, maintenance and creation of new bicycles facilities. Metropolitan Planning Organization, Department of Transportation and Police Department are in the head of this situation in El Paso, meanwhile Policejní Prezidium České Republiky, Dopravní Podnik and Český Publisher Normalizační Institut in Prague.

In both cities, safety is one of the most important issues about bicyclist, for that reason there are laws and rules that regulate the interaction of bicycles and motor vehicles in roads. In both cities bicycle has the preferential pass in intersections when bicyclist ride straight, but in case that motor vehicles and bicycles go in the same direction, bicycle is considerate as a vehicle and has the same rights in road. To keep safety for bicyclists designers use the most critical values in both cities, although there are little differences follow the same concept. As the same in cycle box, in Prague already are many bicycle box in intersections, El Paso is on the proses to adopt this idea and implement in the city infrastructure.

But there are difference between these cities. In El Paso nowadays the government is obligated to take in account the bicycle and pedestrian's needs. Also there are many initiatives and programs to promote the bicycle use. One of the main difference is than in El Paso designers try to maintain separate the bicycles from motor vehicles and pedestrians, in this way all of them can be safer. Meanwhile in Czech Republic in many cases are bicycle infrastructure in sidewalks, this way pedestrians and bicyclist has more contact.

In Prague is on the way to avoid passenger's cars as a result of many problems with private vehicles as parking, and interaction with public transportation in main streets. Prague designers has a point of interest, passing motor vehicles over bicycles is a difficult topic as consequence of narrow streets in Czech Republic. One point to highlight is the existence of many railways in Prague, this obligate to designers to considerate the direction and intersection with bicycle infrastructure.

El Paso and Prague are in process to improve the bicycle infrastructure to motivate and increment the use of this transportation mode. There are many differences in the process, but this is accordingly the actual situation off the city.

Chapter 4: Geometric Design of Bicycle Facilities

4.1 Design Guidelines of U.S., Texas and El Paso

Design is an important stage of implementing a bicycle transportation system. In this stage, facilities, scope, maintenance and the functionality are the main factors to taking into account. In U.S., there is a hierarchical order in the counties, states and national laws. El Paso should satisfy the minimum requirements established by Texas and U.S. Accordingly, there are criteria and guidelines for the design of the bicycle transportation facilities. In general, the design criteria establish the minimum requirements needed to design a functional transportation infrastructure. On the other hand design guidelines determine the process to design, in other words; how, what and why use the tools to design. El Paso has its own design method based on the data and tools available.

Markings on the road are very important tool to maintain the safety ride of bicyclist. Markings means the space designated for bicycle flow, where bicycles are the main traffic and have the preferential passing over motor vehicles or pedestrians. Markings in the road solve many problems in conflict zones give to bicycles the preferential passing in traffic flow, in turns or intersections. In bicycle lanes, the most common marking is a white bicycle to inform other vehicles and pedestrians that bicycle pass in that line. In many cases this marking is accompanied with direction mark.

4.1.1 Design Criteria

The importance of design criteria is to give enough effective tools for the design of the bicycle transportation infrastructure. These tools should satisfy the minimum requirements for the law without sacrificing the user needs. The design criterion involves cover signs, pavement markings, maintenance of these for the use of motor vehicles and bicycles in roadways and shared use paths.

In the first instance the bicycle signs have shape, legend and color in standard design. But the lateral sign clearance has minimum and maximum values from the near edge of the path to the edge of the sign. On shared use paths, the minimum value is 0.9 m (3 ft) while the maximum value is 1.8 m (6 ft). On the other hand the height also has minimum and maximum values. These are 1.2 m (4 ft) and 1.5 (5 ft) respectively from the bottom of the sign. **Figure 4.1** shows the sign placement on shared use paths.

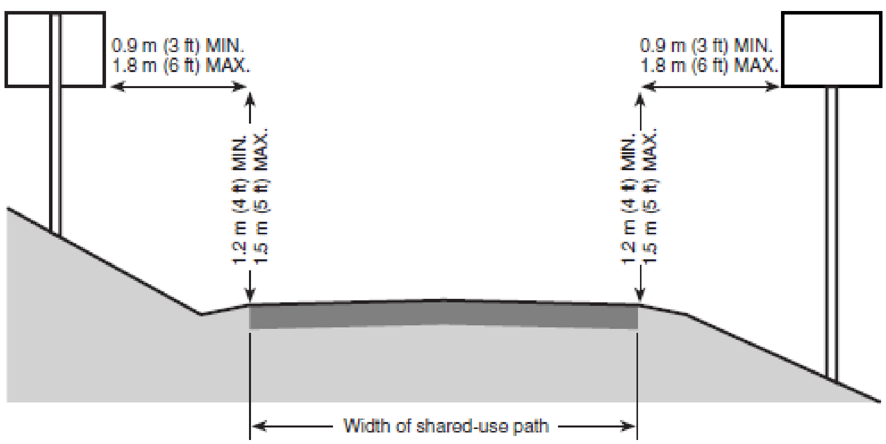


Figure 4.1: Sign Placement on Shared-Use Paths
Source: (Federal Highway Administration, 2003)

The size of signs depending on their uses. In bicycle facilities the sizes are showed in **Table 4.1**. The table show the comparison between shared use path and roadway.

Table 4.1: Minimum Sign Sizes for Bicycle Facilities.

Sign	MUTCD Code	Minimum Sign Size - mm (in)	
		Shared-Use Path	Roadway
Hill	W7-5	450 x 450 (18 x 18)	600 x 600 (24 x 24)
Bump or Dip	W8-1,2	450 x 450 (18 x 18)	600 x 600 (24 x 24)
Bicycle Surface Condition	W8-10	450 x 450 (18 x 18)	600 x 600 (24 x 24)
Bicycle Surface Condition Plaque	W8-10p	300 x 225 (12 x 9)	300 x 225 (12 x 9)
Advance Grade Crossing	W10-1	375 Dia. (15 Dia.)	375 Dia. (15 Dia.)
Bicycle Warning	W11-1	450 x 450 (18 x 18)	600 x 600 (24 x 24)
Pedestrian Crossing	W11-2	450 x 450 (18 x 18)	600 x 600 (24 x 24)
Low Clearance	W12-2	450 x 450 (18 x 18)	750 x 750 (30 x 30)
Playground	W15-1	450 x 450 (18 x 18)	600 x 600 (24 x 24)
Share the Road Plaque	W16-1	—	450 x 600 (18 x 24)
Diagonal Arrow Plaque	W16-7p	—	600 x 300 (24 x 12)
Bicycle Guide	D1-1b	600 x 150 (24 x 6)	600 x 150 (24 x 6)
Street Name	D1-1c	450 x 150 (18 x 6)	450 x 150 (18 x 6)
Bicycle Parking	D4-3	300 x 450 (12 x 18)	300 x 450 (12 x 18)
Bike Route	D11-1	600 x 450 (24 x 18)	600 x 450 (24 x 18)
Bicycle Route Sign	M1-8	300 x 450 (12 x 18)	300 x 450 (12 x 18)
Interstate Bicycle Route Sign	M1-9	450 x 600 (18 x 24)	450 x 600 (18 x 24)
Bicycle Route Supplemental Plaques	M4-11,12,13	300 x 100 (12 x 4)	300 x 100 (12 x 4)
Route Sign Supplemental Plaques	M7-1,2,3,4,5,6,7	300 x 225 (12 x 9)	300 x 225 (12 x 9)

Source: (Federal Highway Administration, 2003)

Table 4.1: Minimum Sign Sizes for Bicycle Facilities (continued).

Sign	MUTCD Code	Minimum Sign Size - mm (in)	
		Shared-Use Path	Roadway
Stop	R1-1	450 x 450 (18 x 18)	750 x 750 (30 x 30)
Yield	R1-2	450 x 450 x 450 (18 x 18 x 18)	750 x 750 x 750 (30 x 30 x 30)
Bike Lane	R3-17	—	750 x 600 (30 x 24)
Bicycle Lane Supplemental Plaques	R3-17a,b	—	750 x 300 (30 x 12)
Movement Restriction	R4-1,2,3,7	300 x 450 (12 x 18)	450 x 600 (18 x 24)
Begin Right Turn Lane Yield to Bikes	R4-4	—	900 x 750 (36 x 30)
Bicycle Wrong Way	R5-1b	300 x 450 (12 x 18)	300 x 450 (12 x 18)
No Motor Vehicles	R5-3	600 x 600 (24 x 24)	600 x 600 (24 x 24)
No Bicycles	R5-6	600 x 600 (24 x 24)	600 x 600 (24 x 24)
No Parking Bike Lane	R7-9,9a	—	300 x 450 (12 x 18)
Pedestrians Prohibited	R9-3a	450 x 450 (18 x 18)	450 x 450 (18 x 18)
Ride With Traffic Plaque	R9-3c	300 x 300 (12 x 12)	300 x 300 (12 x 12)
Bicycle Regulatory	R9-5,6	300 x 450 (12 x 18)	300 x 450 (12 x 18)
Shared-Use Path Restriction	R9-7	300 x 450 (12 x 18)	—
Push Button for Green Light	R10-3	225 x 300 (9 x 12)	225 x 300 (9 x 12)
To Request Green Wait on Symbol	R10-22	300 x 450 (12 x 18)	300 x 450 (12 x 18)
Railroad Crossbuck	R15-1	600 x 112 (24 x 4.5)	1200 x 225 (48 x 9)
Turn and Curve Warning	W1-1,2,3,4,5	450 x 450 (18 x 18)	600 x 600 (24 x 24)
Arrow Warning	W1-6,7	600 x 300 (24 x 12)	900 x 450 (36 x 18)
Intersection Warning	W2-1,2,3,4,5	450 x 450 (18 x 18)	600 x 600 (24 x 24)
Stop,Yield,Signal Ahead	W3-1,2,3	450 x 450 (18 x 18)	750 x 750 (30 x 30)
Narrow Bridge	W5-2	450 x 450 (18 x 18)	750 x 750 (30 x 30)
Bikeway Narrows	W5-4a	450 x 450 (18 x 18)	750 x 750 (30 x 30)

Source: (Federal Highway Administration, 2003)

Figures 4.2 and **4.3** show the regulatory and warning signs in color. Some of these are used in just bicycle facilities but the majorities are focused on the interaction between bicycle and motor vehicle. The signs have different colors for different purposes. The red one means major precaution or prohibited actions. The white/black signs regulate the interaction with other vehicles and inform about the facilities' designations. Signs with yellow color means precaution ahead, inform about the facilities conditions and characteristics. The green sign give information about the road and destinations.

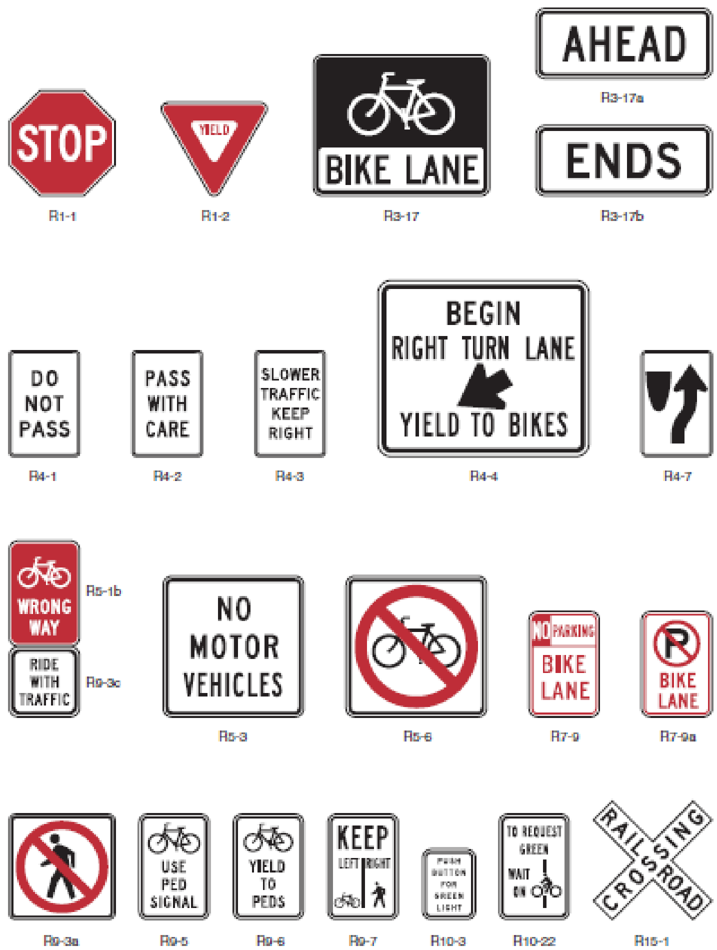


Figure 4.2: Regulatory Signs for Bicycle Facilities

Source: (Federal Highway Administration, 2003)

Figure 4.3: Warming Signs for Bicycle Facilities

Source: Federal Highway Administration, 2003)

An important factor to keep the bicyclist safe is markings. Marking on pavement limits the space for road users, maintains the separation between motor vehicles and bicycles. Moreover marking indicates the correct traffic flow including turning or crossing at intersections. Bicyclists are assisted by the marking on the pavement that indicates travel paths and space delimited for bicycles.

The markings, word messages and symbols on pavement are made with a material that will minimize loss of traction and be visible on day and night. Yellow line that separates two direction indicates if the zone have passing permission. Finally, object markers indicate objects adjacent to the paths to indicate to bicyclist the existence of potential danger. The **Figures 4.4** and **4.5** show the types of passing restriction and **Figure 4.6** indicates the object markers.

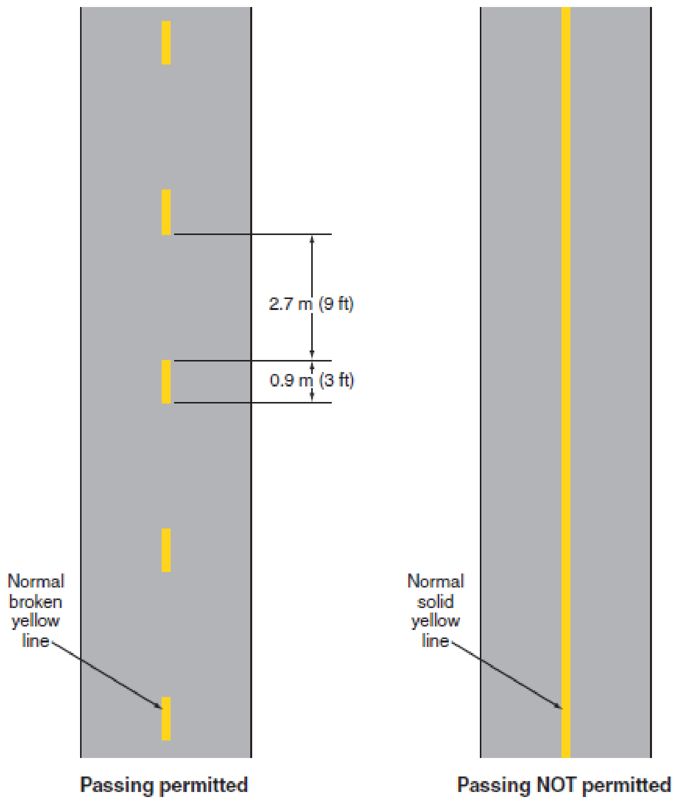


Figure 4.4: Examples of Centerline Markings for Shared-Use Paths

Source: (Federal Highway Administration, 2003)

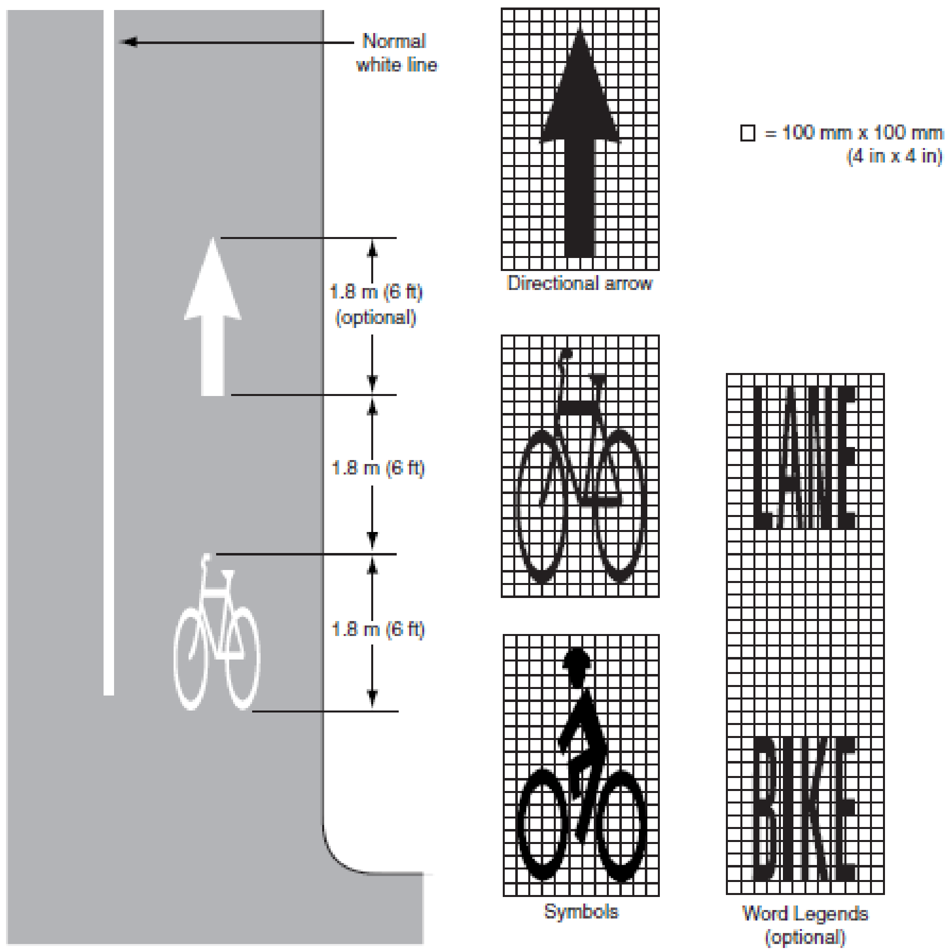


Figure 4.5: Example of Optional Word and Symbol Pavement Markings for Bicycle Lanes

Source: (Federal Highway Administration, 2003)

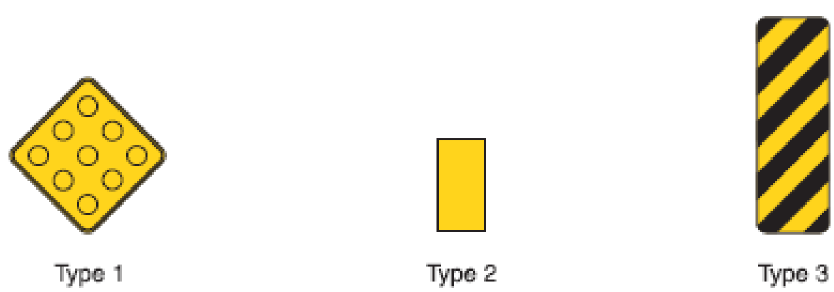


Figure 4.6: Object Markers for Shared-Use Paths

Source: (Federal Highway Administration, 2003)

Figures 4.7 and **4.10** show the bicycle transportation infrastructure. The figures show the distances and distribution of signs according to the regulations.

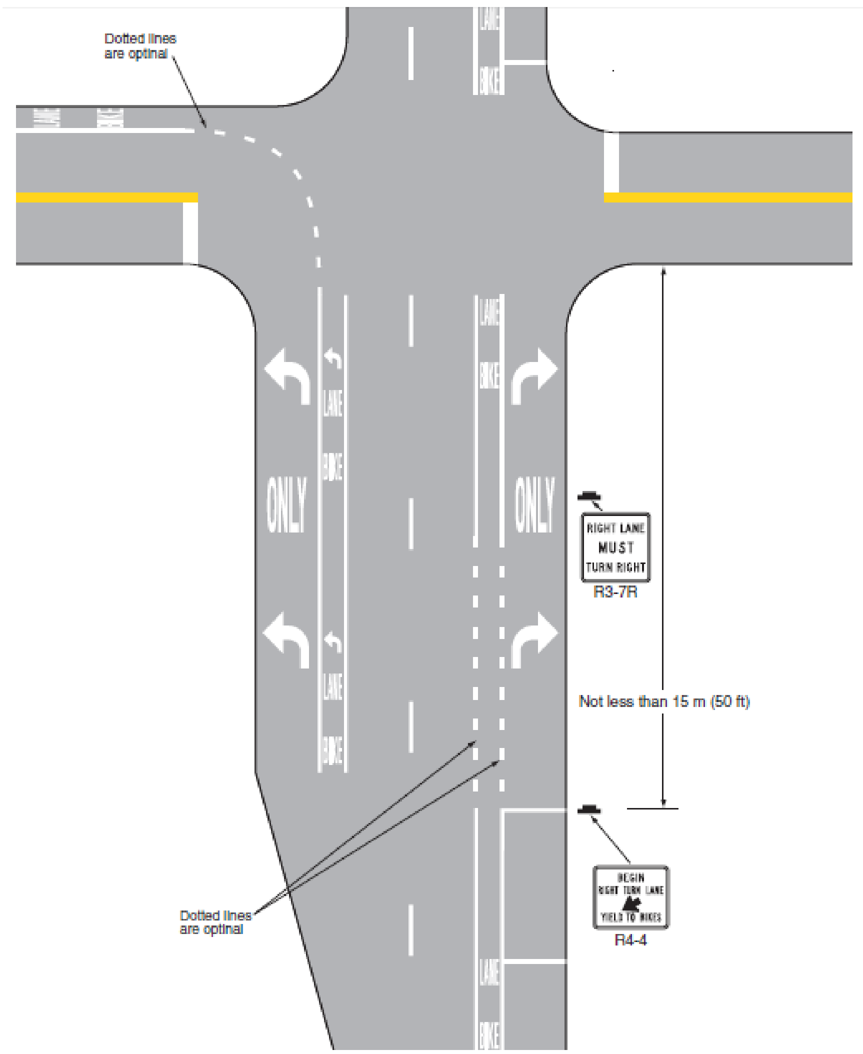


Figure 4.7: Example of Intersection Pavement Markings

Source: (Federal Highway Administration, 2003)

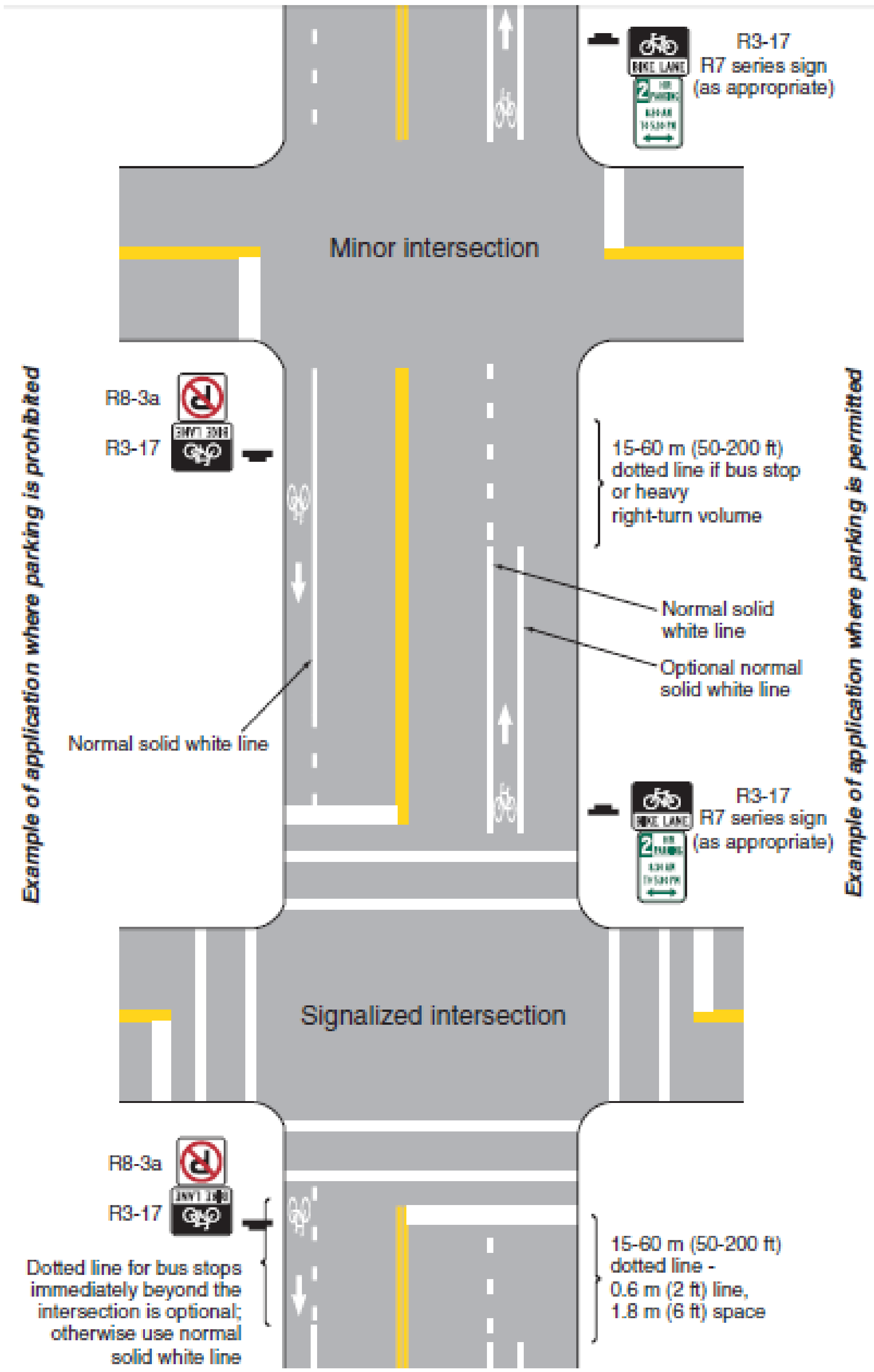


Figure 4.8: Example of Pavement Markings for Bicycle Lanes on Two-Way Street

Source: (Federal Highway Administration, 2003)

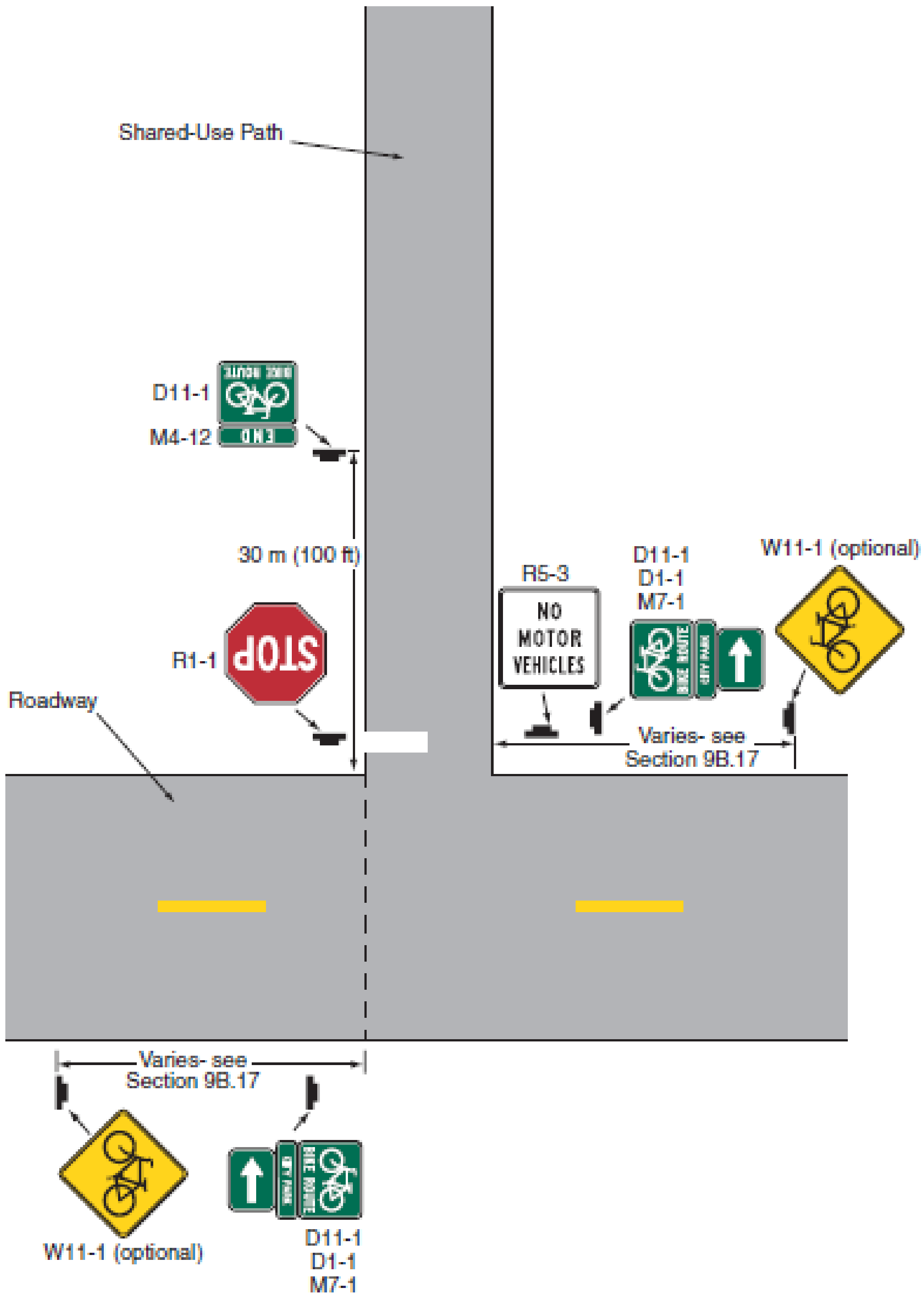


Figure 4.9: Example of Signing for the Beginning and End of Designated Bicycle Route on a Shared-Use Paths

Source: (Federal Highway Administration, 2003)

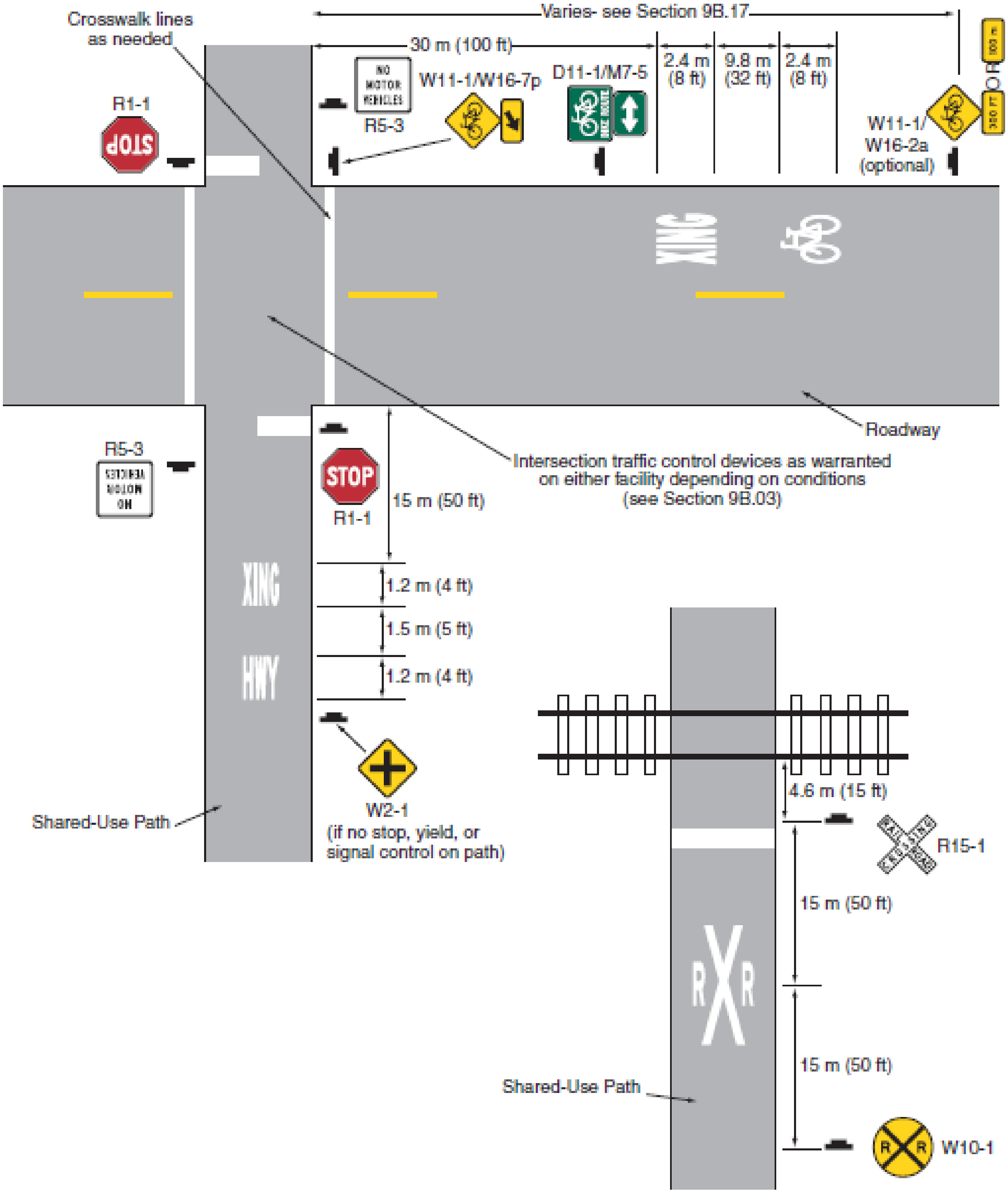


Figure 4.10: Example of Signing Markings for Shared-Use Paths

Source: (Federal Highway Administration, 2003)

4.1.2 Design Guidelines

In U.S., accordingly to American Association of State Highway and Transportation (2010), the main reference for design guidelines is AASHTO's Guide for the Development of Bicycle Facilities. This guide is update regularly. In addition, FHWA has National Association of City Transportation Official's Urban Bikeway Design Guide.

Data collection about existing conditions is very important for the design. Flow analysis or bicycle count and movement analysis has several applications:

- Identify routes
- Identify patterns of usage
- Forecast bicycle travel demand
- Project future bicycle use
- Analyze specific travel patterns

When the data is not available, the local planning authority estimates the bicycle traffic volume by multiplying the bicycle commuting percentage by highway traffic volume. The necessary data is from the census data.

Bicycle Level of Service (LOS) analysis is done with the main purpose of knowing the safety and comfort of bicyclists, when motor vehicles interacts with bicyclists. This is to improve the riding conditions at roadway during peak travel conditions.

Bicycle demand analysis to evaluate if bicycle transportation facility is enough to cover the future needs. This analysis should include latent demand. This analysis may be conducted using one of the following methods:

- Comparison study
- Sketch plan methods
- Market analysis/ land use models
- Discrete choice survey models

The geometric design of bicycle paths is the same that is used in general highway design. This criterion should be ideal for bicyclist taking in account the pedestrians and other potential users. First, sidewalks are not suitable for bicycles. The space and unexpected pedestrian flow made the bicycle travel dangerous (for the pedestrians and bicyclists). Accordingly it is preferable that bicycles travel next to the roads.

Surface for bicycle trip is important because it generates the necessary friction in different conditions. The local planning authority should consider different types of surfaces and chose the better ones according to the environmental and topographic conditions. The most common surfaces used in bicycle transportation facilities are:

- Concrete: Concrete has the hardest surface to support the most users. This surface has lowest maintenance. Moreover, it may offer better functionally in wet condition. The cost is the highest initially, but the low maintenance and over the life time make the difference from other surfaces.
- Hot Mix Asphalt (HMA): HMA has hard surface, enough for any bicycle transportation mode. Also, it has low maintenance. It has higher initial cost but over the life time its cost is lower than concrete.
- Bituminous Surface Treatment (BST): BST has a considerable stability and is less expensive than concrete or HMA.
- Crushed aggregate surface: This surface is the least expensive, but it provides a shorter service time than other surfaces. It requires constant maintenance to keep its permeable surface.

The separation between motor vehicles and bicyclist is an important safety factor. When bicycle path is located in the right of way of the road, a separation should be considered to maintain safety. The following minimum separations are recommended.

- Urban cross section: The minimum distance between path and the face of the curb is 5 ft (1.5 m). **Figure 4.11** show the graphical representation.

- Rural cross section: The minimum distance is based on the speed limit of motor vehicles.
    - For speed limit of 45 mph or less, the separation recommended is 5 ft (1.5 m).
    - For speed limit greater than 45 mph the minimum separation is 10 ft (3 m).

When the separation is not feasible, a visual or physical barrier is provide to prevent bicycle path users or motor vehicle users move between the motor vehicle and bicycle facilities.

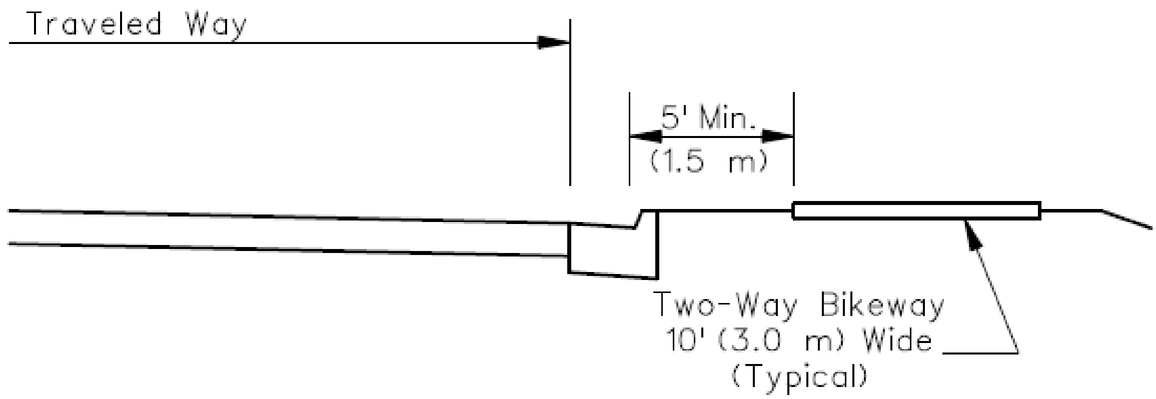


Figure 4.11: Minimum Separation of Bicycle Path from Roadway

Source: (Bureau of Local Road & Streets Bicycle Facilities, 2013)

Bicycle speed is an important factor for the design of bicycle paths. In general on paved surface the minimum design speed is 18 mph (30 km/h) in areas where the grade is under 4.0%. When the downgrade is greater than 4.0% the design speed is 30 mph (50 km/h) because the inclination increase the velocity in downhill. Meanwhile, in unpaved paths the design speeds are 14 mph (25 km/h) and 25 mph (40 km/h).

Horizontal alignment design is affected by centrifugal force accordingly the mass combined from bicyclist and bicycle.

The design of horizontal curves considers the following factors:

- Lean angle: Lean angle is the bicyclist inclination to counteract the centrifugal force. At the leaning time the internal pedal strikes the ground. Accordingly, the lean angles are between 15 – 20degrees from the vertical. **Tables 4.2** and **4.3** shows the minimum radii and length of horizontal curve based on the design speed.

- Cross slope/superelevation: This factor is for bicyclists with disabilities. A pavement cross slope shall not exceed 2.0%.
- Lateral Clearance: The bicyclist tend to ride in the middle of the path when the path is narrow. When there are two or more bicyclists riding side by side the probability of collision increases. To avoid this situation, installing a center line or “curve ahead” warning signs, in recommended by MUTCD. **Figure 4.12** show the additional pavement width accordingly the curve radius.

Table 4.2: Minimum Radius and Length of Curve for Paved Paths (15 grade Lean Angle).

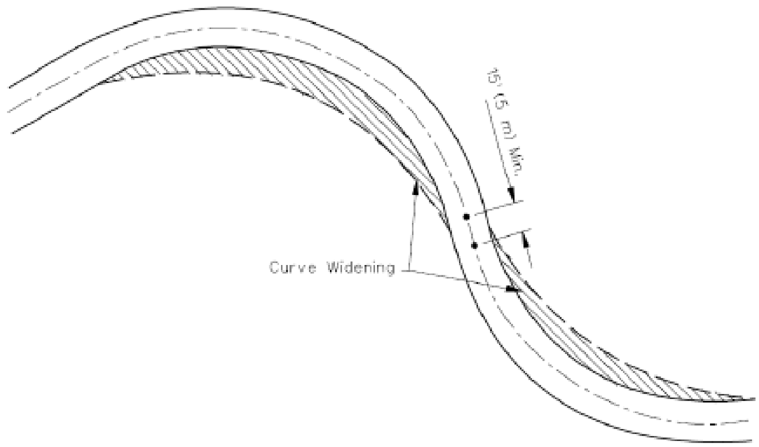
DESIGN SPEED (V)		MINIMUM RADIUS (R_{min})		MINIMUM LENGTH OF CURVE (L_{min})	
mph	km/h	ft	m	ft	m
12	19	36	11	10	3
14	23	49	16	13	4
16	26	64	20	17	5
18	29	81	25	21	7
20	32	100	30	26	8
25	40	156	47	41	12
30	48	225	68	59	18

Source: (Bureau of Local Road & Streets Bicycle Facilities, 2013)

Table 4.3: Minimum Radius and Length of Curve for Paved Paths (20 grade Lean Angle).

DESIGN SPEED (V)		MINIMUM RADIUS (R_{min})		MINIMUM LENGTH OF CURVE (L_{min})	
mph	km/h	ft	m	ft	m
12	19	27	8	10	3
14	23	36	11	13	4
16	26	47	15	17	5
18	29	60	18	21	7
20	32	74	22	26	8
25	40	115	35	41	12
30	48	166	54	59	18

Source: (Bureau of Local Road & Streets Bicycle Facilities, 2013)



CURVE RADIUS		ADDITIONAL PAVEMENT WIDTH	
ft	m	ft	m
0 – 25	0 – 7.5	4	1.2
25 – 50	7.5 – 15	3	0.9
50 – 75	15 – 22.5	2	0.6
75 – 100	22.5 – 30	1	0.3
100 +	30 +	0	0

Note: Only use additional pavement width where curve radii are less than design speed of bike path or where a 20° lean angle is assumed

Figure 4.12: Bike Curve Widening for Various Curve Radio

Source: (Bureau of Local Road & Streets Bicycle Facilities, 2013)

To design the vertical alignment considers the following factors:

- Grades: The grade in shares use path with grades greater than 5.0% should be evaluated for ADA compliance. For unpaved facilities the upgrade should not exceed 3.0%. For grade that exceeds this percentage, some action need to be taken for the sake of safety:
  - ➢ Provide additional width for slower bicyclist or pedestrians
  - ➢ Provide adequate signing
  - ➢ Provide horizontal clearances bigger than the minimums requirements
- Sight distance: The sight distance (S) in ft is calculated based on velocity (V) in mph, coefficient of friction (f) and grade (G) in ft/ft in the next equation:

$$S = \frac{V^2}{30\,(f \pm G)} + 3.67V \tag{4.1}$$

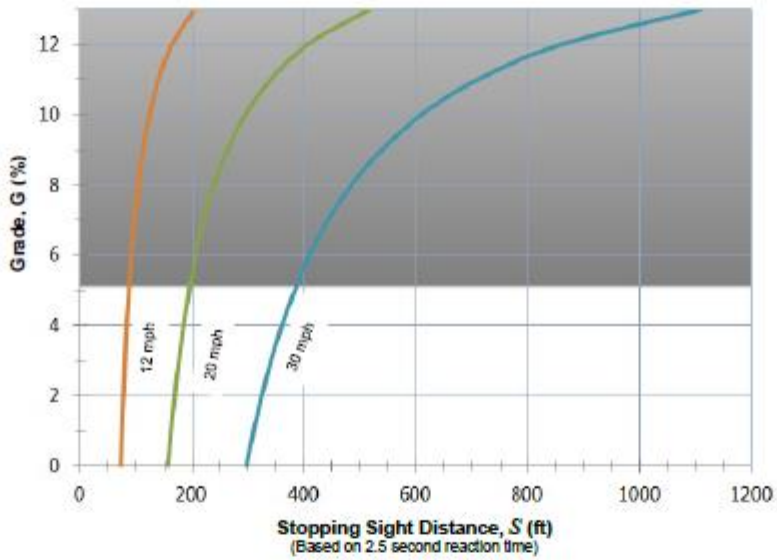


Figure 4.13: Stopping Sight Distances for Downgrades

Source: (Washington State Department of Transportation Design Manual, 2012)

Figure 4.13 gives the graphical representation of the stopping sight distance (S) depending on grade and design speed.

- Vertical curve lengths: Accordingly to sight distance (S), absolute difference between the two tangent grades (A), height of eye above the road surface (h1) with a standard value of 4.5 ft (1.4 m), height of object above the road surface (h2) with a value of 0 ft (0 m), the length of a crest vertical curve should be:

$$L = \frac{AS^2}{200\left(\sqrt{h_1}+\sqrt{h_2}\right)^2} \tag{4.2}$$

Table 4.4: Minimum Lengths for Crest Vertical Curves.

A (%)	Stopping Sight Distance, S (ft)													
	40	60	80	100	120	140	160	180	200	220	240	260	280	
2	3	3	3	3	3	3	3	3	3	3	30	70	110	150
3	3	3	3	3	3	3	20	60	100	140	180	220	260	300
4	3	3	3	3	15	55	95	135	175	215	256	300	348	400
5	3	3	3	20	60	100	140	180	222	269	320	376	436	500
6	3	3	10	50	90	130	171	216	267	323	384	451	523	600
7	3	3	31	71	111	152	199	252	311	376	448	526	610	700
8	3	8	48	88	128	174	228	288	356	430	512	601	697	800
9	3	20	60	100	144	196	256	324	400	484	576	676	784	900
10	3	30	70	111	160	218	284	360	444	538	640	751	871	1,000
11	3	38	78	122	176	240	313	396	489	592	704	826	958	1,100
12	5	45	85	133	192	261	341	432	533	645	768	901	1,045	1,200
13	11	51	92	144	208	283	370	468	578	699	832	976	1,132	1,300
14	16	56	100	156	224	305	398	504	622	753	896	1,052	1,220	1,400
15	20	60	107	167	240	327	427	540	667	807	960	1,127	1,307	1,500
16	24	64	114	178	256	348	455	576	711	860	1,024	1,202	1,394	1,600
17	27	68	121	189	272	370	484	612	756	914	1,088	1,277	1,481	1,700
18	30	72	128	200	288	392	512	648	800	968	1,152	1,352	1,568	1,800
19	33	76	135	211	304	414	540	684	844	1,022	1,216	1,427	1,655	1,900
20	35	80	142	222	320	436	569	720	889	1,076	1,280	1,502	1,742	2,000
21	37	84	149	233	336	457	597	756	933	1,129	1,344	1,577	1,829	2,100
22	39	88	156	244	352	479	626	792	978	1,183	1,408	1,652	1,916	2,200
23	41	92	164	256	368	501	654	828	1,022	1,237	1,472	1,728	2,004	2,300
24	43	96	171	267	384	523	683	864	1,067	1,291	1,536	1,803	2,091	2,400
25	44	100	178	278	400	544	711	900	1,111	1,344	1,600	1,878	2,178	2,500

Minimum Length of Vertical Curve, L (ft)

Source: (Washington State Department of Transportation Design Manual, 2012)

The **Table 4.4** show the minimum length of crest vertical curve depending on the absolute difference in grade and stopping sight distance.

Intersections have a significant impact on bicyclist comfort, mobility and safety. For this reason the design of intersections have an important role in bicycle transportation. To maintain the bicyclist integrity in intersection some crossing control is required. The most usual devices are signage, marked crosswalks, flashing lights, pedestrian hybrid beacons, in-pavement lights, among others. At high volume intersections, MUTCD recommends median refuge for bicyclists. The design of intersection is dependent on motorized traffic and bicycle volumes.

4.2 Design Guidelines of EU, Czech Republic and Prague

In Czech Republic, the design, construction and maintenance are important issues in the design of bicycle transportation infrastructure. Prague as a capital city has to satisfy the minimum requirements of Czech national rules and regulations. These rules and regulation are established to maintain enough safety and functionality for bicyclists. edip dopravní inženýrství (EDIP) and Český Publisher Normalizační Institut (ČSN) have developed design criteria and guidelines for bicycle transportation infrastructure.

4.2.1 Design Criteria

The main purpose of the Czech design criteria is to establish the minimum requirements to ensure the safety and functionality of the bicycle infrastructure.

Traffic sign has a minimum and a maximum distance from the near bicycle edge, depending on the speed of motor vehicles. On shared used paths, the maximum value is 0.5 m (1.65 ft.) while the minimum is 0.25 m (0.8 ft). The sign also has a maximum and minimum height. The maximum height is 2.5 m (8.2 ft) and the minimum is 1.2 m (4 ft) from the bottom of the sign, **Figure 4.14** shows the sign placement measurements.

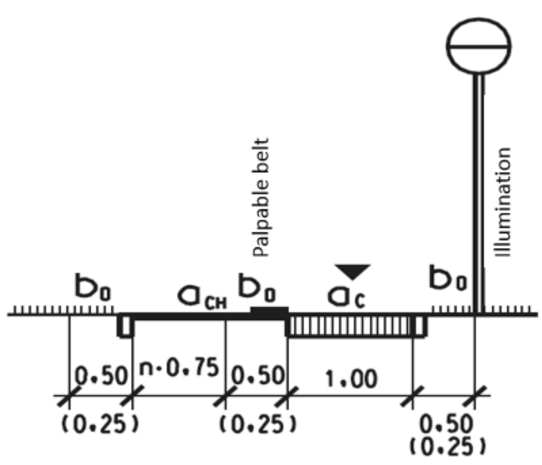


Figure 4.14: Signal placement measurements.

Source: (Český normalizační institut, 2005)

The signs are used to inform and regulate the flow of bicycles, pedestrians and motor vehicles. In bicycle transportation in Czech Republic, the colors of signs has special purposes. The blue color means regulation. The red color is for precaution or prohibition. The yellow signs have information for cyclist such as distance and direction. Finally the white with/or black colors regulate the traffic between bicycles and motor vehicles. In **Figures 4.15** and **4.16** some of the most common signs in the bicycle transportation infrastructure in Czech Republic are shown.

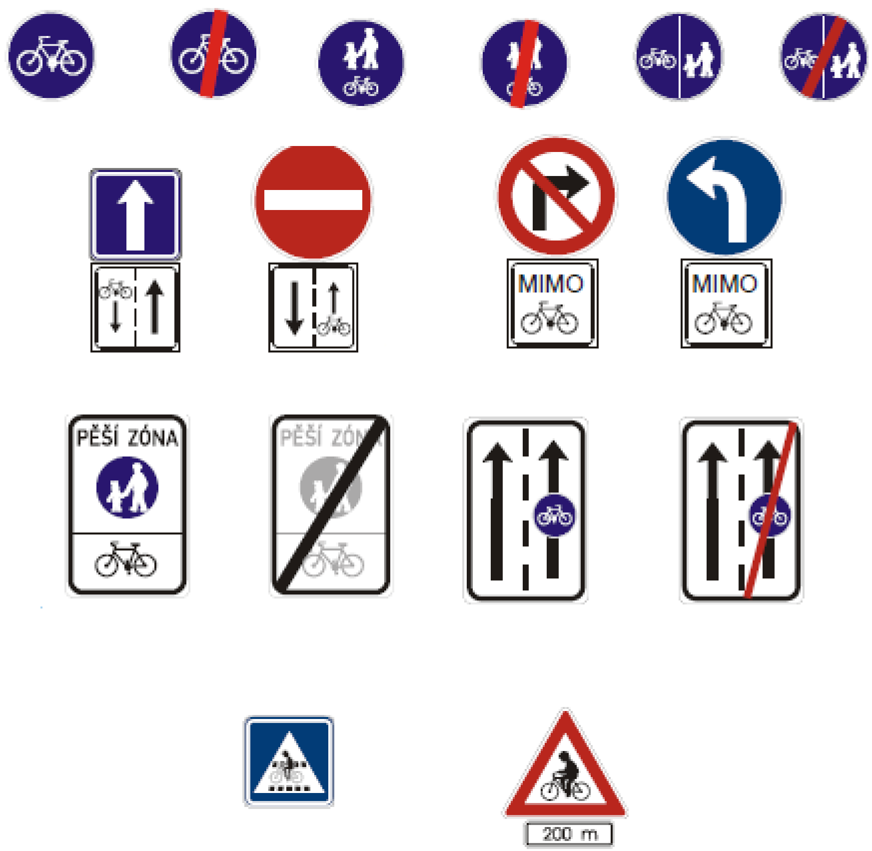


Figure 4.15: Bicycle transportation infrastructure signals.

Source: (EDIP)

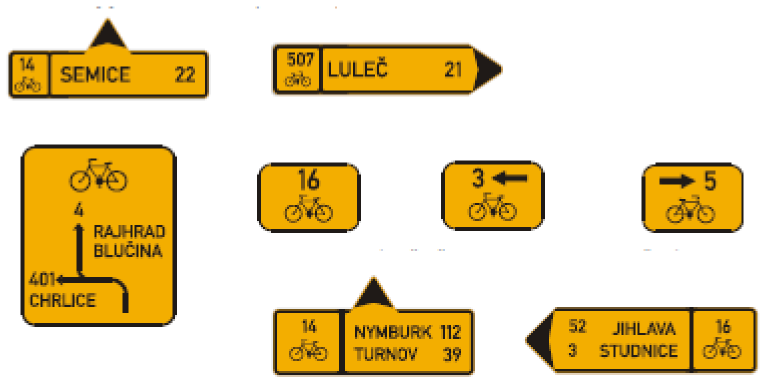


Figure 4.16: Bicycle transportation infrastructure signals.

Source: (EDIP)

Figure 4.17 show the most common bicycle and directional markings used in Prague.

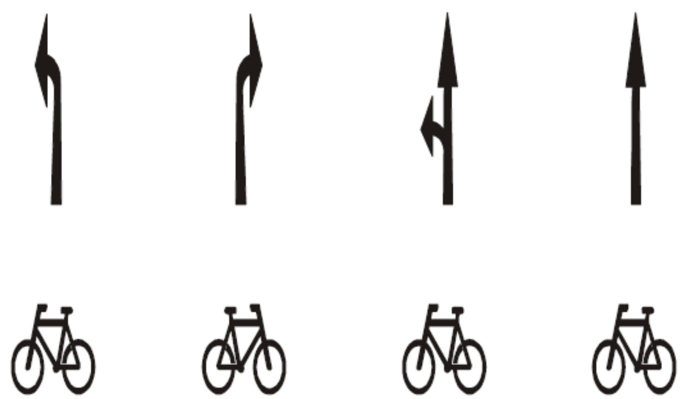


Figure 4.17: Directional pavement marks.

Source: (EDIP)

A bicycle lane is marked in the sides with non-continuous white lines. This line has specific dimensions. At non-intersection the dimensions are 1.5/1.5/0.25 m, for length, space and width respectively. But in cases where motor vehicles have permission to use this lane at intersections or turns, the line dimensions are 0.5/0.5/0.25. In this way users can distinguish these zones. **Figure 4.18** is the representation of the lane markings.

Figure 4.18: Bicycle lane marks.

Source: (EDIP)

Another important marking for bicycles is the box at intersection stop line. This box permits the bicyclist to advance until the front of motor vehicle traffic when the light is red. This has two purposes. First the safety of the bicyclist making a left turn is higher when the bicyclist starts the movement at the front. This way the motor vehicle drivers can see the bicyclist. Second, the bicyclist inhale less exhaust produced by vehicles. The dimension for the bicycle box are 3.0 m in length (minimum, it depends of the volume of bicycle flow) and the width of the lane of motor vehicles. **Figure 4.19** shows a few examples of the dimension and location of the bicycle.

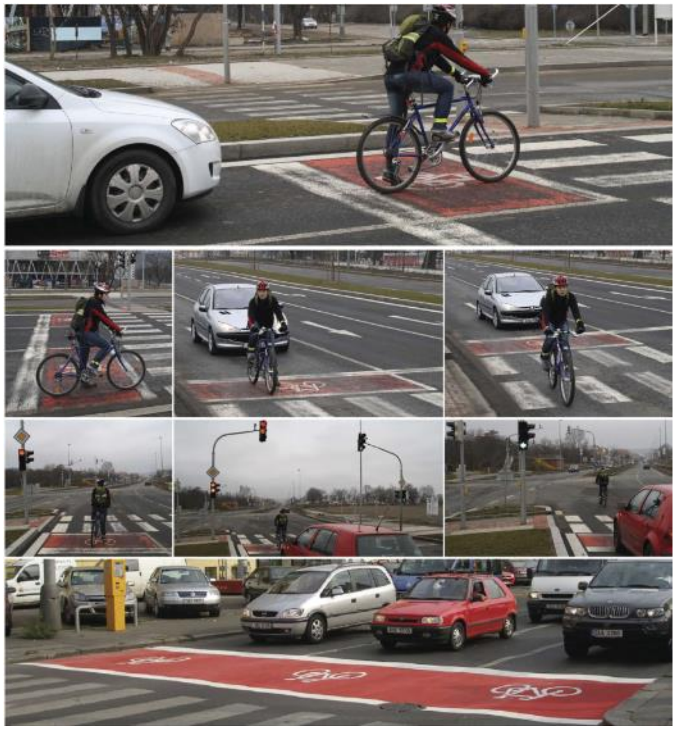


Figure 4.19: Bicycle box at intersection.

Source: (Praha Cyklisticá, 2010)

4.2.2 Design Guidelines

In Czech Republic some agencies are in charge of the design of bicycle transportation infrastructure. This agencies should satisfy some requirements to ensure the functionality and satisfaction of user's needs. Český Publisher Normalizační Institut (ČSN) is the main reference for the design guidelines for bicycle infrastructure. Edip dopravní inžený́rství (EDIP) is one of the main support for the design with "Navrhování Komunikací Pro Cyklisty".

First of all, the surface is important for bicyclists. Surface provides the comfort into the trip. The designers should consider different types of material. For infrastructure situated as part of roads (HMA) with a distinguishable color or separate line mark with different texture is recommended.

In bicycle infrastructure, the geometric design begins with the definition of type of infrastructure, if the bicyclists have infrastructure for themselves or they have to share with other transportation modes. **Table 4.5** shows the different types of bicycle infrastructure.

Table 4.5: Možnosti vedení cyklistů (Options leadership cyclists).

	Společný provoz (joint operation)	Oddělený provoz (Department operation)
V hlavním dopravním prostoru (In the main traffic area)	- v jízdním pruhu pro motorová vozidla místních komunikací funkčních skupin B a C a účelových komunikací - v autobusovém nebo trolejbusovém pruhu - v obytných a pěších zónách (- In the lane for motor vehicles of local roads functional groups B and C and tertiary roads - In the bus or bus lane - In residential and pedestrian areas)	samostatný jízdní pruh pro cyklisty v hlavním dopravním prostoru komunikací funkční skupiny B a C (separate lane for cyclists in the main traffic area roads functional groups B and C)
V přidruženém prostoru (In a related area)	společný pruh/pás pro chodce a cyklisty (Common strip for pedestrians and cyclists)	jízdní pruh/pás pro cyklisty (lane for cyclists)
Samostatné stezky (separate trails)	stezka pro chodce a cyklisty (route for pedestrians and cyclists)	stezka pro cyklisty (cycleway)
POZNÁMKY (COMMENTS) - společný provoz chodců a cyklistů je možný při převažujícím podílu chodců; - oddělený provoz podle 10.4.2.2. (- The joint operation of pedestrians and cyclists is possible when the predominant proportion of pedestrians; - Separate operation by 10.4.2.2.)		

Source: (Český normalizační institut, 2005)

One of the most important criteria for design is the motor vehicle speed limit. In roads with speed limit over 50 km/h (30mph) the bicyclist have to ride in an exclusive lane. If the geometric design of the road do not allow that bicyclists to have their own lane, the speed limit has to be reduced. Show in **Table 4.6** are the limits of traffic volume of motor vehicles and bicycle in different speed limit zones. The design is based on 20 km/h in road, 10 km/h at intersections, and 30 km/h downhill.

Table 4.6: Doporučené limity intenzit pro návrh odděleného provozu cyklistů (Recommended limits intensities for the design of the traffic separation of cyclists).

	Počet jízdních kol za špičkovou hodinu v jednom směru (The number of bicycles per peak hour in one direction)	Počet motorových vozidel za 24 hodin v obou směrech The number of motor vehicles per 24 hours in both directions)
Místní komunikace v území zastavěném (Local roads in built-up areas)	10	> 20 000
	20	10 000 – 20 000
	30	5 000 – 10 000
	60	2 500 – 5 000
	150	< 2 500
Místní komunikace v území nezastavěném a nezastavitelném (Local roads in built-up areas and unstoppable)	10	> 10 000
	15	5 000 – 10 000
	30	2 500 – 5 000
	90	< 2 500
POZNÁMKY - tabulka platí pro novostavby i rekonstrukce - hodnoty se určují pro výhledové období totožné s výhledovým obdobím pro motorovou dopravu COMMENTS - Table applies to new construction and renovations - Values are determined for the prospective period identical to the prospective period for motor traffic		

Source: (Český normalizační institut, 2005)

There are other parameters to define if bicycle infrastructure is needed. **Table 4.7** show some of the most important factors that determine if bicycle can ride on the main road or an exclusive bicycle infrastructure is needed.

Table 4.7: Kritéria pro vedení cyklistické dopravy v hlavním nebo přidruženém dopravním prostoru (Criteria for the management of cycling in the capital or carriageway).

	Jízdní pruh pro cyklisty v hlavním dopravním prostoru (Lane for cyclists in the main traffic area)	Jízdní pruh/pás pro cyklisty v přidruženém prostoru (Lane for cyclists in the associated space)
Uživatelé (users)	Vhodnější pro denní provoz do zaměstnání a zdatnější uživatele (More suitable for daily operations and to work more experienced users)	Vhodnější pro rekreační a nákupní provoz s účastí dětí a starších uživatelů (Best suited for leisure and shopping traffic with the participation of children and elderly users)
Vzdálenost křižovatek (distance intersections)	Při malých vzdálenostech křižovatek (do cca 150 m) vhodnější uspořádání (vyvolává méně konfliktů s vozidly odbočujícími vpravo i vlevo) [At small distances intersections (up to 150 m) suitable arrangement (raises fewer conflicts with vehicles branching right and left)]	Při malých vzdálenostech křižovatek (do cca 150 m) méně vhodné uspořádání (vyvolává četné konflikty s vozidly odbočujícími vpravo) [At small distances intersections (up to 150 m) are less suitable arrangement (raises numerous conflicts with vehicles branching right)]
Uspořádání u zastávek MHD (The arrangement at bus stops)	Vhodné uspořádání pro zastávku v zálivu i v jízdním pruhu (Suitable arrangements for a stopover in the Gulf and in the lane)	Pro zastávku v zálivu vhodné pouze při dostatečné šířce přidruženého prostoru (To stop the Gulf appropriate only when a sufficient depth of the associated space)
Konflikt s parkujícími vozidly (Conflict with parked vehicles)	- vedení jízdního pruhu pro cyklisty podél parkovacího pruhu nebo pásu může být zdrojem konfliktů - možné konflikty se zásobováním (- Keeping lane for cyclists along the parking lane or strip can be a source of conflict - Potential conflicts with supply)	- vedení jízdního pruhu pro cyklisty podél parkovacího pruhu nebo pásu může být zdrojem konfliktů - možné konflikty se zásobováním (- Keeping lane for cyclists along the parking lane or strip can be a source of conflict - Potential conflicts with supply)
Prostorové možnosti (spatial options)	Zpravidla úspornější řešení (Usually more economical solution)	Zpravidla náročnější řešení (Usually demanding solutions)

Source: Český normalizační institut, 2005)

Figure 4.20 is the graphical representationship of the relation about bicyclist in the road with or without special bicycle infrastructure. **Table 4.8** shows the borders of the different zones in the chart.

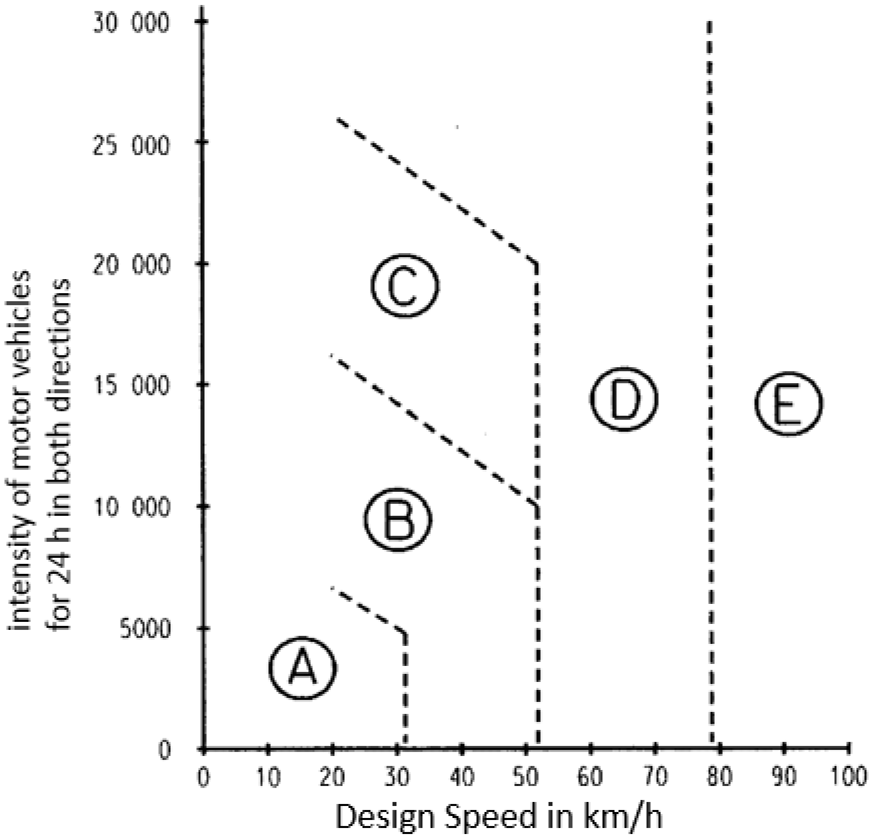


Figure 4.20: Orientační kritéria pro způsob vedení cyklistické dopravy ve vztahu k intenzitám a rychlostem motorových vozidel (Indicative criteria for how the cycling transport in relation to intensities and speeds of motor vehicles).

Source: (Český normalizační institut, 2005)

Table 4.8: Doporučené meze pro vedení cyklistické dopravy v provozu společném nebo odděleném (Recommended limits for the leadership of cycling in traffic together or separately).

Pole (field)	Provoz (traffic)	Prostor (space)	způsoby vedení cyklistické dopravy (methods of conducting bicycle transport)
A	Společný (common)	hlavní dopravní prostor (main traffic area)	- v jízdních pruzích v hlavním dopravním prostoru - v pěší / obytné zóně (- In the lanes in the main traffic area - - Walking / residential zone)
B	společný nebo oddělený (together or separately)	hlavní dopravní prostor nebo přidružený prostor (main traffic area or associated space)	- v jízdních pruzích v hlavním dopravním prostoru - v jízdních pruzích pro cyklisty v hlavním dopravním prostoru - na jízdních pruzích pro cyklisty v přidruženém prostoru - na společných pásech pro provoz cyklistů a chodců v přidruženém prostoru (- In the lanes in the main traffic area - In the lane for cyclists in the main traffic area - On the lanes for cyclists in the associated space - On joint strips for the operation of cyclists and pedestrians in the associated space)
C	Oddělený (separate)	hlavní dopravní prostor nebo přidružený prostor (main traffic area or associated space)	- v jízdních pruzích pro cyklisty v hlavním dopravním prostoru - na jízdních pruzích pro cyklisty v přidruženém prostoru - na společných pásech pro provoz cyklistů a chodců v přidruženém prostoru - na stezkách pro cyklisty/pro cyklisty a chodce mimo prostor místní komunikace (- In the lane for cyclists in the main traffic area - On the lanes for cyclists in the associated space - On joint strips for the operation of cyclists and pedestrians in the associated space - On the trails for bikers / cyclists and pedestrians outside the local roads)
D	Oddělený (separate)	přidružený prostor (associate space)	- v přidruženém prostoru na jízdních pruzích/pásech pro cyklisty - na společných pásech pro provoz cyklistů a chodců v přidruženém prostoru - na stezkách pro cyklisty/pro cyklisty a chodce mimo prostor místní komunikace (- The associated space lanes / strips for cyclists - On joint strips for the operation of cyclists and pedestrians in the associated space - On the trails for bikers / cyclists and pedestrians outside the local roads)
E	Oddělený (separate)	mimo prostor místní komunikace (outside the local roads)	- na stezkách pro cyklisty/pro cyklisty a chodce (místní komunikace funkční skupiny D2) mimo prostor místní komunikace (- On the trails for cyclists / pedestrians and cyclists (local roads functional groups D2) outside the local roads)
POZNÁMKA Vedení cyklistické dopravy se zásadně nenavrhuje v prostoru místní komunikace s návrhovou (dovolenou) rychlostí ≥ 80 km/h (funkční skupina A). [NOTE Leadership bicycle transport is fundamentally not proposed in the area of communication with local design (holiday) at a rate ≥ 80 km / h (functional group A)]			

Source: (Český normalizační institut, 2005)

The width of the bicycle lane can vary from 8.00 m to 3.00 m. depending of the road classification.

Designers take the critical value of 5% in gradient and extension of 50% in breaking distance in wet surface. **Table 4.9** show the design stopping distance accordingly the design speed.

Table 4.9: Délka rozhledu pro zastavení (Length vision to stop).

Návrhová rychlost km/h (Design speed km / h)	Doporučená nejmenší délka rozhledu v m (The recommended minimum length of vision in m)
20	15
30	25

Source: (Český normalizační institut, 2005)

Bicyclist is affected in horizontal alignment plane by the centrifugal forces and bicycle and bicycles body. For this reason designers have minimal values of radius and expansion in lanes accordingly the design speed. **Table 4.10** shows the most common speed velocities used in different cases and their respective radius and expansions.

Table 4.10: Nejmenší doporučené poloměry vnitřního okraje oblouků při dostředném sklonu 2% a rozšíření pruhu v závislosti na návrhové rychlosti (Smallest radio recommended inner edge concentric arcs at 2% inclination and extension bar, depending on the design speed).

Návrhová rychlost km/h (Design speed km / h)	Poloměr oblouku v m (Arc radius in m)	Rozšíření v m (Enhancements in m)
10	2,5	0,5
15	4,5	0,5
20	8,0	0,5
25	14,0	0,25
30	22,0	–

Source: (Český normalizační institut, 2005)

A cross sectional gradient of 2.0% is provided to maintain a good drainage. This gradient has to be in the same direction of the main road.

In Czech Republic when the bicycle path is in the main road, it has to be in the right side of the road with a considerable separation from the motor vehicle lane. **Figure 4.21** show the main layout of the cross section of road with bicycle lane and their dimensions.

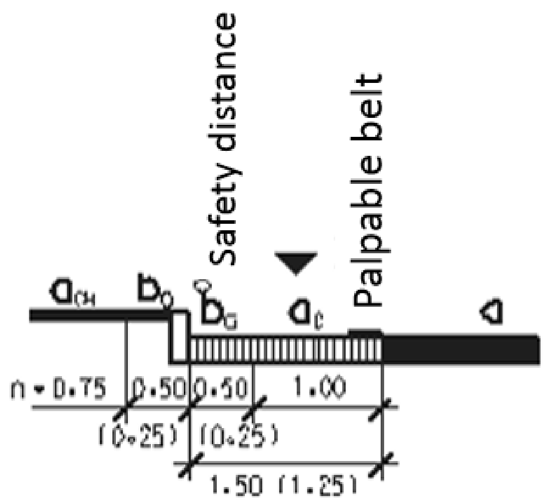


Figure 4.21: Minimum Separation of Bicycle Path from Roadway

Source: (EDIP)

4.3 Comparison

The design of bicycle infrastructure is an important topic in El Paso as in Prague. The increasing number of bicycles on the roads have generated the need for bicycle infrastructure Dopravní inženýrství (EDIP) and Český Publisher Normalizační Institut (ČSN) are the two most important agencies in this topic in Czech Republic, AASTHO is the main authority in El Paso, Texas.

The work scope for both cities for designers involve current facilities, rebuilding, design and maintenance. In both cities, designers follow the same work structure. Collecting of data, processing of information and forecast of future traffic behavior are consideration for designers in both countries. After that, work includes signs, pavements markings, and types of surfaces and design of roads. These designs are based on design speed, safety stopping distance and the conditions of topographic profile and traffic flow. Both cities do the same work but each city follow its own design criteria.

In Prague design uses the same HMA surface for bicycle infrastructure as motor vehicle pavement surface, while in El Paso there are four possible surface types of surface. The marking on the surface to separate and control the traffic flow appear I different, color and texture in Prague, in el Paso just is one color (white).

Traffic Signs in this two cities are completely different. Both cities use different color for the signs with different shapes and legends. They use similar both not exactly location in the roads. But the main purpose is the same, mediate and inform of the existing of bicycle infrastructure and its performance to all transportation modes.

The most important and relevant similarity is that in both cities bicycle transportation system is an important deal for the cities. Agencies and companies have noticed and started including this transportation mode in cities pacification. In conclusion designers work in similar ways but differ in the tools and conditions of work.

Chapter 5: Bicycle Infrastructure and Usage

5.1 El Paso

El Paso, Texas, U.S. is located on the border with Mexico in the far west of Texas. This city occupies the 19th place in largest cities in U.S. with a population of 833,478 according to United States Census Bureau (2013). El Paso is recognized with some awards such as "Americas' Best Performing Cities", "Happiest Cities to Work" and "America's Safest City". El Paso in the recent years has undergone huge developments in many areas including the transportation system.

The weather of El Paso is hot desert climate that consists of more than 300 sunshine days. The annual average rainfall is 9.7 in (250 mm) with July – September as the rain season. Sand and dust storms are common between March – May with average wind speed of 30 mph (50 km/h) with gusts up to around 70 mph (120 km/h). In general, the weather is hot, but residents do not stop outdoors activities, including cycling, in these conditions.

5.1.1 Overview El Paso Transportation

El Paso has an efficient transportation system to satisfy the community needs. The El Paso international Airport is the main airport for the city, county and the region. Sun Metro, the city's bus system, has a great reputation in efficiency. In 2014, the Texas Transit Association (TTA) rewarded Sun Metro with the Outstanding Metropolitan Transit System of the Year. In 2011, the American Public Transportation Association (APTA) awarded Sun Metro the most outstanding public transit system of the year in all of North America for a mid-size transit system.

According to Carlos Najera (1997) based in 1994 Travel Survey Data, El Paso, where the bicycle information is limited, there were 26,887 bicycle owners on record. **Figure 5.1** shows the distribution of 26,887 registered cyclist. About 1.5% of the labor force uses bicycle as transportation mode. Meanwhile the total bicycle trips are classified as home based work, home based non-work and non-home-based trips. **Figure 5.2** shows the distribution of types of bicycles trip.

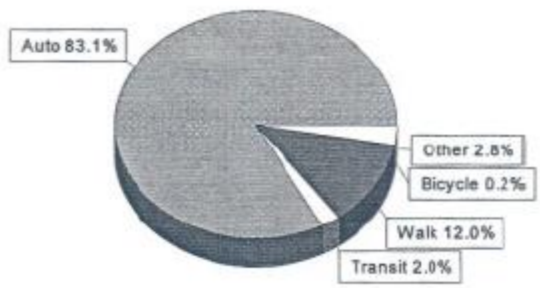


Figure 5.1: Trip Mode Travel

Source: (Regional Bikeways Plan study, 1997)

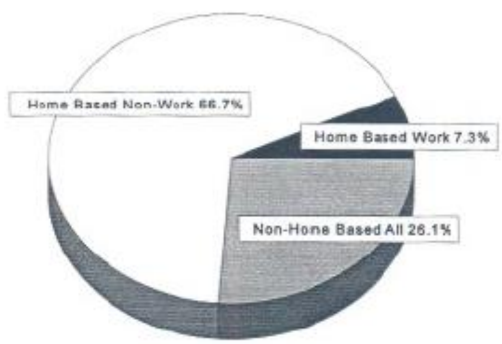


Figure 5.2: Bicycle Trip Purpose

Source: (Regional Bikeways Plan study, 1997)

Several agencies are in charge of planning, operating and maintain the transportation facilities in El Paso. Some of these agencies in El Paso are:

- Sun Metro (which operates the bus system)
- Texas Department of Transportation
- El Paso Metropolitan Planning Organization
- The City of El Paso

- Camino Real Regional Mobility Authority (which manages the toll roads)

Figure 5.3 shows the major highways in El Paso and the El Paso International Airport.

El Paso has three international Ports of Entry (POE) where “60,000 passenger vehicles cross every day” accordingly Texas Department of Transportation (El Paso Regional Ports of Entry Operations Plan 2011). The Ports of Entry are:

- Paso del Norte (PDN)
- Bridge of the Americas (BOTA)
- Ysleta

Meanwhile, there are other two international crossing outside the City of El Paso but in the region :

- Santa Teresa (in New Mexico)
- Fabens (in Texas)

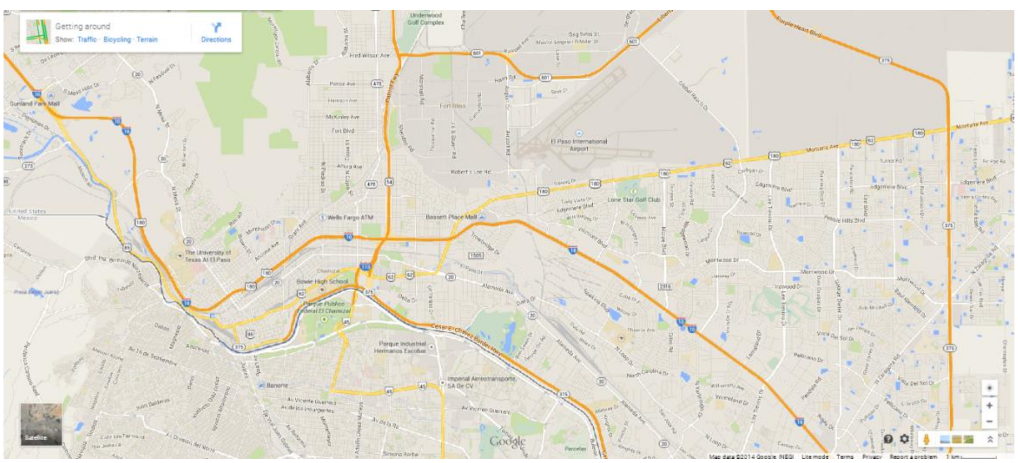


Figure 5.3: Major Highways in El Paso and El Paso International Airport.

Source: (Google maps, 2014)

5.1.2 Bicycle Lane Network

The City of El Paso, like many others cities across the country, is currently pursuing the creation of a network of bicycle transportation facilities. El Paso offers bicycle lanes and road markings to create and maintain safer and comfortable rides for bicyclists. El Paso has 90 miles of bicycle trails, but just 45 miles are paved and are part of the city's bicycle transportation network.

The City of El Paso in conjunction with other transportation agencies, have installed bicycle lanes and implement changes to increase safety. To do this, "bike lane counts at several locations were conducted to analyze the usage of bike facilities based on an average, continuous 15-hour period" according to El Paso Department of Transportation (2015). According to this analysis, the future for bicycle transportation is predicted. **Figure 5.4** shows the existing bicycle lanes in the El Paso area. The blue lines represent the bicycle lanes which are on state highway (in charge by Texas Department of Transportation (TXDOT)). The red lines are on city streets (in charge by the City of El Paso Department of Transportation).

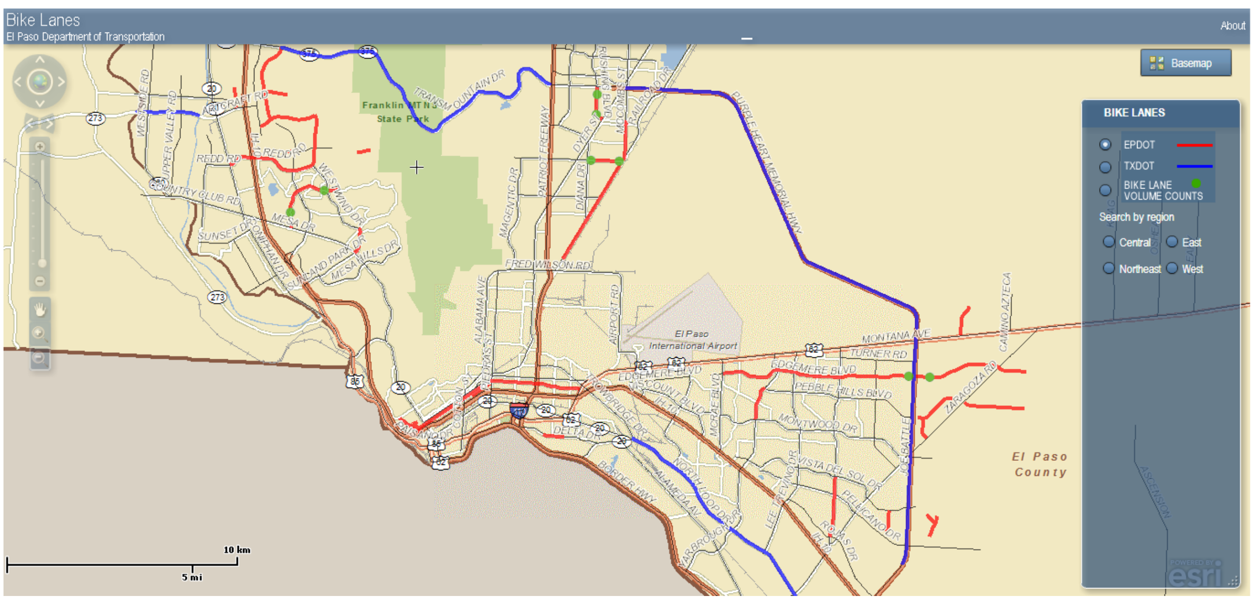


Figure 5.4: Bicycle Lines in El Paso

Source: (El Paso Department of Transportation, 2014)

5.2 Prague

Prague is the capital and largest city of Czech Republic and it is located in the Bohemia region. There are 1,262,000 official residents in Prague, making it the 14th largest city in Europe,

Prague has a combination of oceanic and humid continental climate. Winter in Prague is cold and very little sunshine hours, with accumulation of 8 in (20 cm) of snow between November and March. In summer, the average high temperature is 24 Celsius and wind of 10 mph (16 km/h). Under these conditions outdoor activities are possible.

5.2.1 Overview Prague Transportation

Prague has a very good transportation system. Václav Havel Airport is the main airport in Czech Republic and host of Czech Airlines. The public transport infrastructure (PID, Prague integrated transport system) is integrated by metro with 37 miles (59 km) of subway, tram system, trains, buses and three funiculars and six ferries, with an annual average of 1.2 billon passenger trips.

Technická Správa Komunikací hl.m.Prahy (TSK, 2007)) conducted a survey in Prague to figure out the amount of bicyclists on main roads. This survey showed an increase of bicyclists and determined that weather was the main factor that affects the number of bicyclist in the streets. According to Portál Hlavniho Města Prahy (2009) bicycle has 1% of mode share in Prague against 43% of public transport. **Table 5.1** shows the entire modal split.

Table 5.1: Model split of transportation models in Prague.

public transport	vehicular traffic	pedestrian traffic	bicycle traffic	total
43%	33%	23%	1%	100%

Source: (Portál Hlavniho Města Prahy, 2009)

TSK is in charge to maintain a constant monitoring of bicyclists in the cit. For this reason it has a program called "Unicam Bikecounter" that maintains in constant monitoring the traffic flow of bicyclists. The main zones that this program focuses on are Prague 1, Prague 6 and Prague 12. **Figure 5.5** show the location of unicam bikecounter, the main roads and Prague airport and **Figure 5.6** shows the real view by unicam bikecounter.

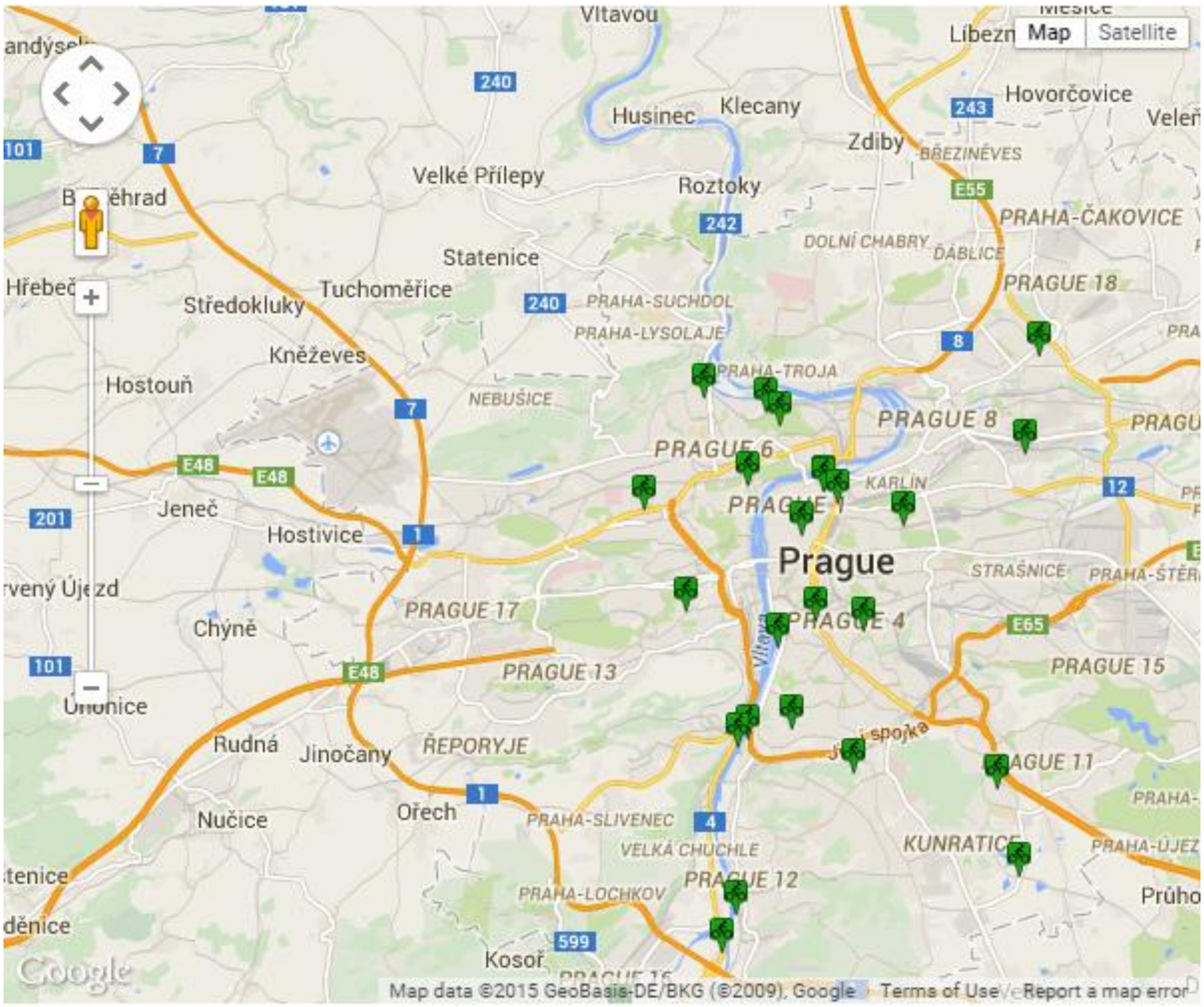


Figure 5.5: Major Highways in Prague, Unicam Bikecounter and Prague Airport Zone

Source: (Google maps, 2015)

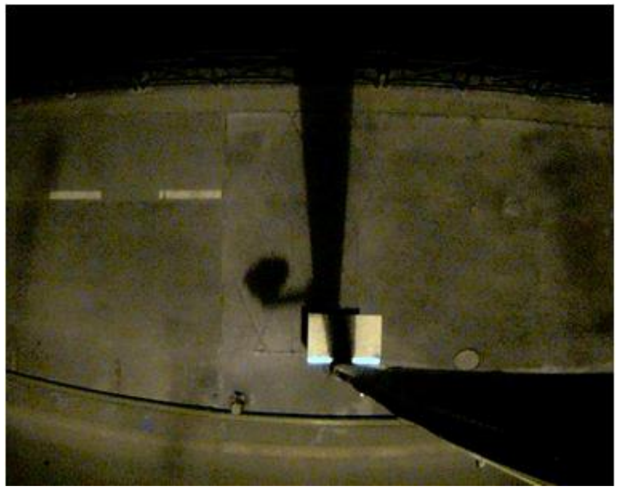


Figure 5.6: Real view of unicam bikecounter.

Source: (TSK, 2015)

5.2.2 Bicycle Lane Network

Prague as capital city of Czech Republic has taken bicycle friendly initiative and have been working to improve the facilities to compete with others transportation modes.

In Prague there are bicycle infrastructure that connects almost every point in the city. There are different kinds of bicycle infrastructure and their uses. **Figure 5.7** shows the distribution of this infrastructure. The colors indicates the infrastructure depending on the conditions. For example, the color blue means bicycle paths, meanwhile color red means cycling routes. This map is provided by Portál Hlavniho Města Prahy and is available in the web-site.

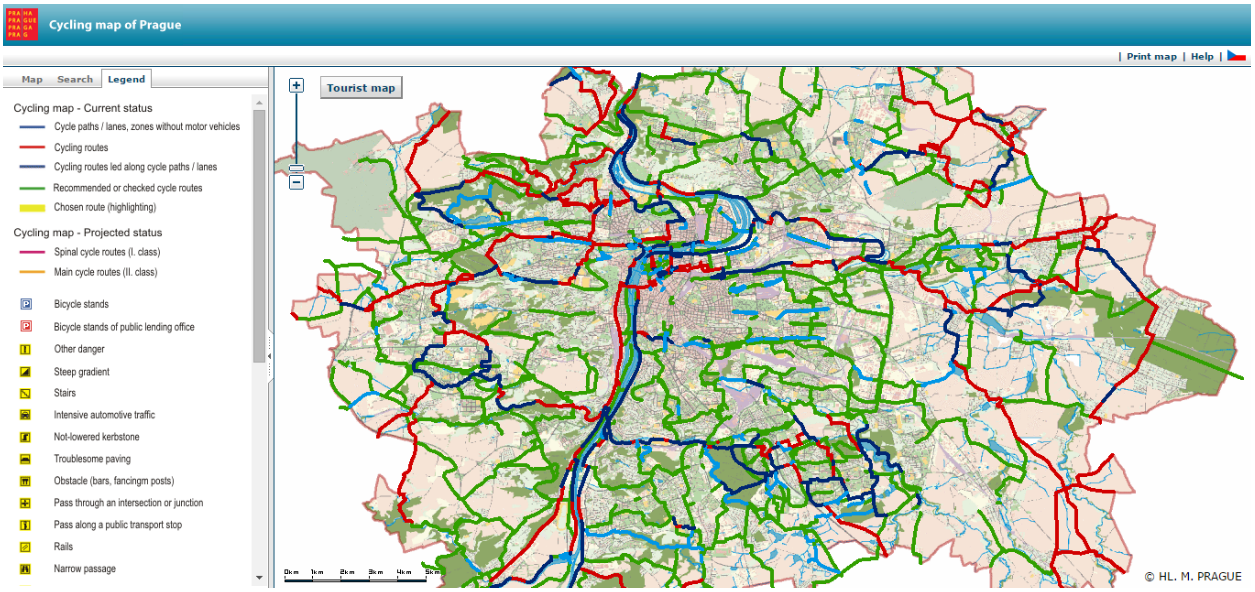


Figure 5.7: Bicycle Lines in Prague

Source: (Portál Hlavniho Města Prahy, 2015)

5.3 Comparison

El Paso Texas and Prague are two cities focusing in improving their respective bicycle transportation systems. In both cities, infrastructure is one of the one of most important factors. Prague has almost the double population than El Paso, and this is reflected in the amount of bicycle users. In Prague, 1% of the trips are made by bicycle, while in El Paso this is only 0.2%. This reflects a difference in cultures between these cities. Even so, bicycle as transportation mode is an important topic in making the cities more environmentally friendly.

The main difference in the bicycle infrastructure between Prague and El Paso is the amount of bicycle path. Prague has more miles (kilometers) of bicycle path than El Paso. Prague has different types of bicycle infrastructure that involve mixed use by motor vehicles, pedestrians and bicyclist. In El Paso, bicycle paths are usually in the main road next to motor vehicles lane. Moreover Prague has more devices dedicated to monitoring the traffic flow of bicycles. In El Paso there is not any device.

Chapter 6: Simulation of Operations of Bicycle Facilities

6.1 Review of VISSIM

PTV VISSIM in a microscopic multi-model software for traffic flow simulation. According to PTV, 2015) this software was development in Germany in 1992 by PTV Planung Transport Verkehr. VISSIM is a microscopic traffic simulation tool that models the flow and behavior of different types of vehicles on the roads, including passenger cars, trucks, buses, trams, light rails and etc. It can also handle pedestrians and bicycles.

Although VISSIM is originally dedicated to motor vehicle traffic, it now offers a reliable model for bicycles and pedestrians. The internal model has the ability to manage in detail link, connections and geometries to ensure a maximum possible accuracy. This way, using VISSIM traffic engineers can model, predict and solve the main problems of, for example, bicyclists riding in mixed traffic.

6.2 Base network

In this chapter, the main purpose is to simulate the current interaction of the bicyclists and motor vehicles in selected bicycle facilities. In this way, problems with certain design is demonstrated. The comparison is based on an intersections in El Paso, and one intersection in Prague. In the case of El Paso, the selected intersection is Mesa Street and Glory Road. This intersection is one of the main entrances to The University of Texas at El Paso. In Prague, the intersection modeled is on Reslova strat and Karlovo nam. This intersection is close to České vysoké učení technické v Praze Fakulty dopravní compus. This intersection is used by student to arrive to this campus Trams and motor vehicles can be founded at this intersection.

Another objective of the comparison is to find new ways to moderate the interaction between bicycles and motor vehicles, to improve bicycle safety. For both models some assumption are used:

- Bicyclists keep the right side of the right lane, unless they want to turn left at the intersection.
- For preparation of a left turn the bicyclist should switch to the left lane at a considerable distance before arriving at the intersection.
- All bicyclists have a constant velocity and not overpassing is allowed.
- Bicycles should respect the traffic signal as any vehicle.

These two intersection are model with this assumption.

6.2.1 Intersection in El Paso, Texas, U.S.

Figure 6.1 shows the location of the selected intersection in El Paso. The intersection has two lanes per direction with a median in Mesa Street. Moreover the two approaches in Mesa Street each has an exclusive left turn lane.

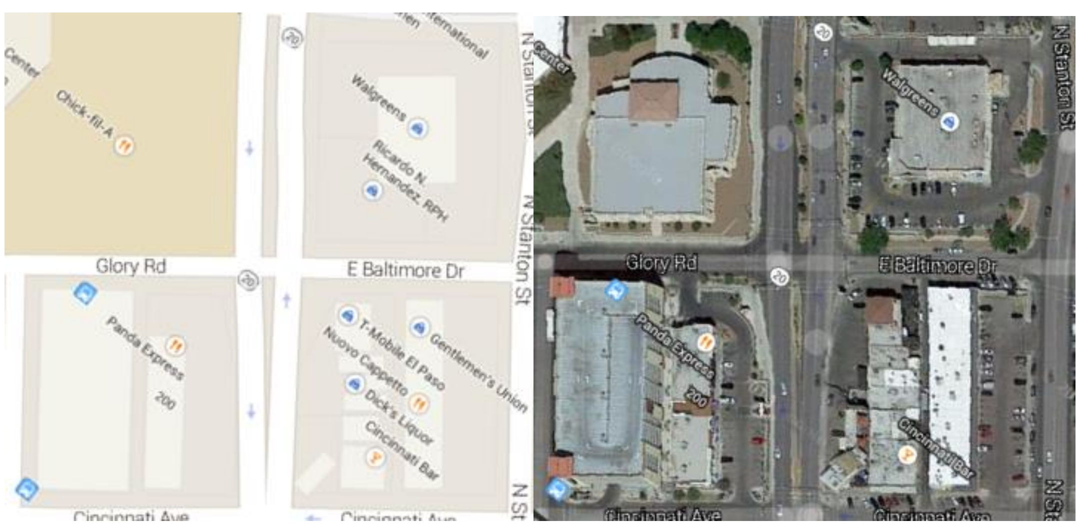


Figure 6.1: Mesa Street/Glory Road, El Paso Tx.

Source: (Google maps 2015)

Figure 6.2 shows a layout of the model in VISSIM. The higher risk for bicyclist at this model is the left turn movements from Mesa Street to Glory Road. This is because, bicycles have to cross as a pedestrian, It means crossing the Glory Road and wait for the green pedestrian signal in the east-west direction. **Figure 6.3** shows some of the conflict areas of the left turns for bicyclist.

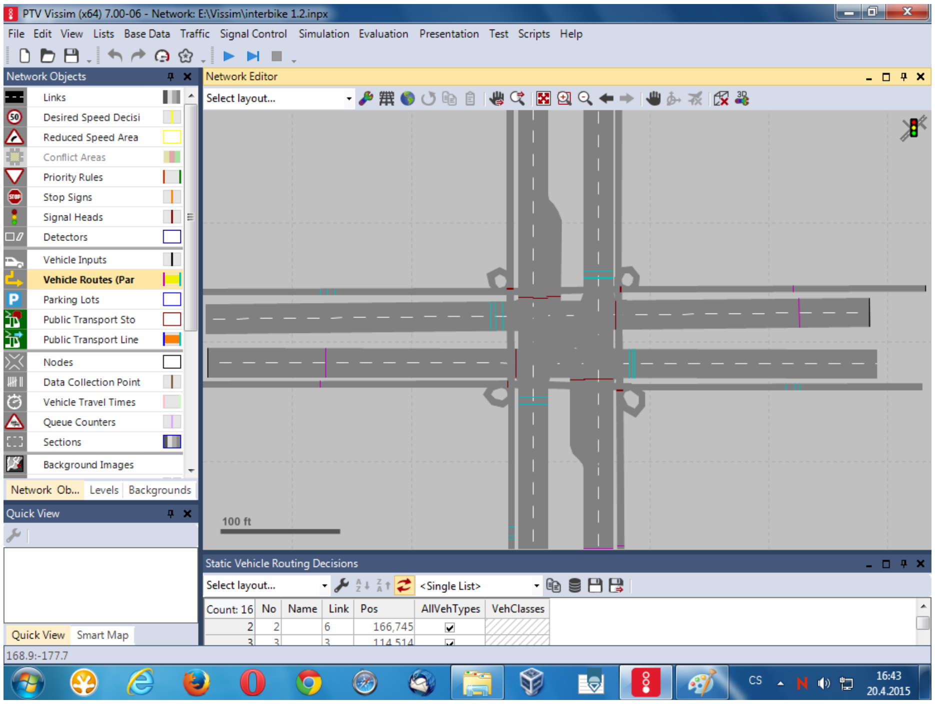


Figure 6.2: Mesa Street/Glory Road layout.

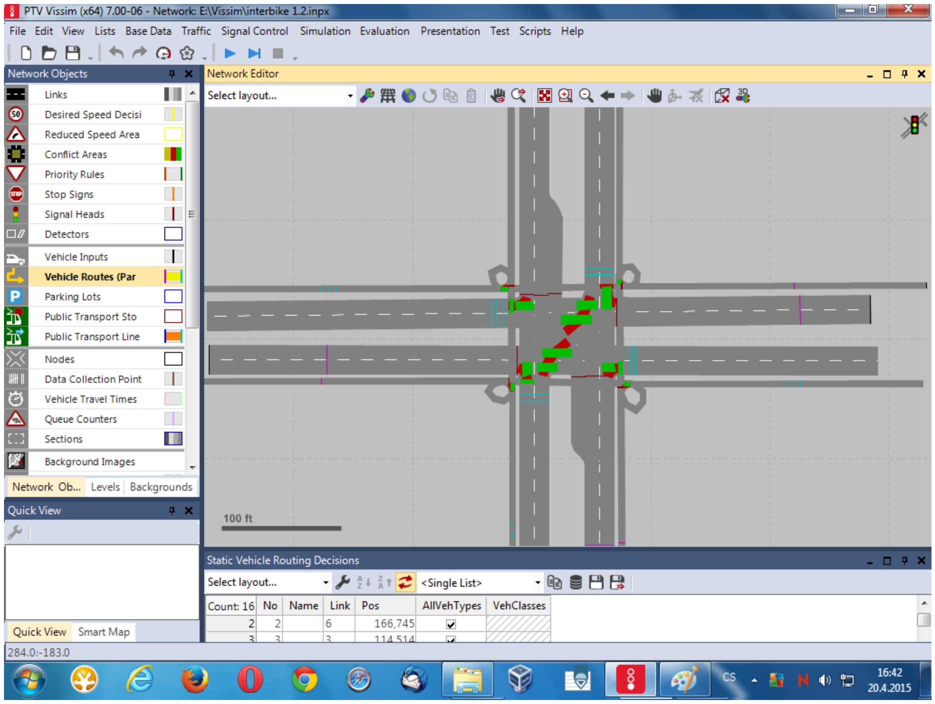


Figure 6.3: Mesa Street/Glory Road conflict zones.

6.2.2 Intersection in Prague, Czech Republic

The intersection in Prague is showed in **Figure 6.4**. This intersection is particular because it has three one-way approaches: north, south and east. The north approach has only southbound traffic, the east approach has only eastbound traffic, while the south “approach” accommodates only the southbound traffic. Moreover there is a tram line that runs in the street in north, south and east bounds. The signals plan is designed to separate conflicts between trams and bicycles.

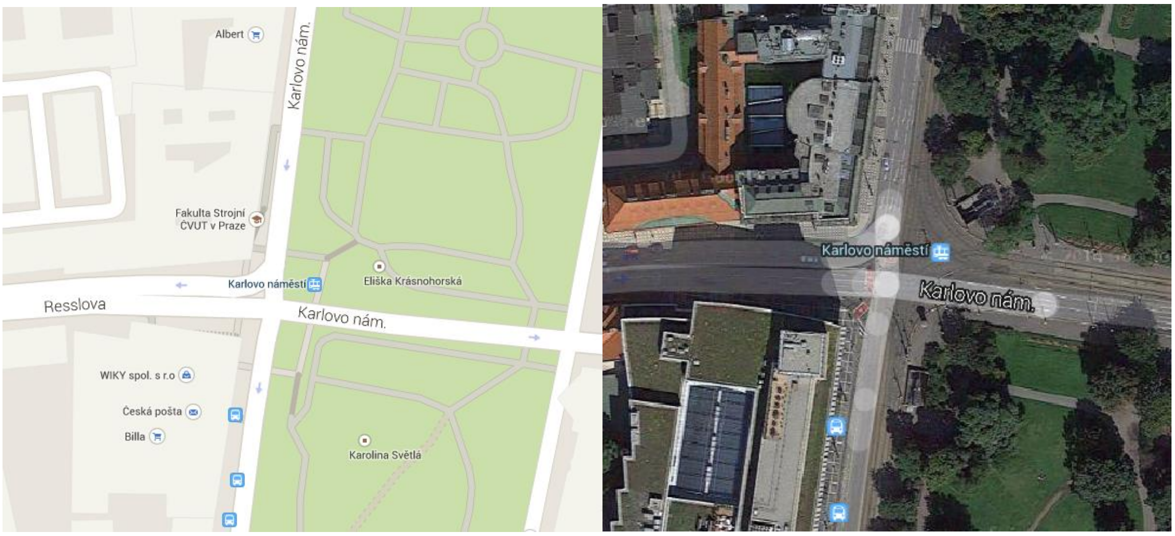


Figure 6.4: Reslova strat and Karlovo nam.

Source: (Google maps 2015)

The main problem with this intersection is when bicyclists cross this intersection in the north-south direction. In the north approach, the southbound traffic has two right-turn lanes. It means that if a bicyclist rides in this direction (in the rightmost lane) and wants to continue to the south, he/she should move two lanes to the left and continue to cross the intersection. **Figure 6.6** shows the layout of the intersection coded in VISSIM. When a bicycle coming from the north and is heading south, according to the Czech traffic regulation, the motor vehicles in the two right lanes should yield (or give way) for the bicycle to move to the left. To simulate this, several conflict areas are coded in the VISSIM model, **Figure 6.7** shows the main confliction areas at this intersection.

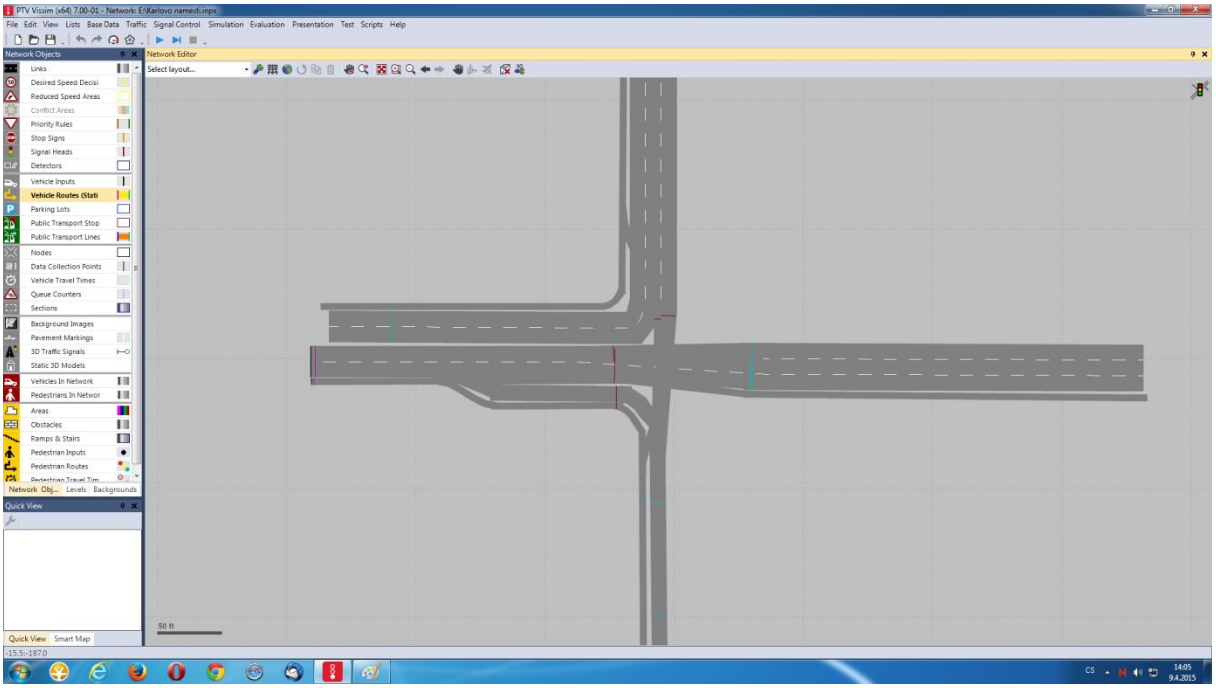


Figure 6.5: Reslova strat and Karlovo nam. Layout.

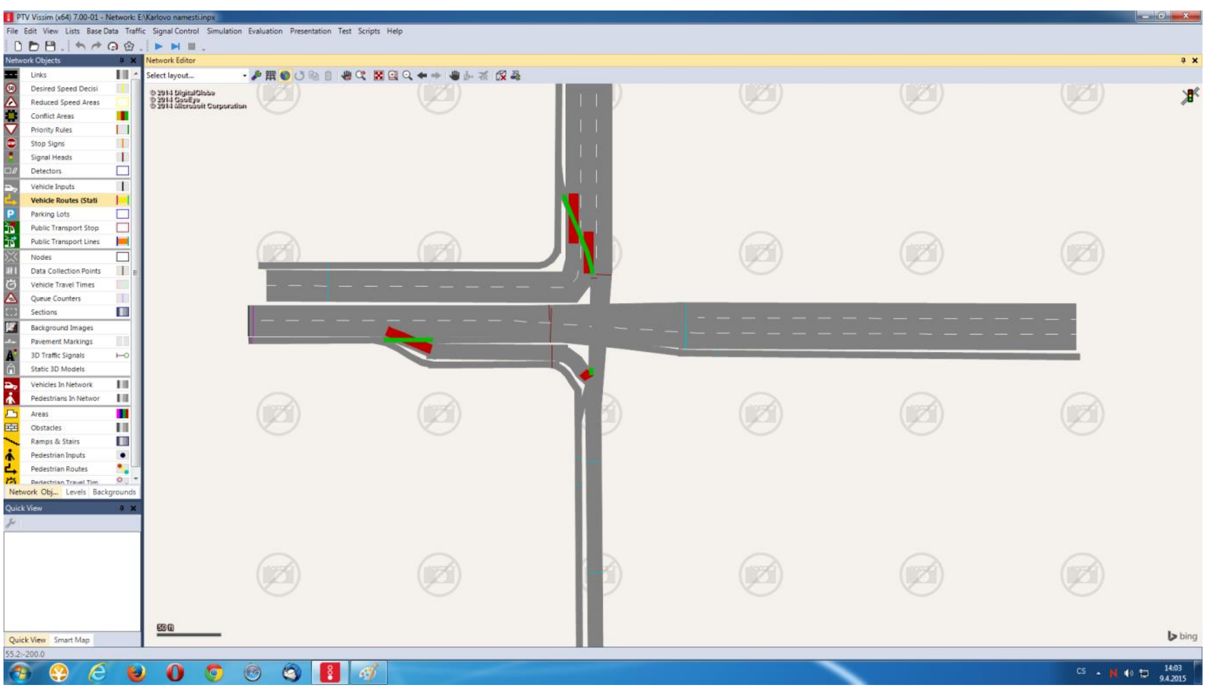


Figure 6.6: Reslova strat and Karlovo nam. Conflict zones.

6.3 VISSIM results

VISSIM simulation model was coded for each intersection to visualize the interaction between motor vehicles and bicycles in a real situation.

In the case of El Paso in Mesa Street and Glory Road, the bicyclist keep to the right side of the right lane, obeying the traffic signals as other vehicle. When a bicyclist wants make a left turn, makes a movement as a pedestrian and wait to the nea.t light. After that, he/she crosses the Mesa Street like a pedestrian. Figure 6.7 show the routes that bicyclist have taken. One example of the simulation is illustrated in Figure 6.8.

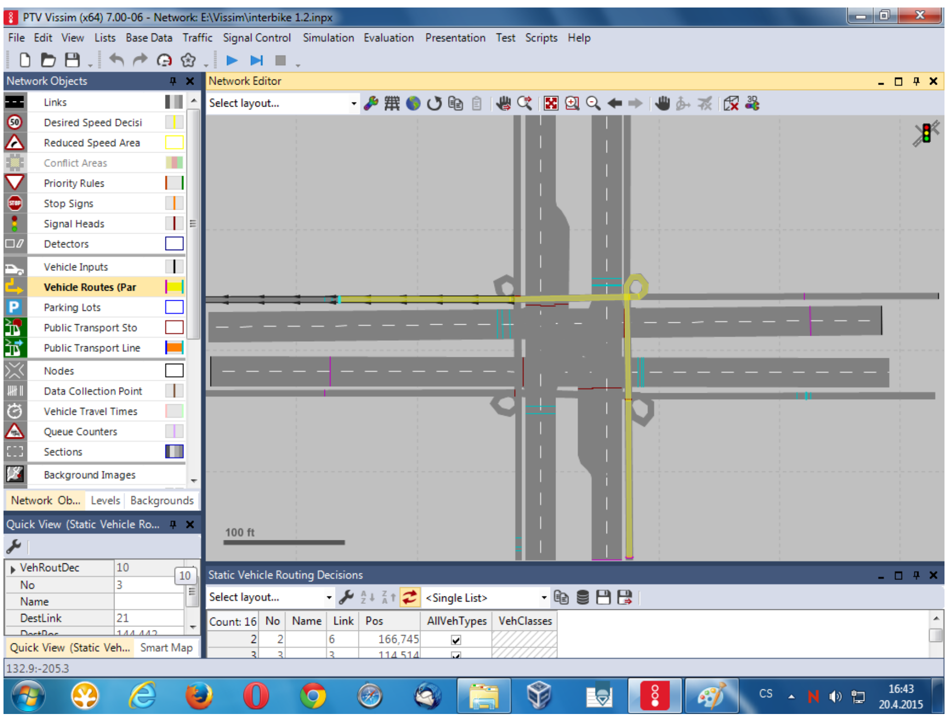


Figure 6.7: Mesa Street/Glory Road routes option.

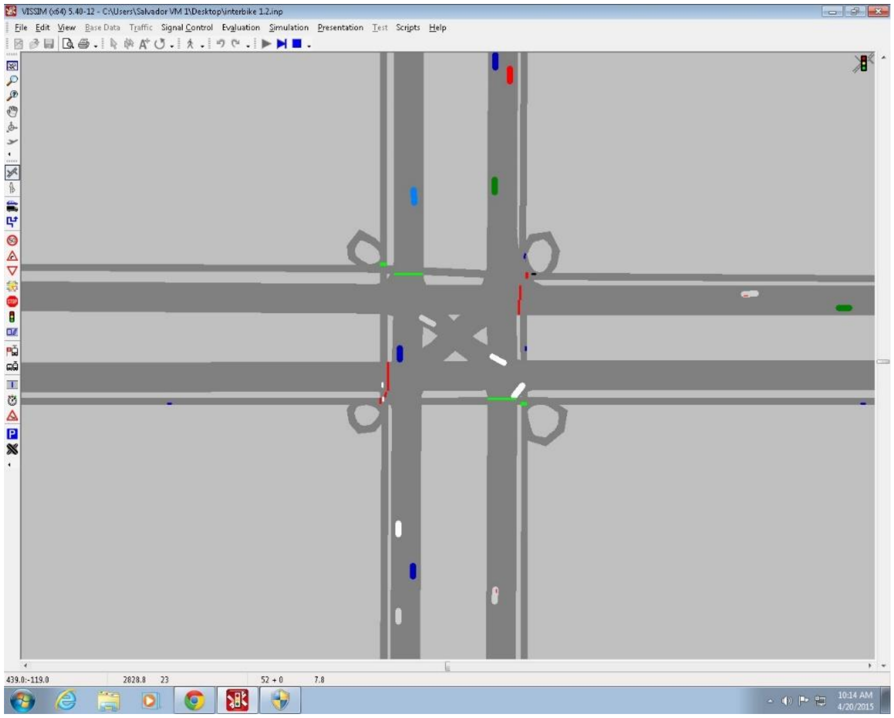


Figure 6.8: Mesa Street/Glory Road VISSIM simulation.

The intersection in Prague has a completely different structure than El Paso intersection, but the main bases of traffic flow remains. The most complicated case at this intersection in bicyclists from north approaching south, because the bicyclists have to move from the right side until the left lane to continue. After the bicyclist cross the intersection should take the right side of the road. Figure 6.9 Show the routes that a bicycle has to follow. Figure 6.10 shows a the simulation in VISSIM.

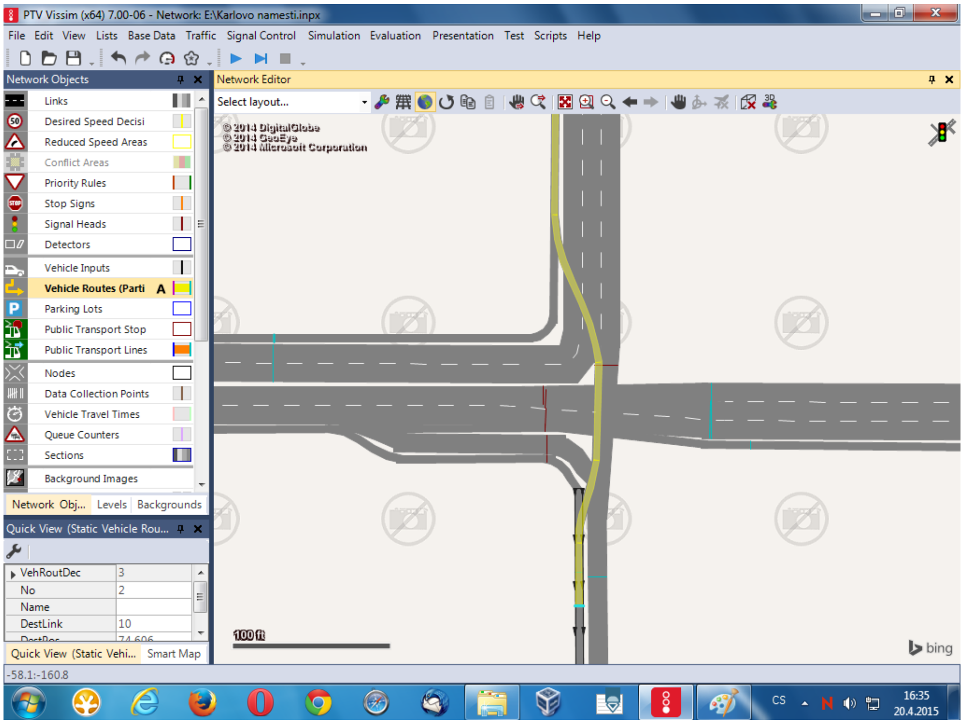


Figure 6.9: Reslova strat and Karlovo nam. Routes option.

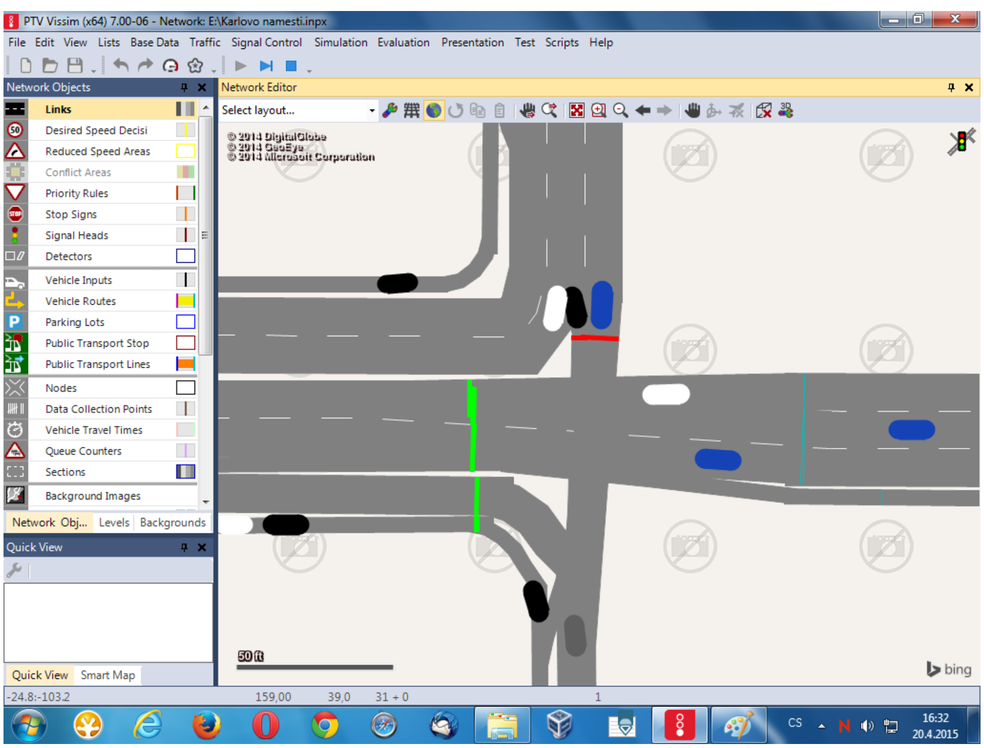


Figure 6.10: Reslova strat and Karlovo nam. VISSIM simulation.

6.4 Summary

VISSIM models have been coded to represent two intersections in two different countries. With VISSIM, one can visualize the problem faced by bicyclists when trying to use the intersections of certain designs. The models can be modified to represent the improvements to mitigate operational and safety issues.

Chapter 7: Conclusions

7.1 Thesis Summary

This thesis presents a comparison of bicycle infrastructure system, its design, and rules and regulation in El Paso Texas, U.S. and Prague, Czech Republic. Chapter 1 provides a general view of the impact of bicycle as transportation mode. The history of bicycle development and the creation of agencies and organizations involved in this transportation mode are described in Chapter 2.

The next 3 chapters are associated with the design and current condition of the bicycle infrastructure. Chapter 3 shows the laws and regulations that each country have to mediate bicycle use and provides the difference in the technical aspects used in the designs of bicycle infrastructure. Chapter 3 also describes the correct way of riding bicycle in mix traffic. In the next chapter, design guidelines and design criteria are covered. Finally Chapter 5 compares the current infrastructure situations in both cities.

In the last chapters, simulation of models of two intersections, one in El Paso and one in Prague, are coded in VISSIM to demonstrate how the selected rules of bicycles in mixed traffic can be visualized.

7.2 Contributions

This thesis shows the main characteristics of designing bicycle infrastructure. The main contribution is highlighting the most important in design criteria and guidelines. The results to compare two methodologies in bicycle infrastructure in transportation systems are as follows:

- Less traffic in the streets, the replacement of motor vehicles per bicycles increase the number of motor vehicles in streets.

- Les CO2 production and less consumption of fuels, bicycle is an ecofriendly transportation mode with cero CO2 emissions.
- People get healthier and less stressed, icycle is a transportation mode operate by human calories.
- Two different countries have the same purpose, both countries have been improving their bicycle infrastructure.
- Less investment in road maintenance, bicycle cause less damage in roads.

7.3 Recommendations for Future Research

The future research should be oriented to the need to collect bicycle count data. Having more precise data is very helpful for design process and make a forecast more accurate for bicycle infrastructure planning. Many methods of data collection can be placed in both cities according to their characteristics.

Some improvements can be based on the number of traffic accident that involve biycle with different transportation modes as, motor vehicles, bicyclists, pedestrians, among others. Classification of transportation accidents by categories will be a very important information when the designers try to the current designs.

VISSIM is a good tool for designers that want to visualize the improvement of current facilities, for urban planners and policy makes who that want to improve rules and regulation in roads. VISSIM has the capacity to simulate different scenarios. This software model the driver's behavior accordingly to the bicycle by laws and regulations.

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Appendix:

Curriculum Vita

Jose C Hernandez was born in El Paso, Texas on March 28, 1991 as son of Jose Hernandez and Patricia Rodriguez. After graduating from the University of Texas at El Paso in bachelor in Civil Engineering in 2013 he continued as graduate student in the same university as part of Transatlantic Dual Masters Degree Program. For the second year of masters he moved to Prague, Czech Republic to continue his studies in The Czech Technical University in Prague, Faculty of Transportation Sciences in September of 2014.

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