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Research paper

ALGORITHM FOR POSITIONING CYCLING INFRASTRUCTURE WITHIN THE EXISTING CITY ROAD PROFILE

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Abstract

This paper presents an algorithm for positioning cycling infrastructure within the existing cross-section of a roadway. The analysis focuses on roadways in urban areas, specifically city streets. The input data consists of the geometric elements of the site plan, longitudinal profile, and cross-sections. The algorithm first classifies them according to the street category criterion and conducts different analyses depending on whether the street falls into the category of arterial, collector, or local roads. At this stage, the algorithm examines the elements of the cross-section of the city roadway. Upon completing this step, a preliminary solution for the positioning of cycling infrastructure is formed, followed by a detailed analysis of all geometric elements of the street, considering the conditions for bicycle traffic in an urban area. Additionally, an analysis of the horizontal and vertical geometry of the examined street is conducted. If all criteria are met, the preliminary solution is adopted as the final one.

Key words: *Cycling infrastructure, Algorithm, Analysis.*

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1. INTRODUCTION

Due to climate change and the increasing carbon footprint caused by the high intensity of motor vehicle traffic using fossil fuels, there is a growing tendency toward alternative and environmentally sustainable modes of transportation. Cycling is a highly accessible, healthy, and environmentally friendly mode of transport. Good infrastructure must be adapted to the needs of cyclists to promote and affirm cycling as a sustainable means of transportation in urban areas.

Cycling infrastructure should be planned as a connected network at the city-wide level, providing enough space for the safe movement of all cyclists and preventing congestion, which is a common issue in cities characterized by high bicycle usage, such as Copenhagen. An analysis of Copenhagen's cycling infrastructure network has shown that, although the city generally has a well-developed network of bike lanes, there are significant inequalities in infrastructure accessibility across different parts of the city [1].

A key characteristic of a good cycling infrastructure network is its connectivity, which integrates it into the overall urban transportation system. An efficiently designed cycling infrastructure, including well-connected routes and protected lanes, is crucial for reducing detours and improving accessibility in urban areas. Cycling corridors significantly reduce deviations from the shortest path (RDR - Realized Detour Ratio), while a lack of connected lanes and physical barriers increase the distance cyclists must travel, thereby reducing the efficiency of bicycle transportation [2].

Providing cycling infrastructure is a way to encourage cycling, which can contribute to improving the urban environment and reducing the impact of traffic on climate. Although cycling infrastructure is relatively inexpensive, it still requires certain costs and occupies valuable urban space [3]. Therefore, it is important to assess its impact on the volume of bicycle traffic, considering the significance of location and infrastructure type.

A large number of cities around the world have negligible infrastructure for safe cycling. The development of urban transportation has historically been strongly oriented toward automobiles, resulting in well-connected road networks for motor vehicles, while cycling networks remain fragmented and underdeveloped [4]. Accordingly, systematic strategies are necessary to expand cycling infrastructure at the city-wide level.

The limitations of public transport and the need for physical distancing during the COVID-19 pandemic contributed to a significant increase in bicycle traffic in many cities worldwide, including London [5]. The pandemic highlighted the need for an urgent reorganization of existing city road profiles to support active transportation. The redistribution of traffic space in favor of walking and cycling should not be just a temporary measure but part of a long-term strategy for sustainable urban mobility. Identifying key transport corridors and optimizing the street network can significantly contribute to creating an efficient and resilient cycling infrastructure.

An effective cycling network should allow cyclists quick and direct access to desired destinations with minimal alternative detour routes. Although the total length of the cycling network is often measured, it does not necessarily guarantee good connectivity and functionality [6]. Strategic planning of cycling infrastructure can help optimize bicycle traffic, reduce dependence on cars, and improve the quality of life in cities. A comprehensive approach to the development of cycling infrastructure is necessary to make cycling a competitive and attractive option for daily commuting.

2. TRANSPORT INFRASTRUCTURE

The term "transport infrastructure" refers to the transportation network of a given area, encompassing all types of traffic present. For a better understanding and analysis of issues related to bicycle traffic in urban areas, it is necessary to consider all aspects that directly and indirectly influence this mode of transport.

2.1. Categorization of the urban road network

The urban road network has a dual purpose: to connect different parts of the city and to ensure the efficient servicing of facilities and locations directly adjacent to the roadway [7]. Based on these tasks, the road network of an urban area can be divided into two categories:

- Primary road network (urban)
- Secondary road network (local)

The primary road network aims to provide traffic connectivity, accommodating a larger number and variety of vehicles traveling at higher speeds. The roads within the primary network are designed for the smooth flow of motor vehicle traffic and include:

- Urban highways
- Major city arterials
- City arterials
- Collector streets

Urban highways are sections of long-distance roads that pass through densely populated urban areas. They connect the city with higher-ranking national roads as well as the international road network. Due to the high speeds of motor vehicle traffic, urban highways are constructed without the possibility of longitudinal bicycle and pedestrian traffic.

Major city arterials are roads with exceptionally high traffic capacity that pass through the city center and connect it with out-of-town connecting roads. They facilitate the flow of fast passenger traffic, public urban transport, and the routing of freight flows.

City arterials connect entire parts of the city with specific activity centers and can rely on regional roads. They are intended for both individual and public passenger transport. Pedestrian and bicycle traffic is accommodated within the designated roadway width.

Collector streets link the primary and secondary road networks of an urban area and distribute traffic at the level of urban planning units. They are intended for both individual and public motor vehicle traffic, as well as for pedestrian and bicycle movement directly alongside the roadway.

The secondary road network consists of roads primarily intended for access to specific facilities and locations. This network level is characterized by a reduced emphasis on conventional traffic parameters such as flow and speed, as high speeds and intensive traffic flows are fundamentally undesirable and unacceptable [7]. Elements of this segment of the road network include:

- Access streets
- Parking areas

Access streets belong to the most numerous category of urban roads and serve the function of directly providing access to adjacent facilities, such as commercial and residential buildings. Bicycle traffic on access streets can be accommodated either at the roadway level or on a designated section of the pedestrian path.

Parking areas are transportation infrastructure facilities designed to serve specific locations, intended for vehicle stopping and parking. In the context of widespread individual motorization, parking areas have become a highly scarce yet essential necessity in urban areas.

2.2. Basic concepts and characteristics of cycling infrastructure

Cycling infrastructure refers to the entire traffic area designated for bicycle traffic, as well as facilities for parking and storing bicycles. This paper will focus on areas designated for cycling traffic in urban environments, which include:

- Cycling paths
- Cycling lanes
- Cyclists on the roadway

A cycling path is a part of the traffic surface designated for the movement of bicycles and motorized bicycles, which is physically separated from the roadway or placed at a different level. In populated areas, this path can be separated from the roadway by a curb, while outside populated areas, it is secured with a steel protective fence.

A cycling lane is a designated longitudinal section of the roadway intended for the movement of bicycles and motorized bicycles. It is not elevated in relation to the roadway, and to enhance safety, its surface is often painted red.

The concept of cyclists on the roadway means that bicycle traffic takes place alongside motor vehicles, with appropriate traffic signaling. This model is applied in urban areas where there is insufficient space to build separate cycling infrastructure. It is also more suitable for roads with lower motor traffic intensity.A cycling path is a part of the traffic surface designated for the movement of bicycles and motorized bicycles, which is physically separated from the roadway or placed at a different level. In populated areas, this path can be separated from the roadway by a curb, while outside populated areas, it is secured with a steel protective fence.

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The dimensions of the cross-sectional profile of the roadway are defined by the following profiles:

- Traffic profile represents the space in which a moving vehicle can be found. This profile consists of the transverse section of the reference vehicle, the space required for vehicle movement, and the central protective width between vehicles [8].
- Clearance profile includes the traffic profile, edge protective width, and protective height. No permanent obstacles are allowed within the clearance profile. The dimensions of the clearance profile are defined by regulations [8] and must be adhered to when designing the roadway.

Figure 1 shows the traffic and clearance profiles of one-way and two-way cycling surfaces.

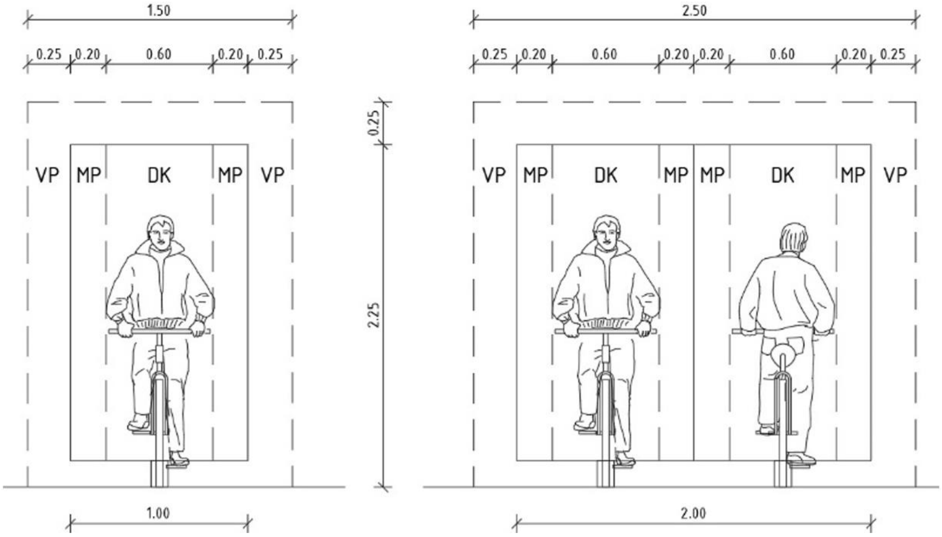

Figure 1. Traffic and free profile of the cycling surface

The labels for width in Figure 1 represent:

- DK – bicycle dimension
- MP – maneuvering space
- VP – safety space

3. DESCRIPTION AND DEVELOPMENT OF THE ALGORITHM

The algorithm presented in this paper serves the function of determining the position of the cycling surface within the existing cross-section of the urban roadway. Additionally, it analyzes the geometric elements of the site plan and the longitudinal profile of the street in question. According to its organizational structure, the algorithm can be divided into five main steps (Figure 2).

1. Input data
2. Defining the street category
3. Analysis of the cross-sectional profile
4. Analysis of the geometry of vertical and horizontal street characteristics
5. Proposed solutio

In the first step, all necessary data for its operation are entered. These data primarily refer to the geometric elements of the roadway, as well as traffic data. The following data are entered:

- Street category
- Radius of horizontal and vertical curves
- Longitudinal and transverse road slopes
- Orientation of the transverse slope
- Traffic flow of motor vehicles
- Presence of parking lanes
- Presence of public transport lanes

- Number of lanes for motor vehicles and traffic lanes
- Traffic flow regime
- Maximum allowed speed of motor vehicles
- Geometric characteristics of the cross-sectional profile

In the second step, the further course of the analysis is determined. Specifically, in this step, based on the street category, the algorithm defines how the analysis will proceed through the next step. Figure 2 schematically shows the algorithm.

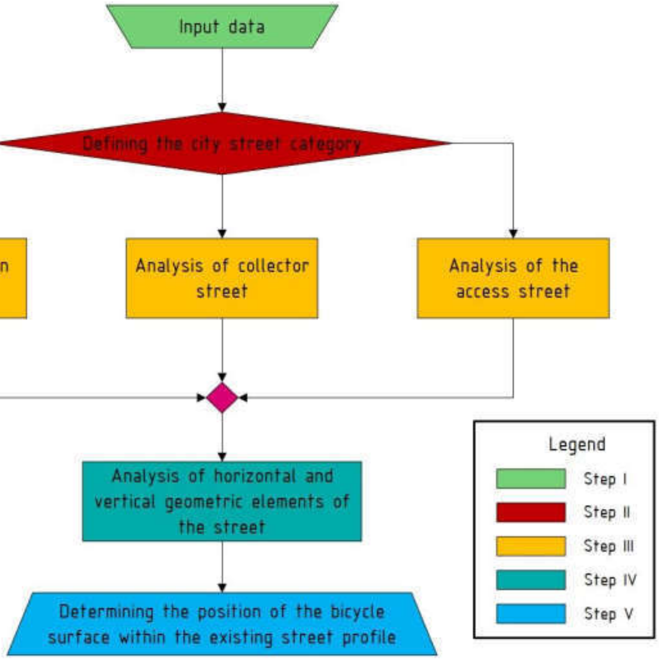

Figure 2. Schematic representation of the algorithm

The third step of the algorithm deals with the analysis of the geometric elements of the cross-sectional profile of the street in question. This step varies depending on the category of the roadway and can, therefore, be divided into three parts. Each part is dedicated to analyzing a specific category of roadway – arterial, collector, or access.

When analyzing an arterial road, the algorithm examines all key factors that directly or indirectly affect bicycle traffic and infrastructure. Since arterial roads typically have high traffic flow and high motor vehicle speeds, there is a tendency to isolate bicycle traffic from the roadway. This analysis considers the width of pedestrian paths, the presence of tree lines, and street furniture for pedestrians (e.g., benches). After reviewing these factors, in this step, the algorithm proposes a preliminary location for the cycling surface within the arterial road profile. Then, depending on whether the proposed solution is a cycling path or a lane, further analysis follows. If the solution involves a cycling lane, the algorithm considers the presence of a public transport lane and proposes solutions to increase bicycle traffic safety. Conversely, if a cycling path is proposed, the algorithm analyzes the proximity of public facilities that people naturally gravitate toward, to consider the option of positioning the path closer to these facilities. This would make the proposed solution more attractive to cyclists.

In the analysis of the collector road, the algorithm checks the traffic flow method. Depending on how the traffic is organized, it verifies the widths of pedestrian paths.

Additionally, the algorithm examines whether the width of the pedestrian paths is constant or variable. These parameters are crucial due to the desire to physically separate bicycle traffic from motor vehicle traffic, if possible. In the case of one-way streets, the algorithm also considers the number of traffic lanes and the presence of parking lanes. At the end of this step, the algorithm proposes a preliminary location for the cycling surface within the collector road profile.

In the part that deals with the analysis of access streets, the first step is to determine whether the street is one-way or two-way. For two-way streets, the algorithm checks the motor vehicle traffic flow and the width of pedestrian paths. One-way access streets undergo a more extensive analysis. This includes checking the number of traffic lanes, the presence of parking lanes, the traffic flow, and the width of pedestrian paths. Upon completion of this step, a preliminary solution for the location of the cycling surface is proposed.

The fourth step of the algorithm involves analyzing the horizontal and vertical geometric elements of the urban roadway (Figure 2). The necessary input parameters for this phase are:

- Number of vertical and horizontal curves
- Number of grade changes
- Design speed

Due to the potentially larger number of data points passing through the same analysis, this step is organized by applying "for" and "while" loops. The first loop in this step checks if the radius of horizontal curves in the roadway are greater than the minimum required value for cycling surfaces. The condition of this loop includes a counter that tracks how many times the loop has repeated. This solution is applied to avoid the occurrence of an infinite loop, which would prevent the algorithm from completing its work.

Next, the analysis of vertical curvature and longitudinal slopes follows. In this part, an array of elements is formed, where each element represents an individual value of the longitudinal slope of the roadway. The values in the array are entered in the same order in which they appear, observed in the direction of increasing stationing.

After the array is formed, a "for" loop is applied to iterate through the array and analyze the values of two consecutive elements, i.e., the values of two consecutive longitudinal slopes. Depending on the values of the longitudinal slopes, the algorithm checks whether additional vertical curvature is needed or not, with the restriction that the radius value cannot be smaller than the minimum allowed.

The final part of this step analyzes the length of the section with a longitudinal slope greater than 10%. This analysis is conducted using a new "for" loop, which iterates through the previously formed array and checks whether the given condition is met.

After this step, the algorithm verifies if all the parameters are in accordance with the proposed preliminary solution. If they are, the preliminary solution is accepted as final, which marks the fifth step and the end of the analysis.

The developed algorithm provides a clear and systematic approach to planning cycling infrastructure within existing urban road networks. It enables the adoption of optimal solutions that are safe, functional, and adapted to the urban environment.

Its implementation can significantly contribute to the development of a safer and more connected cycling network, making cycling more comfortable and accessible to all citizens.

4. CONCLUSION

Cycling infrastructure plays a key role in creating sustainable and functional cities, and this paper presents an algorithm that helps in its efficient planning. Through the analysis of different categories of urban streets and their geometric characteristics, the algorithm allows for optimal positioning of bike lanes and tracks, considering safety, space, and traffic flows.

The results of the research show that arterial roads are the most challenging for integrating cycling traffic, while collector and access streets offer more opportunities for adaptation and further flexibility for designers to optimize the proposed solution. It is crucial for cycling facilities to be well-connected and safe in order to promote cycling as a sustainable alternative to car transportation

By applying this algorithm, cities can improve their cycling networks, which not only enhances the mobility and safety of cyclists but also reduces traffic congestion and the negative impact on the environment.

Furthermore, testing the algorithm in real urban conditions would allow for its calibration and adaptation to the specific needs of cities of different sizes and structures.

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