THE BALTIC JOURNAL OF ROAD AND BRIDGE ENGINEERING
2024/19(3)

ISSN 1822-427X/eISSN 1822-4288
2024 Volume 19 Issue 3: 102–131
https://doi.org/10.7250/bjrbe.2024-19.644

BICYCLE INFRASTRUCTURE SAFETY ASSESSMENT FROM THE PERSPECTIVE OF URBAN DEVELOPMENT SPECIALISTS AND ENGINEERS

MIGLĖ ZABIELAITĖ-SKIRMANTĖ*, MARIJA BURINSKIENĖ

Faculty of Environment Engineering, Department of Roads, Vilnius Gediminas Technical University, Vilnius, Lithuania

Received 17 May 2024; accepted 30 July 2024

Abstract. The safety of bicycle infrastructure is a primary factor influencing bicycle travel. While cyclists' perspectives on infrastructure safety are extensively studied, they are merely the end users. Decisions on infrastructure design are made by engineers and urban development specialists. Therefore, it is crucial to determine if these professionals' safety assessments align with those of cyclists. A qualitative survey was conducted with 5 expert engineers and 5 urban development specialists, each having 5 to 20 years of experience in transportation infrastructure planning. Kendall's coefficient of concordance W was used to assess the compatibility of their opinions. The results showed significant compatibility: W = 0.697 for engineers and W = 0.511 for urban development specialists. Seventeen cycling infrastructure installation schemes were evaluated. Both engineers (M = 10.0, SD = 0.0) and urban development specialists (M = 9.8, SD = 0.44) indicated the DT_2 option as providing the greatest sense of security, where the bicycle path is physically separated from both the carriageway and pedestrian path. The key findings reveal agreement on the safety of straight-street segments of bicycle infrastructure but diverging opinions at intersections zones. Urban development specialists are

* Corresponding author. E-mail: migle.zabielaite-skirmante@vilniustech.lt

Miglė ZABIELAITĖ-SKIRMANTĖ (ORCID ID 0000-0002-0207-0171)
Marija BURINSKIENĖ (ORCID ID 0000-0002-6685-5840)

influenced by existing practices and legal frameworks lacking detailed cycling infrastructure guidelines at intersections. Engineers align more closely with cyclists' perceptions, emphasising physical separation and speed reduction measures. The study concludes that urban development specialists need to better understand cyclists' needs and prioritize safer infrastructure solutions.

Keywords: behavioural shifts, bicycle intersection safety, cyclist safety evaluation, engineering safety solutions, infrastructure efficacy, sustainable mobility, urban infrastructure planning.

Introduction

The United Nations (United Nations, 2015) estimated that by 2050, around 70% of the world's population will live in cities. This high level of urbanization identifies that cities will face major challenges in terms of environmental, economic and social sustainability due to the problems caused by urban growth (Bibri et al., 2020). In most cities, the car is the main means of transportation, which pollutes the environment and generates noise, which has a negative impact on air quality and on people's psychological and physical well-being. With increasing levels of urbanisation and a larger population, changes are needed both in travel behaviour and in the transport system itself. Cities around the world are striving to introduce more sustainable transport systems due to existing congestion, air pollution, and high accident rates (European Commission, 2011). Many researchers recognise the need for a sustainable transport system. The development of a sustainable urban transport system must include areas such as mobility and quality of life (Sodiq et al., 2019). A sustainable transport system is one that supports mobility and accessibility in the long term, considering environmental, economic, and social aspects (McQueen et al., 2021). Sustainable urban mobility requires addressing transport-related urban environmental problems in a comprehensive way, through an integrated approach to transport and urban planning, taking into account a wide range of – sometimes conflicting – economic, social, and environmental criteria (Anastasiadou & Gavanas, 2023). Facilitating walking and cycling should become an integral part of urban mobility and infrastructure design (Gössling et al., 2016). Meeting the transport needs of cities by bicycle would meet the essential environmental, social, and economic needs of a sustainable transport system. Cycling is less polluting because it is powered by human physical strength, improves people's physical and psychological well-being, and its infrastructure is cheaper and less space consuming than cars.

Although it is obvious that bicycles should be one of the main means of transport in the city, the real situation and urban planning prioritise car transport. A study by Gössling et al. (2016) carried out in three neighbourhoods in Freiburg, Germany showed that most of the street space was taken up by the carriageway and parking spaces, with only 1.3 to 4.1% of the street infrastructure occupied by bicycle lanes. A study by Erbas Melis & Okumus Prini (2023) showed that students living on campus most often did not choose to use a bicycle as a means of transport for their commute to university, either because they did not have one (46.28%) or because they did not feel safe (22.31%). To ensure sustainable development of the transport system and to make streets more than just corridors for transport needs, urban streets must be redesigned to make them safer and more attractive to citizens. To date, few studies have examined the impact of street redesign on residents' quality of life (Aldred et al., 2019; Blitz et al., 2020). The results of the study by Lanzendorf et al. (2022) showed that the reduction of the infrastructure of vehicles and the parallel installation of cycle lanes have a positive impact on the quality of life of urban residents. Therefore, considering the potential to improve the living conditions of residents, Gössling et al. (2016) propose to reduce parking spaces in residential areas. To promote the use of non-polluting modes of transport in urban areas, it is essential to provide traffic calming zones and to extend the network of cycling infrastructure (Anastasiadou & Gavanas, 2023).

Street redesign and humanisation projects are being carried out to ensure sustainable mobility and to adapt the city's streets not only for transport links but also to bring people back to them. One of the typical street redesign solutions is the installation of bicycle infrastructure, which aims to increase the number of trips made in the city by non-polluting means of transport. However, cyclists are not only encouraged to ride bikes due to the presence of the infrastructure but also by the feeling of safety when using this infrastructure. Despite the long-term development of projects, the number of cyclists in the city usually remains low, which means that the infrastructure does not provide cyclists with a sufficient sense of security. In this regard, we conducted a qualitative survey of urban development specialists and engineers to determine whether they value safe infrastructure as the user of it, cyclists.

The first section of the paper presents a literature review on the humanisation projects of streets, perceived safety, and cycling infrastructure. Section 2 describes the methodology used in the study. Section 3 presents infrastructure schemes with descriptions that were present during the evaluation study. Section 4 describes the results obtained. Section 5 presents a discussion comparing the results with existing legal documents in Lithuania. Section 6 presents the conclusions.

1. Literature review

Due to the long-term development of cities to ensure transport capacity, modern cities face problems of congestion, pollution, and injuries to road users (Guo et al., 2023). The European Commission (European Commission, 2023) report pointed out that although Europe encourages cycling, cyclists' deaths have remained among the highest in Europe in recent decades. It also notes that these deaths are caused by poorly designed infrastructure. Accidents involving serious injuries to pedestrians or cyclists can be avoided by reducing vehicle speeds to 30 km/h (World Health Organization, 2021). However, appropriate speed limits should be applied on streets that are designed for shared use by function or where cycling is organised on the carriageway alongside transport. In the USA, 1600 municipalities have adopted street design guidelines aiming to achieve Complete Street (CT) principles (Maisel et al., 2021). European cities such as Vilnius (Lithuania), Helsinki (Finland), Oslo (Norway), and London (England) also have such guidelines.

Street design guidelines used in both Europe and US share the same goals: to ensure safety for all road users on urban streets while at the same time delivering social and environmental benefits (National Complete Streets Coalition, 2011). As Hui et al. (2018) pointed out, streets have different functional purposes depending on traffic flows, type of development and the surrounding environment. Therefore, CT cannot always be applied to all city streets, and the principles should be applied to streets that are intended to provide access for walking, public transport, and cycling. Such streets are identified as service and ancillary streets, with vehicle speeds of 50–30 km/h, dominated by a variety of service provision locations or workplaces. Rapid streets are characterised by speeds above 50 km/h and are designed to provide connectivity between different areas of the city. Although many countries and cities apply CT principles, there is insufficient analysis of the projects implemented and their impact on the traffic situation.

Santa Monica, California, part of Ocean Park Boulevard was redesigned using CT principles. The project included widening sidewalks, installing benches, planting 100 new trees, upgrading bike lanes and pedestrian crossings, and adding a safety island. Although the project did not reduce vehicle traffic flow, it did increase pedestrian flow by 37% and bicycle flow by 37%, and improved street air quality (Shu et al., 2014).

The CT project of Main Street in Williamsville, New York, project included speed reduction measures, wider pedestrian sidewalks in intersection areas, plantings between the roadway and pedestrian sidewalks, safety islands, left turn lanes, parking spaces, and a reduction in the number of traffic lanes. The study found that there were no changes in vehicle traffic flows on the street, no reduction in driving speeds, no increase in pedestrian and bicycle flows, but residents felt more satisfied with the redesigned street environment (Maisel et al., 2021).

The project of Future Streets in Mangere, Auckland, New Zealand included cycle lanes installation, raised pedestrian crossings, speed humps, and widened sidewalks. The study found that the implementation of CT solutions resulted in a safer, more welcoming, and friendly environment for pedestrians. Although interactions between drivers and pedestrians were found to have increased, road users' manoeuvers became more predictable and vehicle speeds decreased (Hirsch et al., 2022).

Jensen et al. (2017) investigated whether street redesign using CT principles and the installation of public transport stops, widening of pedestrian sidewalks, and the installation of bicycle lanes on North Temple Street in Salt Lake City, Utah increased the number of pedestrians in adjacent neighbourhoods. It was found that residents living close by walked more and felt safer on the upgraded street.

Bian et al. (2023) analysed two existing CT projects. The Government St. in Baton Rouge project provided 6.4 km of bicycle lanes on the street, the widening of the pedestrian sidewalks and the reduction of the traffic lanes in the carriageway from 4 to 3. A reduction in vehicle speeds was observed during the morning peak from 43 km/h to 40 km/h. Another project in Thibodaux, Lafourche Parish, a 4.3 km stretch of a street was marked with cycle lanes and widened sidewalks. However, vehicle speeds were found to increase during the morning peak from 53 km/h to 62 km/h.

In Vilnius, a study was carried out to investigate how the application of CT principles had changed the traffic situation on the streets. On T. Ševčenkos Street, the number of lanes was reduced, a roundabout was built, parking spaces were added and sidewalks were widened. The reduction in the number of lanes and lane widths was found to reduce instantaneous vehicle speeds (Mockus, 2023).

The most frequent re-development of the city's streets, as demonstrated by the solutions implemented in the CT project, is to expand pedestrian paths, install bicycle paths, reduce vehicle lanes, and install speed reduction measures. In these examples, the reduction in lanes usually have not led to a reduction in traffic speeds, which is a key factor in determining the survival of road users in an accident. Therefore, although the installation of speed reduction measures may appear to reduce speeds, in reality the expected effect on speed is not obtained. Maisel et al. (2021) noted that street redesign in accordance with CT principles ensures sustainability principles by creating an attractive environment that encourages daily travel by clean means. Once the CT principles and commonly used solutions have been identified, it is also important to know what the main factors are that contribute to the feeling of safety of road users on the streets.

1.1. Perceived safety

It is commonly assumed that the low number of journeys made by bicycle is due to the lack of infrastructure, but the choice to cycle is influenced by a wide range of factors, including social, economic and environmental factors (Zabielaitė-Skirmantė & Burinskienė, 2023). O'Reilly et al. (2024) found that the provision of cycling infrastructure alone would not increase cycling trips and that social and cultural attitudes should be change for cycling infrastructure to be effective. The provision of bicycle paths or lanes may encourage some people to travel by bicycle, but to see a change in travel behaviour, it is necessary to ensure the safety of cycling infrastructure (Reggiani et al., 2022). However, the absence of accidents on a street or at intersections does not mean that traffic conditions are safe or attractive.

A bicycle path separated from the carriageway is the safest in terms of design, but accident or unsafe situations can be caused by downhill slopes, pedestrians, or parking spaces adjacent to the bicycle path, failure to maintain safety distances between road users, pedestrian crossings, and public transport stops near cycle paths. Additionally, the provision of separate bicycle lanes on the streets requires additional space, which is often difficult to find, so infrastructure is often built not to be the safest. Studies have also shown that cyclists use detours to avoid intrusive traffic infrastructure that is perceived as unsafe, including busy road sections or crossings (Gössling et al., 2019; Van Cauwenberg et al., 2018).

A sense of security is a fundamental human need that allows people to function more comfortably, freely, and efficiently in their local environment (Gehl, 2010). If a cyclist does not feel safe using the infrastructure, they will not choose to travel by bicycle. Subjective safety is an essential condition for the design of infrastructure, which will determine its attractiveness to new transport users (Gössling & McRae, 2022). It is the feeling of safety that determines the choice of vehicle (Friel et al., 2023). High traffic volumes, conflicts with motorists, and speeding reduce subjective safety (Müggenburg et al., 2022).

To increase the number of people making daily trips by bicycle, it is necessary to determine what kind of environment is comfortable and perceived as safe for cyclists (Fitch et al., 2022). Cyclists with different cycling skills feel differently when using the same infrastructure. Consequently, infrastructure should be designed with the comfort of inexperienced cyclists in mind and assess whether they will want to cycle (Fitch et al., 2022). To some extent, cyclists' perceived safety is influenced by car flow, vehicle speed, and infrastructure design. Therefore, infrastructure changes may be a good way to improve cyclists' perceived safety and increase the attractiveness of cycling as a mode of transport (Rivera Olsson & Elldér, 2023).

1.2. Security of cycling infrastructure

The literature is rich in analysis of cycling infrastructure solutions and their influence on perceived safety. The most common methods to measure perceived safety are surveys of cyclists, in which they indicate when and why they felt unsafe (Friel et al., 2023; Müggenburg et al., 2022), the use of a simulator and the analysis of recorded cycling trip data, such as gaze analysis (Guo et al., 2023) or the analysis of traffic accident data (Bian et al., 2023). The most analysed designs are those of bicycle lanes and paths and their relation to perceived safety.

Nazemi et al. (2021) analysed all options for bicycle infrastructure in the street profile (bicycle lanes, bicycle paths) and found that the safest way for cyclists to feel safe was to ride on a separate bicycle path, separated from both cars and pedestrians. It is clear that a separate bicycle path protected from both cars and pedestrians is the option that offers the most safety, but there is rarely enough space in cities to easily provide this option. A 3.5 m wide bicycle path was perceived to be 83% safer than a 2.5 m wide one (Gössling & McRae, 2022). Cyclists feel freer because they have a larger area to manoeuvre, and slower cyclists can be overtaken by others. Wider bicycle lanes can also allow novice cyclists to use bicycles who do not yet have good cycling skills and feel like they are obstructing other cyclists.

Participants perceived the shared space between pedestrians, bicycles, and cars as the safest (Müggenburg et al., 2022). However, a study by Rivera Olsson & Elldér (2023) shows that cyclists feel safer when using a bicycle street when it has marked cycle lanes and cycle symbols on the carriageway. Traffic flows were also found to be related to feelings of safety when using cycle lanes. The feeling of safety depends on whether bicycles are given priority in the city.

Often bicycle lanes are placed next to parking spaces. Gössling & McRae (2022) found that horizontal markings increased the sense of safety for cyclists by 16%. Huemer et al. (2022) analysed whether horizontal marking options had a different impact on the feeling of safety and found that separating the bicycle lane with two continuous horizontal lines was the best option compared to dotted lines or no lines.

Cyclists feel safer when the bicycle lane in the carriageway is separated not only by markings but also physically (Vasilev et al., 2023). In earlier study, Vasilev et al. (2022) also found the same results, which analysed the safest separation of bicycle lanes for cyclists. It was found that cyclists would feel safest if they were separated from cars by concrete blocks, but if this solution could not be implemented, the same effect could be achieved by planting green areas. Guo et al. (2023) analysed the design of a protected bicycle lane with bollards. The results showed that cyclists concentrated more on the road when using a protected bicycle lane, but their speed was lower due to the perception of an obstacle nearby. Red bike lane markings were found to provide a greater sense of safety than raising the lane over to the street curb (Vasilev et al., 2022).

Although there are visible benefits of physical separation or increased spacing between car lanes and bicycle lanes, there are also negative consequences of such solutions. Garber et al. (2023) found that bicycle lanes separated by parking or curbs and bicycle lanes protected by horizontal markings with wider lanes were considered safer in straight street sections, but caused crashes at intersections. Protected bicycle lanes separate drivers from cyclists either through horizontal markings or through parking spaces. This can prevent a driver from noticing that a cyclist is going parallel to him, and from being able to see the bike when they meet at an intersection. This increases the likelihood of a right-turn accident.

Although intersections have been found to be the most unsafe in terms of traffic safety, there is insufficient analysis of the design of bicycle lanes in intersection areas (Pánek & Benediktsson, 2017). In the study by Friel et al. (2023), four intersection design options were investigated to identify which intersection design was perceived by cyclists as the safest. They found that cyclists felt safest at an intersection where cyclists were protected by raised islands from cars making right turns. These islands must be unplanted so as not to obstruct visibility and their installation clearly indicates the trajectory of the car. The study also found that sharp kerbs, short lengths of waiting islands, small turning radii and narrow cycle paths reduced the feeling of safety. Deliali et al. (2021) analysed which bicycle lane design solutions made drivers more likely to notice cyclists. The results showed that drivers were more likely to notice cyclists and to slow down at intersections with raised islands. Protected intersection can reduce the number of cars hitting cyclists by up to 80% (Preston & Pulugurtha, 2021). Cyclists have been found to feel safer at intersections when using bicycle lanes that are installed on both sides of the street, compared to two-way cycle lanes (Wexler & El-Geneidy, 2017). Analysis of cyclists' safety at the roundabout found that the best way to make cyclists safer was to have a bicycle path around the roundabout, protected by islands and follow the roundabout path (Singleton & Poudel, 2023).

The analysis of the literature showed that most academics analyse the design solutions of bicycle infrastructure that provided a sense of security to cyclists. It has been determined which solutions of bicycle lanes, bicycle paths and intersections ensure a sense of security for cyclists. However, cyclists are only the end users of cycling infrastructure, and decisions about which engineering solutions will be used are proposed by the engineer and approved by the urban development specialist. It was found that there was a lack of analysis that would show whether the views of the users and the decision makers corresponded (Marquart et al., 2020). According to the aforementioned, the article aims to determine whether the opinions of engineers and urban development specialists, as people who create bicycle infrastructure, and cyclists, as users of this infrastructure, correspond to the sense of security it provides. To achieve the aim of the research, the following questions are raised:

1. Do urban development professionals and cyclists equally value the safety provided by bicycle infrastructure design?
2. Do engineers and cyclists equally value the safety provided by bicycle infrastructure design?
3. Do commonly used urban infrastructure designs affect the critical thinking of decision makers and engineers when making new decisions?

2. Methodology

The analysis of the scientific literature shows that there is a lack of analysis which demonstrates whether engineers consider the sense of security of cyclists, when making decisions on the development of bicycle infrastructure, and whether urban development specialists, when approving the engineers' proposed solutions, understand what ensures a sense of security of the users of this infrastructure. In this context, a qualitative survey of engineers and urban development specialists was carried out.

The survey was designed for engineers and urban development specialists who work in Vilnius, Lithuania. The respondent group of engineers was represented by five engineers designing transport infrastructure in Vilnius city with 5 to 20 years of experience in designing street and cycling infrastructure projects. All engineers have a Bachelor's/Master's degree in Civil Engineering from Vilnius Gediminas Technical University. The respondent group of urban development specialists consisted of five employees of Vilnius City Municipality or its affiliated companies, which are responsible for the approval and implementation of transport projects. The urban development specialists also have a Bachelor's/Master's degree in Civil Engineering from Vilnius Gediminas Technical University.

Questionnaires were sent to the participants by email. The questionnaires contained six groups of bicycle infrastructure schemes, each group containing between two and five possible infrastructure options. Three groups of schemes were related to cycling infrastructure on straight street sections, three to cycling infrastructure at intersections.

The respondents were presented with options for bicycle streets (two options), bicycle lanes (five options) and bicycle paths (four options). Given that the academic literature does not provide much analysis of the options for intersections with cycling infrastructure, the study also analysed three types of intersections: intersections with bicycle lanes (two options), intersections with bicycle paths (two options), and three-way intersections with cycle path (two options). Experts were asked to indicate which of the options in the group they considered to provide the greatest sense of safety for cyclists and to rate them on a scale of 1 to 10, where 1 corresponds to the least sense of safety and 10 to the greatest. Also, depending on the type of infrastructure, they were asked to indicate which option the engineer would use and why, and the urban development specialist what option he would support and why.

Design solutions for bicycle infrastructure that ensure the greatest sense of safety for cyclists were identified during the literature analysis. The scientific article databases Web of Science and Science Direct were searched for recent scientific articles (2017–2023) in which research related to infrastructure safety assessment from a cyclist's perspective was conducted. During the literature analysis, 15 scientific studies were identified: Berghoefer et al., (2023), Deliali et al., (2021), Friel et al. (2023), Garber et al. (2023), Gössling & McRae study (2022), Guo et al. (2023), Huemer et al. (2022), Marquart et al., (2020), Müggenburg et al., (2022), Nazemi et al. (2021), Preston & Pulugurtha, (2021), Rivera Olsson & Elldér (2023), Singleton & Poudel, (2023), Vasilev et al., (2023), Wexler & El-Geneidy, (2017).

In the analysed scientific articles, cyclists' sense of safety in relation to infrastructure design was determined through qualitative or quantitative surveys using simulator data and traffic accident data.

Taking into account the identified infrastructure design solutions that ensure the greatest sense of security, the infrastructure schemes used in this study were prepared. They were presented to the groups of engineers and urban development specialists for evaluation during the study.

SPSS Statistics software was used to perform the statistical analysis of the expert survey. Before the results were entered into the software, the cycling infrastructure options presented in the questionnaire were coded to give them a score between 1 and 10 (as rated by the experts). The infrastructure solutions with bicycle street were coded as DVG_1 for Option 1 and DVG_2 for Option 2. The infrastructure solutions with cycle lanes on the carriageway were also coded as DEJ_1 for Option 1, DEJ_2 for Option 2, DEJ_3 for Option 3 and DEJ_4 for Option 4. Solutions with cycle paths were coded DT_1 for option 1, DT_2 for option 2, DT_3 for option 3, and DT_4 for option 4. The scheme with cycle lanes at the intersection has been given the names SDEJ_1 – option 1, SDEJ_2 – option 2. Schemes with cycle lanes at the intersection were given the names SDT_1 – Option 1, SDT_2 – Option 2. The three-way intersection options with cycle lanes were assigned T_1 for Option 1, T_2 for Option 2.

Kendall's coefficient of concordance (W) is a measure that uses ranks to assess agreement between observers. Our objective was to test the utility of Kendall's W for determining the level of agreement among two groups of five observers. To determine whether the opinions of the experts are compatible, the Kendall's coefficient of concordance was calculated using SPSS Statistics.

3. Cycling infrastructure options

For the analysis of cycle streets, two possible options were presented. Option 1 (Figure 1) shows a bicycle street where cyclists use the carriageway alongside cars and drivers are only informed about the traffic management by a road sign. Option 2 (Figure 2) shows a cycling street with red bicycle lanes on the carriageway, a bicycle sign and a road sign informing about the traffic organisation in the street. Rivera Olsson & Elldér (2023) found that the arrangement of the street by Option 2 was perceived as the safest by cyclists.

For the analysis of cycle lanes, five possible options were presented. Option 1 (Figure 3) presents the simplest cycle lane solution, where the cycle lane is separated from car traffic only by a narrow horizontal marking. According to current technical regulations in Lithuania, this lane should have buffer zones from passing cars (0.25 m) and from the street edge (0.5 m). In Option 2 (Figure 4), the bicycle lane is separated from cars by a wide (0.75 m) horizontal marking, providing a greater sense of safety than in Option 1 (Figure 3). In Option 3 (Figure 5), the cycle lane is separated from the carriageway by a narrow planting strip (0.75 m). According to the study by Huemer et al. (2022), this type of cycle lane appears to be the safest for cyclists, as they are physically separated from cars. In Option 4 (Figure 6) and Option 5 (Figure 7), the cycle lanes are separated from the carriageway by parking spaces with a buffer zone for the opening of car doors (0.75 m). However, Option 5 (Figure 7) also includes a pedestrian barrier to prevent unpredictable

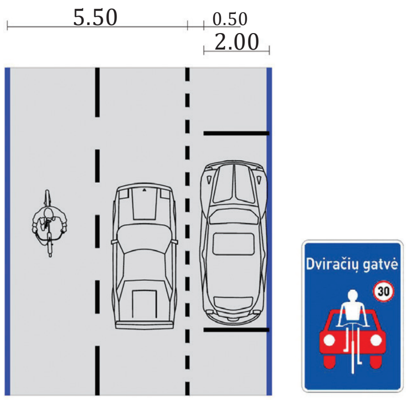

Figure 1. Bicycle street (DVG_1)

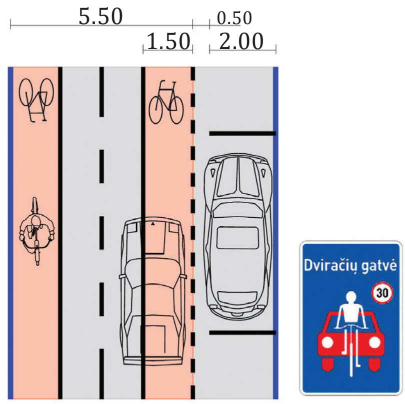

Figure 2. Bicycle street with marked lanes (DVG_2)

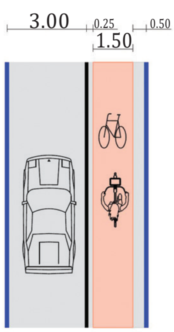

Figure 3. Cycle lane marked by horizontal markings with narrow line 1.1 (DEJ_1)

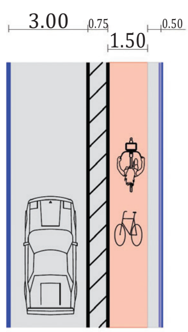

Figure 4. Cycle lane marked by horizontal marking 1.15 (DEJ_2)

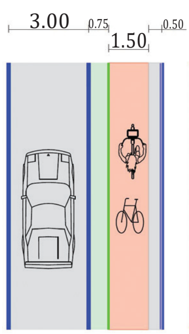

Figure 5. Cycle lane separated by a green space (DEJ_3)

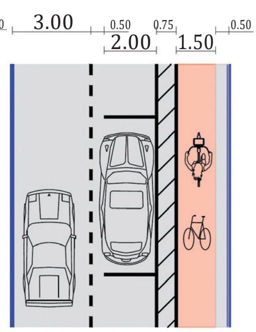

Figure 6. Cycle lane separated by parking lane and horizontal marking line 1.15 (DEJ_4)

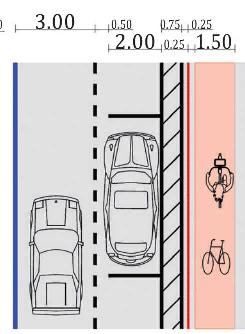

Figure 7. Cycle lane separated by a parking lane, horizontal marking line 1.15 and a pedestrian barrier (DEJ_5)

car users from entering the bicycle lane. Also, according to the results of Garber et al. (2023), the installation of barriers makes cyclists concentrate more on the carriageway and choose a lower speed. This solution could be considered as an advantage in addition to parallel parking, since in the event of a collision between a person getting out of a car and a cyclist, injuries would be reduced, and the guardrail would also prevent the doors from opening into the cycle lane.

Four options were presented for the analysis of cycle paths. In Option 1 (Figure 8) and Option 2 (Figure 9), the bicycle paths were separated from the carriageway by street kerbs and planting strips, with only the

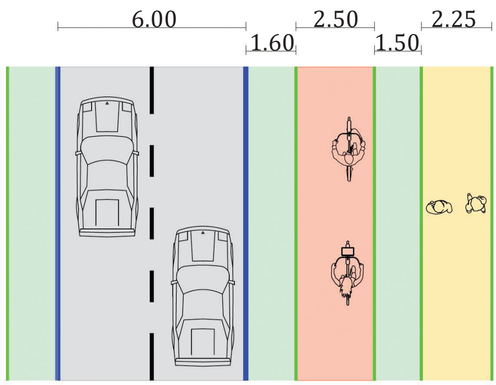

Figure 8. 2.5 m wide bicycle path (DT_1)

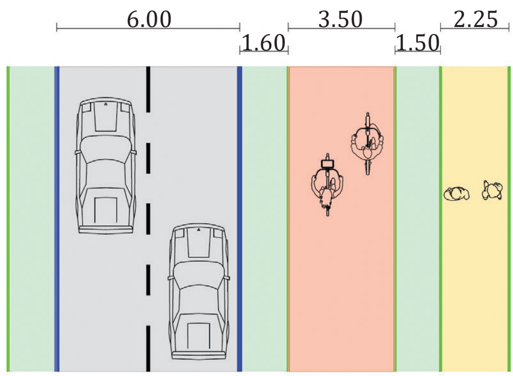

Figure 9. 3.5 m wide bicycle path (DT_2)

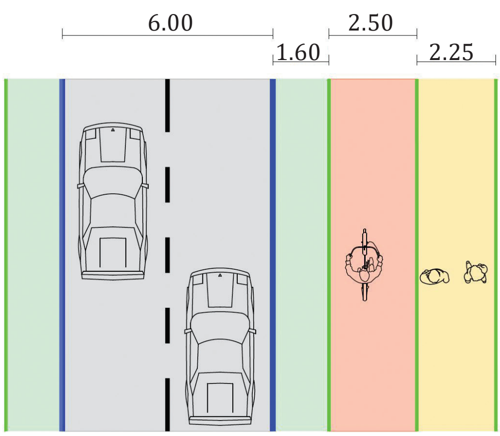

Figure 10. Bicycle path separated from the pedestrian path by a kerb (DT_3)

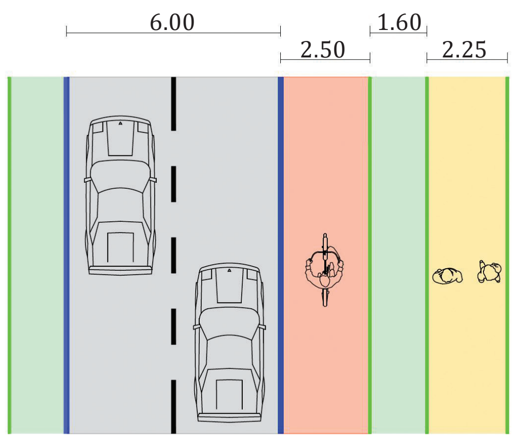

Figure 11. Bicycle path separated from the carriageway by a street kerb (DT_4)

width of the bicycle path differing between options. In Lithuania, two-way bike paths of 2.5 m wide are the most common design, but according to the results of the Gössling & McRae study (2022), a 3.5 m wide bike path is perceived as safer than a 2.5 m wide path. A wider path width provides greater manoeuvrability, and cyclists can easily overtake each other. In Option 3 (Figure 10), the cycle path is separated from the carriageway by a planting strip, but from the pedestrian path only by a grass verge. According to the results of the study by Nazemi et al. (2021), this is only a partially safe solution for cyclists, as cyclists are not restricted from pedestrians. Option 4 (Figure 11) presents a solution for a cycle path, where the cycle path is installed in the carriageway but raised over a 10 cm high street kerb and restricted from pedestrians by a planting zone. This solution can be easily implemented in street humanisation projects, as it is sufficient to raise the car lane over the street kerb and turn it into a cycle path.

For the intersection analysis, options for intersections with cycle lanes were presented. Option 1 (Figure 12) presents an intersection with a bike box for left-turn movements. The cyclist performs the left turn together with the vehicles, and the intersection is not equipped with a red-coloured asphalt surface for the cyclist manoeuvers. In Option 2 (Figure 13), the cyclists' manoeuvers at the intersection area are marked with red asphalt pavement, and left turns are made stopping in pockets placed in front of the bicycle lanes. In this way, cyclists do not have to

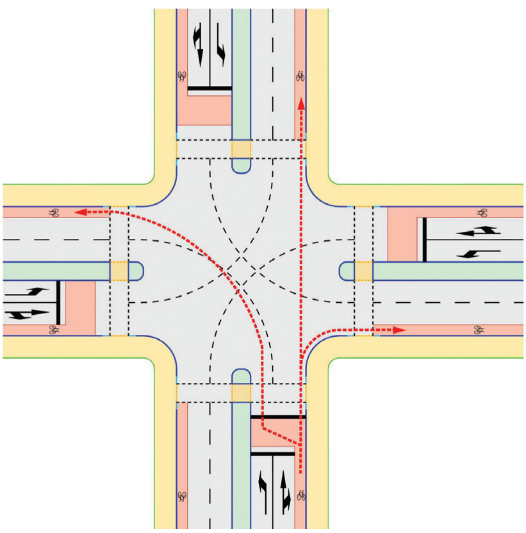

Figure 12. Intersection with bike box for left turn (SDEJ_1)

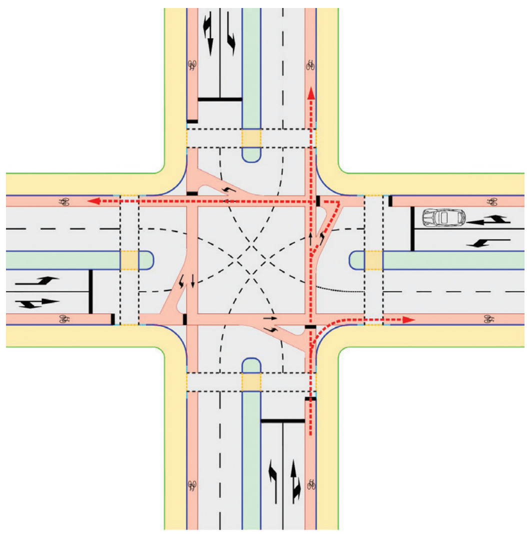

Figure 13. Intersection with two stage turn boxes for left turn (SDEJ_2)

stand in the car lane, and in the bike lanes, the stop lines are brought closer to the pedestrian crossing, which ensures priority to enter the intersection. This is the case in Denmark, Germany, and the Netherlands. In Lithuania, there is no single intersection with cycle lanes. Best of authors' knowledge such intersection safety options for cyclists have not been analysed in the literature. The safer option should be Option 2, as the red cycle lanes are marked in the intersection area, and cyclists stop to wait for a left turn in the cycling areas (Marquart et al., 2020).

For the analysis of intersections with bicycle paths, a typical option is used in Vilnius (Figure 14) and an improved option with raised islands (Figure 15) is presented. In Option 1 (Figure 14), the cycle path and the footpath descend to the carriageway level at the approaches to the intersection (Figure 14 '1'), which puts the pedestrian crossing and the cycle crossing area on the same level with the carriageway for an additional 2–4 m and consequently increases the probability of a car hitting a cyclist or pedestrian. In Option 2 (Figure 15), the pedestrian crossing and the cycle crossing with carriageway are only level in the crossing areas, as they are protected on all sides by raised islands and the street kerb. According to the results of the study by Friel et al. (2023), raised islands at intersections are the safest solution for cyclists.

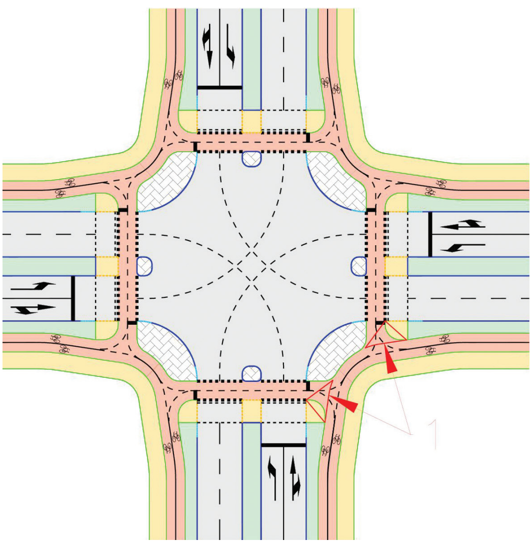

Figure 14. Bicycle path descending to the carriageway in the intersection zone (in the area marked '1') (SDT_1)

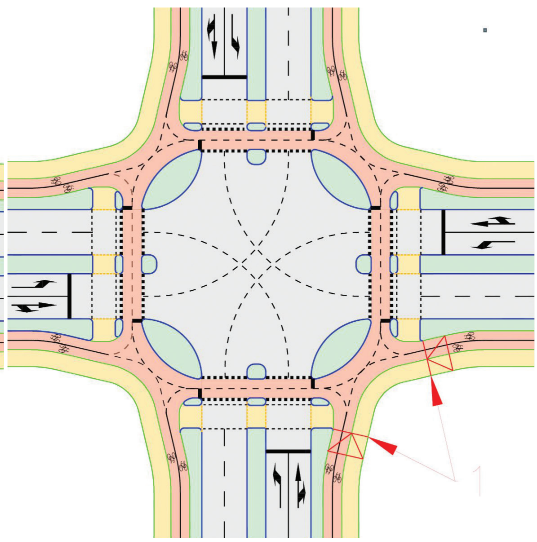

Figure 15. The bicycle path descends to the carriageway before the intersection (in the area marked '1')) and is protected by raised islands (SDT_2)

Solutions for a three-way intersection with cycle lanes were analysed. Option 1 (Figure 16) presents an intersection of a one-way street with parking spaces with a two-way street. The three-way intersection is raised to slow down the speed of vehicles before entering the intersection area, but with this solution the cycle and pedestrian paths and the carriageway in the intersection area are on the same level. This solution does not ensure physical separation between cars and pedestrians, and cyclists making right turns. In poor visibility conditions, a driver would not notice the difference between the carriageway and the pavements. In Option 2 (Figure 17), although the intersection area is not raised, which theoretically does not force vehicles to slow down, cyclists and pedestrians are protected by raised islands. This design prevents vehicles from running over cyclists and pedestrians when making a right turn. Option 2 is safer for cyclists, as physical separation is ensured, and the installation of a red bicycle crossing will reduce vehicle speed (Berghoefer et al., 2023; Deliali et al., 2021).

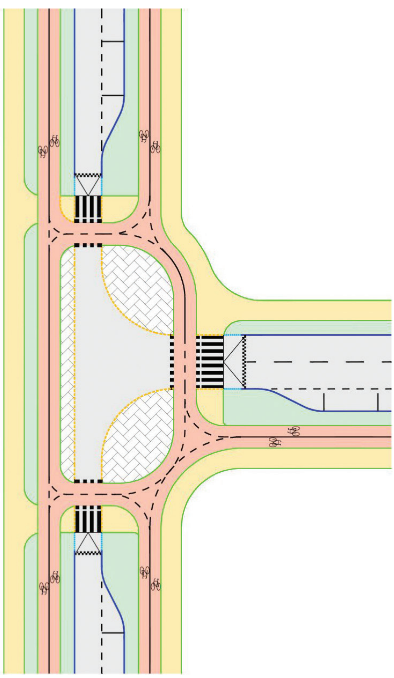

Figure 16. Raised three-way intersection (T_1)

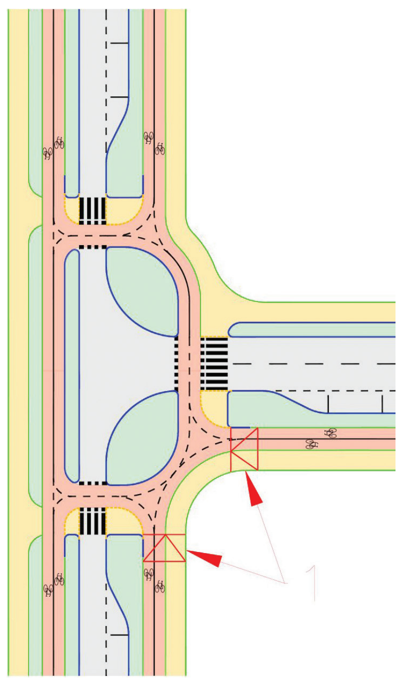

Figure 17. Three-way intersection (T_2)

4. Results

4.1. Results for urban development specialists

Kendall's coefficient of concordance (W) was determined in the article to find out the compatibility of the opinions of the respondents who participated in the survey. The coefficient was calculated for a group of engineers and a group of urban development specialists. The results of compatibility of opinions of urban development specialists are presented in Table 1, of engineers in Table 3. Kendall's W is calculated by Equation (1):

$$W = \frac{12S}{p^2\left(n^3 - n\right) - pT}, \tag{1}$$

where S is the sum-of-squares from row sums of ranks R_i (Equation (2)), n is the number of objects, p is the number of judges and T is a correction for tied ranks (Equation (3); Siegel, 1956, p. 234).

$$S' = \sum_{i=1}^{n} R_i^2 = SSR, \tag{2}$$

$$T = \sum_{k=1}^{m} \left(t_k^3 - t_k\right) \tag{3}$$

where S is the sum-of-squares from row sums of ranks R_i, m is the number of groups and t_k is the number of tied ranks in each (k) of m groups (Siegel, 1956, p. 234).

The null hypothesis of concordance tested: there is no agreement among five respondents regarding the 17 infrastructure schemes.

According to the obtained calculation data presented in Table 1, the opinions of the respondents of the urban development specialists' group were consistent with each other, and the null hypothesis was rejected ($p < 0.001$). The concordance of the opinions is judged in the range from 0 to 1, where 1 is full concordance and 0 is no concordance at all. The coefficient W-0.511 showed that the opinions of the urban development specialists were significantly compatible.

The statistics of the results of the survey of urban development specialists are presented in Table 2. The safest options for cycling infrastructure clusters according to urban development specialists are marked (+). The safest options for cycling infrastructure clusters in the opinion of cyclists have been identified through literature analysis described in Methodology section.

The data in Table 2 shows that both urban development specialists and cyclists perceive safer cycling on streets with marked cycle lanes on the carriageway (DVG_2). Of the second group of options, a bicycle lane separated from vehicles by vegetation (DEJ_3) was the most appreciated by the experts, and accordingly the safest option for cyclists. In the third group of schemes, the installation of bicycle lanes was evaluated. The experts indicated that a 3.5 m wide cycle path separated from both vehicles and pedestrians by planting strips (DT_2) provided the greatest sense of safety for cyclists. When analysing the results of the installation of cycling infrastructure at intersections, respondents and cyclists were divided on the issue of safety. When evaluating intersections with

Table 1. Compatibility of opinions of urban development specialists

Summary of related-samples Kendall's coefficient of concordance	
Total *N*	5
Kendall's *W*	0.697
Test statistics	55.76
Degree of freedom	16
Asymptotic Sign (2-sided test)	< 0.001

Table 2. Results of urban development specialists

Group	Variable	Mean	Std. Deviation	Minimum	Maximum	Rank	The best design by respondents	The best design by cyclists
1	DVG_1	6.000	2,236	3.0	9.0	5.900		
	DVG_2	8.200	0.836	7.0	90	10.300	+	+
2	DEJ_1	5.400	1.816	3.0	8.0	4.000		
	DEJ_2	6.600	2.509	3.0	9.0	7.400		
	DEJ_3	8.600	1.140	7.0	10.0	11.900	+	+
	DEJ_4	6.400	1.516	4.0	8.0	6.100		
	DEJ_5	7.800	0.836	7.0	9.0	9.300		
3	DT_1	9.400	0.547	9.0	10.0	14.800		
	DT_2	9.800	0.447	9.0	10.0	15.900	+	+
	DT_3	7.400	1.949	4.0	9.0	9.300		
	DT_4	4.600	2.701	1.0	8.0	2.700		
4	SDEJ_1	5.400	3.646	1.0	9.0	6.100	+	
	SDEJ_2	4.600	2.880	1.0	8.0	3.600		+
5	SDT_1	7.800	0.447	7.0	8.0	9.000		
	SDT_2	9.400	0.894	8.0	10.0	14.500	+	+
6	T_1	9.200	0.836	8.0	10.0	14.100	+	
	T_2	6.800	2.280	3.0	9.0	8.100		+

bicycle lanes, respondents indicated that cyclists should feel safer at intersections with a bike box facility (SDEJ_1), but the literature analysis showed that a safer option for cyclists should be with two stage turn boxes (SDEJ_2). At intersections with bicycle paths, both cyclists and respondents were in agreement, with the safer option of safety islands between the cycle lanes and the pedestrian crossing areas (SDT_2). The results of the three-way intersection show that the experts consider that the safer option is the one where the carriageway and the cycle paths are at the same level in the intersection (T_1), but the cyclists consider the safer option to be the one where safety islands are installed to prevent the cars from overrunning when making a right-hand turn (T_2).

Taking into account the results of urban development specialists presented in Table 2, the assessment of 17 infrastructure schemes shows that during the study, the safest infrastructure was identified with rank 15.9, a 3.5 m wide cycle path separated from both cars and pedestrians, option DT_2 (M = 9.8, STD = 0.44).

4.2. Results for engineers

The concordance of the opinions of the group of engineer respondents was determined using Kendall's coefficient of concordance (W) (Equation (1)). The null hypothesis of concordance tested: there is no agreement among five respondents regarding the 17 infrastructure schemes. According to the obtained calculation data presented in Table 3, the opinions of the respondents of the engineering group were consistent with each other, and the null hypothesis was rejected ($p < 0.001$). The concordance of the opinions is judged in the range from 0 to 1, where 1 is full concordance and 0 is no concordance at all. The coefficient W = 0.0697 showed that the opinions of the engineers were significantly compatible.

The statistics of the results of the engineers' survey are presented in Table 4. The safest options for the clusters of cycling infrastructure in the engineers' opinion are marked (+). The safest options for cycling infrastructure clusters in the opinion of cyclists were identified through literature analysis.

Table 4 shows that engineers, cyclists and urban developers had the same perception of the safety of cycling on straight street segments, and chose the option with bicycle lane markings on the carriageway (DVG_2). Correspondingly, respondents and cyclists were also in agreement when choosing the safest option for the installation of bicycle lanes (DEJ_3) and bicycle paths (DT_2). It is also noticeable that engineers and cyclists share the same opinion on the safest options at intersections. Engineers indicated that the safer option for intersections with bicycle lanes was to use the two stage turn boxes type (SDEJ_2), and the safer option for cycle lanes was to separate pedestrians and cyclists at intersections with safety islands (SDT_2). The latter solution was also agreed upon by urban development specialists. At the three-way intersection, engineers indicated that greater safety for cyclists was achieved when cyclists were protected from drivers by using raised islands (T_1).

Considering the data in Table 4, it was found that engineers, as well as urban development specialists, valued the DT_2 option as providing the

Table 3. Compatibility of engineers' opinions

Summary of Related-Samples Kendall's Coefficient of Concordance	
Total *N*	5
Kendall's *W*	0.511
Test Statistics	40.862
Degree Of Freedom	16
Asymptotic Sign (2-sided test)	< 0.001

Table 4. Results of engineers

Group	Variable	Mean	Std. Deviation	Minimum	Maximum	Rank	The best design by respondents	The best design by cyclists
1	DVG_1	5.800	2.167	3.0	8.0	3.800		
	DVG_2	8.400	2.607	4.0	10.0	11.200	+	+
2	DEJ_1	4.400	2.302	1.0	7.0	1.900		
	DEJ_2	6.800	1.303	5.0	8.0	6.100		
	DEJ_3	9.000	1.0	8.0	10.0	11.300	+	+
	DEJ_4	6.200	2.863	3.0	10.0	6.400		
	DEJ_5	8.800	1.303	7.0	10.0	10.800		
3	DT_1	9.000	1.0	8.0	10.0	12.000		
	DT_2	10.000	0	10.0	10.0	15.000	+	+
	DT_3	7.400	1.949	4.0	9.0	7.900		
	DT_4	8.000	1.224	7.0	10.0	8.200		
4	SDEJ_1	7.400	1.673	6.0	10.0	6.500		
	SDEJ_2	7.200	1.923	5.0	10.0	7.700	+	+
5	SDT_1	8.400	1.140	7.0	10.0	9.200		
	SDT_2	9.400	0.894	8.0	10.0	13.200	+	+
6	T_1	8.200	0.836	7.0	9.0	9.500		
	T_2	9.200	1.095	8.0	10.0	12.300	+	+

highest sense of security from all the analysed 17 infrastructure options. The DT_2 option is assigned a rank of 15.0, (M = 10.0, SD = 0.) This indicates that maximum safety is achieved when cyclists are physically separated from other road users.

5. Discussion

In most cities, the car is the main means of transportation, causing pollution, noise, and negative impacts on air quality and people's mental and physical well-being. With the projected increase in global and urban populations, changes are needed in both travel behaviour and in the transport system itself. Although it is obvious that the bicycle should be one of the main means of urban transport, the reality of the situation and urban planning prioritising car transport is damaging both to the environment and to the population itself. To ensure sustainable mobility and make city streets more accessible to people other than cars, street redesign and humanisation projects are being carried out. One of the typical solutions for street redesign is the installation of bicycle infrastructure. The aim is to increase the number of bicycle journeys made in the city, which are a low-impact mode of transport. Despite the increasing presence of cycling infrastructure in the city, the number of cyclists in the cities usually remains low, which means that the infrastructure does not provide cyclists with a sufficient sense of security. In this context, qualitative survey of engineers and urban development specialists was carried out to determine whether the opinions of engineers and urban development specialists, as people who create bicycle infrastructure, and cyclists, as users of this infrastructure, correspond to the sense of security it provides. To achieve the aim of the research, the following questions were raised:

- Do urban development professionals and cyclists equally value the safety provided by bicycle infrastructure design?
- Do engineers and cyclists equally value the safety provided by bicycle infrastructure design?
- Do commonly used urban infrastructure designs affect the critical thinking of decision makers and engineers when making new decisions?

The analysis of the results shows that urban development specialists and cyclists have the same views on safe infrastructure in straight-street sections: bicycle streets, bicycle lanes, and bicycle paths. However, the option of assessing the safest infrastructure at intersections differs. Of the three groups of intersections evaluated, cyclists and urban development specialists agreed only in one group – the bicycle path intersection. Cyclists rate intersections with bicycle lanes as safer when designed using the two stage turn box principle, where all bicycle lanes on the carriageway are made of red asphalt (Marquart et al., 2020). However, for urban development specialists, the bike box was a safer option. Some experts pointed out that *"Option 1* (Figure 12) *is simpler and clearer. Option 2* (Figure 13) *is unclear, there is more delay for a cyclist turning left, and cars turning right will hit a cyclist at the stop line. Of course, it all depends on traffic light control, phasing, traffic volume of the intersection. Option 1* (Figure 12) – *Cyclists have sufficient waiting space in front of other vehicles. Cyclists enter the intersection first and are clearly visible to motor vehicles, with fewer conflict points between cyclists themselves."* Urban development specialists also considered that a three-way raised intersection, which reduced vehicle speeds, was a safer option. The results of the study by Berghoefer et al. (2023) showed that the installation of red asphalt on cycle crossings informed drivers to slow down at such places. If the crossing is elevated and cyclists and cars are on the same level at the most dangerous manoeuvring point, the likelihood that car drivers will fail to see cyclists and will run over them when making a right turn increases. However, this option has been chosen by urban development specialists because it reduces the speed of vehicles entering the intersection. The comments of urban development specialists: *"Option 1* (Figure 15) – *speed reduction for cars before entering the intersection. This has a positive impact on the safety of both cyclists and pedestrians at crossings and crosswalks. Option 2* (Figure 16) *–Infrastructure solutions do not increase the " feeling of safety" by not reducing the speed in the intersection area by engineering measures*." Taking into account the results of both groups of respondents, it can be stated that in terms of infrastructure, separating cyclists by physical means both from the roadway and from pedestrians provides the greatest sense of security. The same results were found by Nazemi et al. (2021) and Vasilev et al. (2023).

The analysis of the engineers' results shows that there is full consistency between the safest options in the infrastructure groups analysed. Engineers' opinions are in agreement with cyclists on straight street sections and intersections. Engineers at intersections of bicycle lanes indicate that the two-stage turn box principle is safer, as "the protected left turn and the red asphalt pavement are more likely to alert drivers to the presence of bicycles in the traffic". The three-way intersection does not value the speed of the vehicle, but rather the safety provided by the physical separation, as "the raised kerbs provide a reduction in the speed of cars and an additional 'barrier' to leaving the street, especially in the dark or in the wintertime".

The urban development specialists and engineers who participated in the study had the same degree in civil engineering from the Department of Roads of Vilnius Gediminas Technical University. Therefore, the selection of a safer engineering solution in this case is not related to the level of education acquired. The only difference between the groups of respondents is the nature of the work and the objective of ensuring safety for different groups of road users. For urban development specialists, the main purpose of their work is to plan the transport infrastructure for vehicles. For many years, all infrastructure has been planned with the needs of cars in mind. Accordingly, in Lithuania, sustainable mobility plans aimed at changing the principles of urban mobility have only emerged since 2016, so there is still a sense of car-centric infrastructure planning. Meanwhile, the aim of engineers' work is to create infrastructure that is safe for all road users. Engineers are also directly legally responsible for the safety of engineering solutions, so their decisions primarily ensure safety. While the engineer bears full responsibility for injuries using the infrastructure they designed, the legal regulations norms in Lithuania help ensure only the minimum safety requirements. In Lithuania, engineers are also required to improve their knowledge, attend training courses, and obtain qualification certificates, but this is not a requirement for urban development specialists. Thus, critical thinking of engineers when making infrastructure solutions is not affected by the most commonly seen or used solutions in cities, because they bear the greatest responsibility and constantly improve their professional knowledge. The competence of engineers is also confirmed by the results of the survey – the full agreement of opinions on safe infrastructure with cyclists.

According to the results of the urban development specialist survey, it can be stated that they evaluate safety according to their most commonly applied engineering solutions in the city, despite the fact that they do not always provide the highest safety, but are the most commonly used in practice. The three-way raised intersection is implemented on Algirdas Street, Vilnius. Therefore, this solution seems to be the best already in practice. Urban development specialists are likely to consider that the risk of drivers' breaking traffic rules and speeding is a greater risk than the invisibility zone when making a right turn and hitting a cyclist at a lower speed. However, priority should be given to physical separation, and speed control should be left to the responsible authorities. There are no intersections with bicycle lanes in Vilnius, but this solution appears most clearly in the plan, and in other countries, a "bike box" solution is more commonly seen. Therefore, urban development specialists have indicated that this is the safest solution. Considering the specifics of the work of urban development specialists, the long-term practice of prioritising cars, the absence of direct legal responsibility for approved engineering solutions, it can be argued that their opinion regarding the safest engineering solutions is not critical and is influenced by long-term practice. Such results are confirmed by the survey data, when the opinions of cyclists and urban development specialists regarding the safety of solutions for the installation of bicycle intersections coincide only 1 time out of 3.

The choice of a less safe infrastructure option may also have been influenced by the legal documents that govern cycling infrastructure in Lithuania, which are practically silent on the provision of cycling infrastructure at intersections. For example, the STR 2.06.04:2014 "Gatvės ir vietinės reikšmės keliai. Bendrieji reikalavimai" (STR) only specifies the type of bicycle crossings that must be provided across different categories of streets, regulated and unregulated. The document does not specify how left turns should be made, whether safety islands, bike boxes should be installed, or whether any principles should be applied. The recommendations "Pėsčiųjų ir dviračių takų projektavimo rekomendacijos R PDTP 12" (RPDTP) advise the installation of cycling infrastructure only in some detail. However, some of the guidance duplicates that of the STRs, specifying the materials that should be used for the installation of the cycle infrastructure and the safety distances that should be observed. It specifies that bicycle lanes in intersection areas should be converted to bicycle paths but does not provide any standard schemes for the design of cycle infrastructure at intersections. Accordingly, the RPDTP recommendations are only indicative and can be disregarded. The absence of practical legal provisions on the design of cycling infrastructure and the absence of standard solutions for the provision of cycling infrastructure in the city lead to a wide range of different approaches to the provision of infrastructure.

The results obtained in this paper are relevant both for urban development specialists and engineers. There is a lack of research that identifies the extent to which urban decision makers are aware of the needs, motivations, and daily experiences of cyclists (Marquart et al., 2020). Most of the research on cycling infrastructure and safety has been carried out in the USA and China, and there is a lack of analysis looking at practices in European countries (Hossein Sabbaghian et al., 2023). The results of the study are twofold: in one situation, they show that in straight street segments of cycling infrastructure, both urban developers and engineers share the same sense of safety as cyclists and know which solution will meet the cyclists' expectations. However, when looking at intersection options, urban development specialists and cyclists are beginning to diverge on safety, and decision makers often rely on long-standing practice. However, there is a complete convergence of views between engineers and cyclists on safety at intersections. Similar results were found by Marquart et al. (2020). In their study, they asked urban development specialists and cyclists to identify, in their opinion, quality routes for cycling infrastructure. The results differed by 30% between urban development specialists and cyclists. Therefore, the author found that decision makers should be more focused on understanding the needs of the cyclist. A survey of municipal staff in Europe, Austria, and the USA revealed that urban development policy was still centred on cars and that development priority was only partially given to cycling (Brezina et al., 2022; Robartes et al., 2021). Bell & Ferretti (2015) claim that engineers need to do more to attract people to use bicycles, they need to design better cycling infrastructure and ensure that it is properly implemented. Consequently, urban development specialists should be more appreciative of the solutions that engineers propose and choose new infrastructure options that have not been implemented in cities yet.

Conclusions

The literature analysis of scientific articles related to cyclists' perceived safety shows that streets are most often redesigned with bicycle infrastructure in humanisation projects but that this is not directly related to increasing cyclist numbers. Cycling is motivated by a perceived sense of safety, which is not related to the actual number of accidents. Researchers tend to analyse the safest cycling infrastructure solutions on straight street segments, but pay very little attention to cycling infrastructure at intersections, where most accidents occur. The literature analysis has shown that the safety of cycling infrastructure is most often viewed from the perspective of cyclists, but there is a lack of research that reveals whether those responsible for the installation and design of such infrastructure also estimate the safest solutions for cycling infrastructure as much as the users of this infrastructure – cyclists.

A qualitative survey of urban development specialists and engineers from Vilnius city found that the opinions of city development specialists and cyclists about the safest solutions for cycling infrastructure coincide only in straight street sections, but at intersection areas 2 out of 3 times the opinion of specialists did not coincide with the opinion of the cyclist. However, engineers and cyclists' opinions on the safest solutions for cycling infrastructure were in full agreement both in straight street sections and at intersections.

The results of the survey presented in the article show that closer cooperation is needed in the design of cycling infrastructure between cyclists and urban development specialists and not only with engineers. The results presented in the paper are useful for urban development specialists and engineers, as they understand which design solutions for cycling infrastructure on streets and intersections provide a sense of security for cyclists.

REFERENCES

Aldred, R., Croft, J., & Goodman, A. (2019). Impacts of an active travel intervention with a cycling focus in a suburban context: One-year findings from an evaluation of London's in-progress mini-Hollands programme. *Transportation Research Part A: Policy and Practice, 123,* 147–169. https://doi.org/10.1016/j.tra.2018.05.018

Anastasiadou, K., & Gavanas, N. (2023). Enhancing urban public space through appropriate sustainable mobility policies. A multi-criteria analysis approach. *Land Use Policy*, *132*, Article 106765. https://doi.org/10.1016/j.landusepol.2023.106765

Bell, W., & Ferretti, D. (2015). What should planners know about cycling? In J. Bonham & M. Johnson (Eds.), Cycling Futures (pp. 321–356). University of Adelaide Press. http://www.jstor.org/stable/10.20851/j.ctt1sq5x1g.20

Berghoefer, F. L., Huemer, A. K., & Vollrath, M. (2023). Look right! The influence of bicycle crossing design on drivers' approaching behaviour. *Transportation Research Part F: Traffic Psychology and Behaviour*, *95*, 98–111. https://doi.org/10.1016/j.trf.2023.03.017

Bian, R., Tolford, T., Liu, S., & Gangireddy, S. (2023). Lessons learned from evaluating complete streets project outcomes with emerging data sources. *Transportation Planning and Technology*, *46*(6), 754–772. https://doi.org/10.1080/03081060.2023.2214136

Bibri, S. E., Krogstie, J., & Kärrholm, M. (2020). Compact city planning and development: Emerging practices and strategies for achieving the goals of sustainability. *Developments in the Built Environment, 4*. https://doi.org/10.1016/j.dibe.2020.100021

Blitz, A., Busch-Geertsema, A., & Lanzendorf, M. (2020). More cycling, less driving? Findings of a cycle street intervention study in the Rhine-Main metropolitan region, Germany. *Sustainability (Switzerland), 12*(3). https://doi.org/10.3390/su12030805

Brezina, T., Lemmerer, H., & Leth, U. (2022). Mental barriers in planning for cycling along the urban–rural gradient. *Transportation Research Interdisciplinary Perspectives*, *16*, Article 100689. https://doi.org/10.1016/j.trip.2022.100689

Deliali, K., Christofa, E., & Knodler, M. (2021). The role of protected intersections in improving bicycle safety and driver right-turning behaviour. *Accident Analysis and Prevention*, *159*, Article 106295. https://doi.org/10.1016/j.aap.2021.106295

Erbas Melis, O., & Okumus Prini, D. (2023). Understanding Active Mobility and Micromobility in a Studentified Neighbourhood. Online *Journal of Art and Design, 11, 5*.

European Commission (EC). (2011). White paper 2011: Roadmap to a single European transport area – towards a competitive and resource efficient transport system. fromhttp://ec.europa.eu/transport/themes/strategies/2011_white_paper_en.htm

Fitch, D. T., Carlen, J., & Handy, S. L. (2022). What makes bicyclists comfortable? Insights from a visual preference survey of casual and prospective bicyclists. *Transportation Research Part A: Policy and Practice*, *155*, 434–449. https://doi.org/10.1016/j.tra.2021.11.008

Friel, D., Wachholz, S., Werner, T., Zimmermann, L., Schwedes, O., & Stark, R. (2023). Cyclists' perceived safety on intersections and roundabouts – A qualitative bicycle simulator study. *Journal of Safety Research*, *87*, 143–156. https://doi.org/10.1016/j.jsr.2023.09.012

Garber, M. D., Watkins, K. E., Flanders, W. D., Kramer, M. R., Lobelo, R. L. F., Mooney, S. J., Ederer, D. J., & McCullough, L. E. (2023). Bicycle infrastructure and the incidence rate of crashes with cars: A case-control study with Strava data in Atlanta. *Journal of Transport and Health*, *32*, Article 101669. https://doi.org/10.1016/j.jth.2023.101669

Gehl, J. (2010). *Cities for people*. Island Press.

Gössling, S., Humpe, A., Litman, T., & Metzler, D. (2019). Effects of perceived traffic risks, noise, and exhaust smells on bicyclist behaviour: An economic evaluation. *Sustainability (Switzerland)*, *11*(2), Article 408. https://doi.org/10.3390/su11020408

Gössling, S., & McRae, S. (2022). Subjectively safe cycling infrastructure: New insights for urban designs. *Journal of Transport Geography*, 101, Article 103340. https://doi.org/10.1016/j.jtrangeo.2022.103340

Gössling, S., Schröder, M., Späth, P., & Freytag, T. (2016). Urban space distribution and sustainable transport. *Transport Reviews*, *36*(5), 659–679. https://doi.org/10.1080/01441647.2016.1147101

Guo, X., Tavakoli, A., Angulo, A., Robartes, E., Chen, T. D., & Heydarian, A. (2023). Psycho-physiological measures on a bicycle simulator in immersive virtual environments: how protected/curbside bike lanes may improve perceived safety. *Transportation Research Part F: Traffic Psychology and Behaviour*, *92*, 317–336. https://doi.org/10.1016/j.trf.2022.11.015

Hirsch, L., Mackie, H., Crombie, C., Bolton, L., Wilson, N., & Cornille, Z. (2022). Road user interaction changes following street improvements from Te Ara Mua – Future Streets: A case study. *Journal of Transport and Health*, *25*, Article 101384. https://doi.org/10.1016/j.jth.2022.101384

Hossein Sabbaghian, M., Llopis-Castelló, D., & García, A. (2023). A safe infrastructure for micromobility: The current state of knowledge. *Sustainability (Switzerland)*, *15*(13), Article 10140. https://doi.org/10.3390/su151310140

Huemer, A. K., Rosenboom, L. M., Naujoks, M., & Banach, E. (2022). Testing cycling infrastructure layout in virtual environments: An examination from a bicycle rider's perspective in simulation and online. *Transportation Research Interdisciplinary Perspectives*, *14*, Article 100586. https://doi.org/10.1016/j.trip.2022.100586

Hui, N., Saxe, S., Roorda, M., Hess, P., & Miller, E. J. (2018). Measuring the completeness of complete streets. *Transport Reviews*, *38*(1), 73–95. https://doi.org/10.1080/01441647.2017.1299815

Jensen, W. A., Brown, B. B., Smith, K. R., Brewer, S. C., Amburgey, J. W., & McIff, B. (2017). Active transportation on a complete street: Perceived and audited walkability correlates. *International Journal of Environmental Research and Public Health*, *14*(9), Article 1014. https://doi.org/10.3390/ijerph14091014

Lanzendorf, M., Scheffler, C., Trost, L., & Werschmöller, S. (2022). Implementing bicycle-friendly transport policies: Examining the effect of an infrastructural intervention on residents' perceived quality of urban life in Frankfurt, Germany. *Case Studies on Transport Policy, 10*(4), 2476–2485. https://doi.org/10.1016/j.cstp.2022.10.014

Maisel, J. L., Baek, S. R., & Choi, J. (2021). Evaluating users' perceptions of a Main Street corridor: Before and after a Complete Street project. *Journal of Transport and Health*, *23*, Article 101276. https://doi.org/10.1016/j.jth.2021.101276

Marquart, H., Schlink, U., & Ueberham, M. (2020). The planned and the perceived city: A comparison of cyclists' and decision-makers' views on cycling quality. *Journal of Transport Geography*, *82*, Article 102602. https://doi.org/10.1016/j.jtrangeo.2019.102602

McQueen, M., Abou-Zeid, G., MacArthur, J., & Clifton, K. (2021). Transportation Transformation: Is Micromobility Making a Macro Impact on Sustainability? *Journal of Planning Literature, 36*(1), 46–61. https://doi.org/10.1177/0885412220972696

Müggenburg, H., Blitz, A., & Lanzendorf, M. (2022). What is a good design for a cycle street? – User perceptions of safety and attractiveness of different street layouts. *Case Studies on Transport Policy*, *10*(2), 1375–1387. https://doi.org/10.1016/j.cstp.2022.04.021

Mockus, A., & Jasiūnienė, V. (2024). The Impact of Street Humanisation on Road Safety. *The Baltic Journal of Road and Bridge Engineering, 19*(2), 66–84. https://doi.org/10.7250/bjrbe.2024-19.636

National Complete Streets Coalition (2011). What are complete streets? Smart Growth America. http://www.smartgrowthamerica.org/complete-streets/complete-streets-fundamentals/complete-streets-faq

Nazemi, M., van Eggermond, M. A. B., Erath, A., Schaffner, D., Joos, M., & Axhausen, K. W. (2021). Studying bicyclists' perceived level of safety using a bicycle simulator combined with immersive virtual reality. *Accident Analysis and Prevention*, *151*, Article 105943. https://doi.org/10.1016/j.aap.2020.105943

O'Reilly, R. K., Kollmann, A., Cohen, J. J., & Reichl, J. (2024). Macro-factors driving bicycle adoption as a primary transport mode across Europe. *Travel Behaviour and Society*, *34*, Article 100669. https://doi.org/10.1016/j.tbs.2023.100669

Pánek, J., & Benediktsson, K. (2017). Emotional mapping and its participatory potential: Opinions about cycling conditions in Reykjavík, Iceland. *Cities*, *61*, 65–73. https://doi.org/10.1016/j.cities.2016.11.005

Preston, A., & Pulugurtha, S. S. (2021). Simulating and assessing the effect of a protected intersection design for bicyclists on traffic operational performance and safety. *Transportation Research Interdisciplinary Perspectives*, *9*, Article 100329. https://doi.org/10.1016/j.trip.2021.100329

Reggiani, G., Salomons, A. M., Sterk, M., Yuan, Y., O'Hern, S., Daamen, W., & Hoogendoorn, S. (2022). Bicycle network needs, solutions, and data collection systems: A theoretical framework and case studies. *Case Studies on Transport Policy*, *10*(2), 927–939. https://doi.org/10.1016/j.cstp.2022.03.006

Rivera Olsson, S., & Elldér, E. (2023). Are bicycle streets cyclist-friendly? Micro-environmental factors for improving perceived safety when cycling in mixed traffic. *Accident Analysis and Prevention*, *184*, Article 107007. https://doi.org/10.1016/j.aap.2023.107007

Robartes, E., Chen, E., Chen, T. D., & Ohlms, P. B. (2021). Assessment of local, state, and federal barriers to implementing bicycle infrastructure: A Virginia case study. *Case Studies on Transport Policy*, *9*(2), 488–496. https://doi.org/10.1016/j.cstp.2021.02.004

Shu, S., Quiros, D. C., Wang, R., & Zhu, Y. (2014). Changes of street use and on-road air quality before and after complete street retrofit: An exploratory case study in Santa Monica, California. *Transportation Research Part D: Transport and Environment*, *32*, 387–396. https://doi.org/10.1016/j.trd.2014.08.024

Siegel, S. (1956). *Nonparametric statistics for the behavioural sciences*. McGrawHill.

Singleton, P. A., & Poudel, N. (2023). Bicycling comfort at roundabouts: Effects of design and situational factors. *Transportation Research Part F: Traffic Psychology and Behaviour*, *94*, 227–242. https://doi.org/10.1016/j.trf.2023.02.008

Sodiq, A., Baloch, A. A. B., Khan, S. A., Sezer, N., Mahmoud, S., Jama, M., & Abdelaal, A. (2019). Towards modern sustainable cities: Review of sustainability principles and trends. *Journal of Cleaner Production, 227,* 972–1001. https://doi.org/10.1016/j.jclepro.2019.04.106

United Nations, 2015. World urbanization prospects. The 2014 revision. Department of Economic and Social Affairs. http://esa.un.org/unpd/wup/Publications

Van Cauwenberg, J., Clarys, P., De Bourdeaudhuij, I., Ghekiere, A., de Geus, B., Owen, N., & Deforche, B. (2018). Environmental influences on older adults' transportation cycling experiences: A study using bike-along interviews. *Landscape and Urban Planning*, *169*, 37–46. https://doi.org/10.1016/j.landurbplan.2017.08.003

Vasilev, M., Pritchard, R., & Jonsson, T. (2022). Mixed-methods approach to studying multiuser perceptions of an interim Complete Streets project in Norway. *Travel Behaviour and Society*, *29*, 12–21. https://doi.org/10.1016/j.tbs.2022.05.002

Vasilev, M., Pritchard, R., Jonsson, T., & Panek, J. (2023). An exploration of multiuser perceptions of a Norwegian Complete Streets modification using interim design strategies. *Case Studies on Transport Policy*, *13*, Article 101058. https://doi.org/10.1016/j.cstp.2023.101058

Wexler, M.S., & El-Geneidy, A., 2017. Keep 'em separated: Desire lines analysis of bidirectional cycle tracks in Montreal, Canada. *Transportation Research Record, 2662*(1), 102–115. https://doi.org/10.3141/2662-12

World Health Organization (2021). Campaign launched to make 30 km/h streets the norm for cities worldwide. https://www.who.int/news/item/22-03-2021-campaign-launched-to-make-30-km-h-streets-the-norm-for-cities-worldwide

Zabielaitė-Skirmantė, M., & Burinskienė, M. (2023). Evaluation of the methodology for determining cycling flows in Lithuania. 12th International Conference "Environmental Engineering". https://doi.org/10.3846/enviro.2023.866