

# BICYCLE TRAFFIC FLOW FORECASTING METHODOLOGY FOR DIFFERENT FUNCTIONAL ZONES OF THE CITY

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**Abstract.** The development of bicycle transport infrastructure, like any other, must be based on expected bicycle traffic flow data. The characteristics of the city's functional zones, as well as the presence of existing bicycle infrastructure, determine the choice to travel by bicycle. Existing bicycle traffic flow forecasting methodologies are characterised by complex calculations, specific software, and the need for abundant data. Therefore, there is a clear need for a simpler bicycle flow forecasting methodology that specialists responsible for urban development would be able to use and which could be applied in practice, when designing bicycle infrastructure. Taking this into account, the article analyses the methodologies for predicting bicycle traffic flows for the central and middle zones of the city, created on the basis of a sketch plan methodology, when the infrastructure designed in the middle zone connects and does not connect to the general bicycle network. To determine the precision of the presented methodologies, field studies of bicycle traffic flows were carried out at three locations in the city of Vilnius. The study found that all the examined methodologies were accurate, since the MAPE of the central zone was 17.61%, the MAPE of the middle zone, when the planned infrastructure connects to the general bicycle network – 15.03%, and the MAPE of the middle zone, when the planned infrastructure does not connect to the general bicycle network – 13.85%. The predicted bicycle traffic flows calculated using

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the methodologies presented in the article can be used when it is necessary to decide what type of bicycle infrastructure to choose or what width of technical parameters of bicycle paths to choose.

**Keywords:** infrastructure planning, land use, sketch plan methodology, simple methodology, urban functional zones.

## Introduction

In sustainable cities, bicycle should be seen as an equivalent means of transport to the car, but the infrastructure for cars is expanded after assessing its need, while the bicycle infrastructure is still planned without data on future bicycle flows. Many researchers note the necessity of data on bicycle flows not only for targeted infrastructure planning but also for the impact of the created infrastructure on traffic safety (Elesawey, 2014; Kwigizile et al., 2022; Ryu, 2020). Krizek et al. (2006) pointed out that bicycle infrastructure was installed without assessing its need, because the cost of this infrastructure was relatively low compared to the infrastructure needed for car transport. Therefore, the development of bicycle transport infrastructure was not so much analyzed in terms of payback. However, any infrastructure in the city must be installed after assessing its need, as these are the principles of sustainable urban development.

Most often four-step demand and direct demand methodologies are used to forecast bicycle traffic flows, but the calculations require data on existing bicycle flows in the transport network, specific knowledge and software. Often, engineers responsible for infrastructure planning in a city do not have such resources, so bicycle transport infrastructure is expanded without assessing the forecasted bicycle traffic flows. When comprehensive data on bicycle flows are not available, it is necessary to find alternative ways to estimate them using available data. This usually includes information on population, transport flows, and the city's modal split. Openly available data is the main source of information for the sketch plan method, which is based on previous research findings and empirical observations. The advantage of sketch plan methods is their simplicity and accessibility; they do not require complex data collection processes and can be easily applied by engineers or urban planners who do not have in-depth knowledge of advanced modeling methods. Although this method is not as accurate as the previously mentioned methods, it allows for a quick assessment of bicycle flows and provides reasonable recommendations for infrastructure planning. In addition, the choice of methodology depends on the need for quality and accuracy of the available data; therefore, with the necessary data and computational resources, it is more appropriate to use the four-step demand and direct demand methodologies, but without such resources, the sketch plan methodology could be used. In cities

where the share of trips made by bicycle is low and detailed bicycle flow data is not collected due to a lack of funding or resources, the sketch plan method could become a practical alternative. It provides an opportunity to focus on data-driven decision-making even with limited information.

The scientific literature has widely studied and found that land use affects cycling (Akar et al., 2016; Oliva et al., 2018). Heinen et al. (2010) indicated that travel distance, land use, the presence of bicycle paths, and other factors are important when choosing to travel by bicycle, but the most essential factor is travel distance. Scientists have found that land use and the presence of bicycle infrastructure affect the choice to travel by bicycle (Guo et al., 2022; Jahanshahi et al., 2022; Plămădeală et al., 2023). Guo et al. (2022) confirm that land use is the main factor determining the purpose of the trip, with a predominance of mixed use, the share of trips made by bicycles increases compared to a single-use area. Depending on the use of the area, the intensity of vehicle traffic in it, and the choice of travel, modes change.

Typically, the land use type in the territories is determined according to the existing functional zones in the city. Basically, there are three functional zones in the city – the central zone of the city with the highest concentration of workplaces and other places of attraction. The middle zone of the city has the average intensity of development and the highest concentration of the population. The peripheral zone of the city has suburbs, residential areas, with low development intensity, which are mainly dominated by single-family houses. If functional zones are not distinguished in the city, according to planning documents, they can be determined by the dominance of workplaces, intensive development residential areas, and low development intensity residential areas in the territory. The distance between the functional zones of the city and their specificities creates transport connections, and at the same time the need for bicycle trips. Therefore, it is important to assess the transportation needs of residential and workplace areas in the city.

Considering the need to expand bicycle transport infrastructure in different functional zones of the city and the lack of a bicycle flow forecasting methodology based on easily accessible data and simple calculations, the article analyses a bicycle flow forecasting methodology developed on the basis of a sketch plan methodology for central and middle zones of the city. The aim of the study is to determine the accuracy of the presented bicycle traffic flow forecasting methodology by comparing the data with the bicycle traffic flows determined by manual counts in different functional zones of Vilnius city.

Vilnius city has been chosen as the object of the case study because it is the capital of Lithuania, with the largest and constantly growing population compared to other cities in the country. Like many other European cities, Vilnius aims to develop a sustainable transport system, therefore investing in the development of bicycle infrastructure. However, this development is taking place without assessing the forecasted bicycle flows – the infrastructure parameters are usually determined

in accordance with the sustainable mobility plan, which is typical of many European cities. The aim of this study is to develop a methodology for forecasting bicycle flows based on the number of residents, the number of vehicles and the modal split of trips. Such methodology will help ensure data-based decision-making. This aspect is especially important for cities where the share of bicycle transport is low; therefore, due to lack of funding and resources, there is no investment in the collection and analysis of bicycle flow data, which is the necessary data for decision-making.

The first section presents an analysis of the scientific literature related to bicycle traffic flow forecasting methodologies. The second section describes the developed bicycle traffic flow forecasting methodology, describes the methodology for manual bicycle flow counting, and indicates how the accuracy of the proposed methodology is assessed. The third section presents the results of the bicycle traffic flow forecasting methodology, manual counting, and the assessment of the accuracy of the methodology. The fourth section presents a discussion examining the accuracy of the presented methodology. The fifth chapter draws the conclusions of the study.

## 1. Literature review

Effective planning of bicycle infrastructure networks is essential for the sustainable development of modern cities. Bicycle transport contributes to sustainability, reduces traffic congestion, air pollution and promotes a healthy lifestyle. However, in order to optimally exploit the potential of this means of transport, it is necessary to assess data on expected bicycle flows.

### Four-step demand model

Four-step demand model (SD) is a traditional traffic flow forecasting model that is used in the preparation of strategic development plans or in order to determine how a large attraction will change the traffic situation of the entire territory (or city). This model was created for the analysis of motor vehicle flows; therefore, even now its main object of study is motor vehicles, but there are cases when scientists try to apply this method to the analysis of non-motorized transport flows.

The SD method consists of four stages:

- Trip generation. Trip generation in bicycle traffic models involves estimating the number of trips originating from and to various zones within the study areas. This step takes into account factors such as population density, land use, and socio-economic characteristics.
- Trip allocation. Trip allocation involves determining where trips generated in one zone are likely to end. This step often uses gravity models or other statistical methods to predict trip flows between zones based on factors such as distance and travel time.

- Mode choice. Mode choice models predict the proportion of trips that will be made by bicycle rather than by other modes. Factors that influence mode choice include the availability and quality of bicycle infrastructure, perceived safety, and the relative cost and convenience of cycling compared to other modes.
- Route assignment. Route assignment determines the specific routes that cyclists will use to reach their trip destinations. This step takes into account the network of possible cycling routes and factors such as route linearity, safety and surface quality.

Due to the specific knowledge and data required for all four stages, the software that would represent the territory under consideration, and the specific knowledge and data, it is not widely used in practice to forecast bicycle flows. This model is usually used by transport agencies, city municipalities or private companies when such a model must be created due to the feasibility of obtaining project funding or implementation. However, when comparing the SD model with other models used to forecast bicycle flows, it is the most accurate, and by creating a city SD model, it would be possible to analyse the ever-changing situation of the bicycle infrastructure network and see how the flows change as a result. Despite the complexity of the model, a bicycle cartogram was prepared for the city of Warsaw using the SD model (Jacyna et al., 2017). Bicycle flows were also analysed in the city of Gdynia using the SD model, but this model already assessed the influence of the city's topography on bicycle trips throughout the network (Oskarbski et al., 2021). Another model was created for the city of Krakow, which depicted the distribution of goods delivered by cargo bikes (Naumov et al., 2021).

### Direct demand methods

The second group of models used to predict bicycle flows is direct demand model (DD). DDs are very often used in bicycle flow forecasting due to their ease of application. These models assume that bicycle flow correlates with certain variables that can be calculated using statistical methods or machine learning techniques. DD can be used both for determining and forecasting bicycle flows. The relationship between non-motorized traffic and independent variables can be determined from statistical coefficients or using the relative importance coefficients determined by machine learning models. However, using this model, it is not possible to determine the personal characteristics of the cyclist, it is not possible to determine the psychological connection between the cyclist and the environment, it is not possible to identify what determines the choice of route, and the model is not suitable for preparing strategic planning documents. Melo & Isler (2023) used the DD model to determine bicycle flow using Strava Metro data, in-kind calculations, and population salaries. In this model, in-kind input data were important, as they formed the basis for the forecast. Pogodzinska et al. (2020) used this model to determine the average

annual number of daily cyclists. This model required data on the number of trips made during the day. Kwigizile et al. (2022) used Strava Metro and manual bicycle flow counting data to compile the DD, and assessed the dependence of weather conditions and the number of cyclists on wages. The model corresponded to real calculations on working days. Table 1 presents the most commonly used direct demand models, their description, advantages and disadvantages.

**Table 1. Most often used direct demand models to determine and forecast bicycle flows**  
(source: Griffin, 2009; Kuzmyk et al., 2014; McDonald et al., 2007; Shah et al., 2020)

<b>Model</b>	<b>Description</b>	<b>Advantages/disadvantages</b>
Comparison Studies	Models that predict non-motorized travel patterns based on environmental factors, population size, and land use. Most often, they compare existing infrastructure with predicted bicycle traffic with similar infrastructure planned for installation.	Simple model. Widely applicable. Uses readily available data – land use, population, bicycle traffic (not always). There is a possibility of misinterpretation of results.
Aggregate Behaviour Studies	Models that relate non-motorized travel to the population, land use, and other significant characteristics of the environment under study, usually through regression analysis. The current bicycle traffic is determined, and the most significant environmental factors are identified. With the obtained coefficients, the bicycle traffic is modelled according to the environmental characteristics across the network.	Moderate knowledge of statistical analysis. Moderate data requirements – bicycle traffic, environmental factors, population, land use.
Sketch Plan method	Models that predict non-motorized transport traffic in an area using simple calculations and behavioural rules that are related to the behavioural characteristics of the population, trip length, city modal split, travel habits. The model does not require any specific skills, but its accuracy is not very high.	Easy to understand. Uses readily available data – population, land use, environmental characteristics. Likely to be subject to significant error, but the model can be improved by using factors relevant to the environment under study.
Discrete Choice Models	Models that predict a person's choice of travel mode based on possible travel mode alternatives.	A good understanding of population travel patterns is required. Good technical skills are required. Detailed population surveys are often required.

Of the models described in Table 1, the most popular is the aggregate behavior study model. This model uses a linear or multiple regression formula to determine bicycle flow. The coefficients are obtained through statistical calculations, and the most important environmental factors can be determined using machine learning methods. The aggregate behavior methodology is most often chosen for determining bicycle flows due to its easy application and the availability of the necessary data. When using this model, existing bicycle flows in central zones of the city or territory are used. Then, using statistical analysis methods, the most significant environmental factors that influence bicycle flow are found, such as population size, land use type, terrain conditions, and sociodemographic factors. Coefficients are calculated for these environmental factors. Then, using these coefficients where bicycle flows are not known, and only significant circumstances are known, using linear or multiple regression methods, bicycle flow is calculated.

### Sketch plan methods

Using the sketch plan methodology, bicycle traffic flows are predicted using already established rules that are related to the peculiarities of population behavior. The methodology uses easily accessible data, such as city modal split data, population size, etc. The methodology performs simple calculations that do not require a specific level of knowledge or specific programs. The results obtained can be adjusted according to specific circumstances (Krizek et al., 2006; Turner et al., 1998).

The sketch plan methodology can be used to determine project priorities, predict non-motorized traffic flows by comparing data with existing flows from other similar locations, determine the flows generated by attractions, and determine the impact of bicycle infrastructure on car trips. Despite the ease of calculation, data availability, and potential for practical use, researchers have rarely studied this methodology because of its high error and the influence of all possible factors on the calculations. A methodology that is easy to understand, apply, and explain is much more useful in practical terms, even if it is not accurate (Krizek et al., 2006).

However, this methodology has been studied very little by researchers (Goldsmith, 1997; Griffin, 2009; Krizek et al., 2006; Turner et al., 1998). It was described more than 15 years ago, when Griffin (2009) used vehicle traffic flows to predict pedestrian and bicycle traffic flows in an urban transport network. Using the sketch plan methodology, a methodology was developed for predicting bicycle and pedestrian flows in street sections (Turner et al., 1998), predicting bicycle flows only in the already installed infrastructure (Krizek et al., 2006), and predicting bicycle flows in the entire network (Griffin, 2009).

Goldsmith (1997) used the sketch plan methodology to determine when the provision of bicycle infrastructure increased the number of cyclists and reduced the distance travelled by cars. The study first identified the location and boundaries of

a travel zone from which the highest bicycle traffic was expected. The population in this zone was then estimated from census data, and the proportion of daily commuters was analysed. The proportion of the population already using bicycles was then assessed and, based on current trends and population demographics, the number of new people likely to switch to cycling was predicted. The number of trips that would be taken from a single car, the average trip distances, and how this would reduce the total distance travelled by vehicles and reduce transport pollution were determined.

Turner et al. (1998) developed a methodology for predicting bicycle and pedestrian flows using a sketch plan methodology that can be used to determine flows in existing or planned infrastructure. To determine bicycle flows, a study area was selected, and a zone was determined from which bicycle trips could be made (within a radius of 3.2–4.8 km). Then, land uses were determined in that area (single-family house areas, multi-family house areas, specialized purpose areas, administrative purpose areas), and the number of residential areas was estimated. Accordingly, the number of bicycle trips was assigned to each land use. Then, the total number of bicycle trips was predicted for the entire study area, based on the land use.

Krizek et al. (2006) also developed a bicycle flow forecasting methodology using a sketch plan methodology that can be used to forecast flows in planned infrastructure. The main assumptions of the study, which support this analysis, are that a large proportion of all bicycle trips are made by a small proportion of cyclists who ride frequently for recreational purposes and that many of them are observed in the modal split study. Thus, in an area with a large number of cyclists who ride recreationally, the total bicycle flow will be higher, while in an area with a small number of recreational trips, the total bicycle flow will be lower. The researchers developed three formulas for calculating low, medium, and high bicycle traffic flows, studying the characteristics of bicycle use in the United States. The predicted bicycle flow was calculated based on the proportion of bicycle trips made for commuting purposes and the total number of bicycle trips, and the proportion of recreational trips is calculated from the created dependency graphs. These formulas were used to calculate predicted bicycle traffic in the United States.

Griffin (2009) used a sketch plan methodology to forecast bicycle traffic across the entire city's bicycle infrastructure network, which depended on the city's functional zone and existing vehicle flows. When forecasting bicycle trips, the current share of bicycle trips (modal split) was determined, the number of bicycle trips made for recreational purposes was determined according to the assumptions made, the number of bicycle trips in it was assigned according to the city's functional zone, and the predicted number of bicycle trips was calculated proportionally according to the existing transport flows in the city.

### Other methodologies

In the scientific literature, the number of cyclists is most often predicted in order to determine the occupancy of bike sharing stations or to determine where it is most appropriate to install bike rental points in an urban area (Dey et al., 2021; Karunanithi et al., 2024; Li et al., 2023). When predicting the demand for bicycles at bike sharing stations, the OD matrix methodology is most often used (Dey et al., 2021). Linear mixed models using bike-sharing station, sociodemographic, terrain and weather variables are also used to predict bicycle demand (Dey et al., 2021). Deep Learning methods are also used, which use existing data from bike-sharing stations (Li et al., 2023; Ma & Liu, 2024), or other methods, such as Machine Learning (Karunanithi et al., 2024), Multi Granularity (Zhang et al., 2024), Convolutional and Gated Attention Spatial – Temporal Networks (Qian et al., 2025). Bike sharing service providers have GPS trackers installed on bicycles, so they have all the data about the location of bicycles, which route and how long the bicycle was used.

Bicycle traffic flows are also predicted using new data sources, such as Strava or mobile operator data, and existing environmental factors (Barman et al., 2025; Jean-Louis et al., 2024). The calculations assume that there is a relationship between dependent and independent variables. The dependent variable is usually already calculated bicycle flows, which can be obtained from field surveys, bicycle counter data or bicycle flow data from crowdsourced data sources. Independent variables are usually land use, population size, weather conditions, sociodemographic characteristics, etc. Using these variables, bicycle flows in cities were predicted by Fan et al. (2021), Jean-Louis et al. (2024), Kwigizile et al. (2022), Nelson et al. (2021). In all sources, bicycle flow data from Strava Metro are compared with already measured bicycle flows and then, based on the identified significant environmental factors, bicycle flows are determined in places where natural bicycle flow data are not determined. Kwigizile et al. (2022) used Machine Learning models, Nelson et al. (2021) used Least Absolute Shrinkage and Selection Operation technique, Jean-Louis et al. (2024) used Generalised Boosted (Regression) Models, and Qian et al. (2025) used Convolutional and Gated Attention Spatio-Temporal Network model to predict bicycle flows.

Bicycle flows can be predicted using Agent-Based models. Kaziyeva et al. (2021) used an Agent-Based model to determine daily bicycle flows for a region by considering sociodemographic factors, behavioral rules from surveys, information on existing infrastructure, land use, and existing data on bicycle flows. Zare et al. (2024) simulated bicycle traffic in a developed area in an Australian city using an Agent-Based model based on land use factors, existing infrastructure, and Strava data. Machine learning models can also be used for bicycle flow predictions. Baumanis et al. (2023) used a LASSO regression technique to predict bicycle traffic flows based on the number of Covid-19 cases and weather conditions. Myhrmann & Mabit (2023) used Machine Learning methods to predict bicycle traffic based on

weather conditions only. Hitge & Joubert (2021) used Machine Learning methods to predict bicycle traffic flows in 20 different US cities.

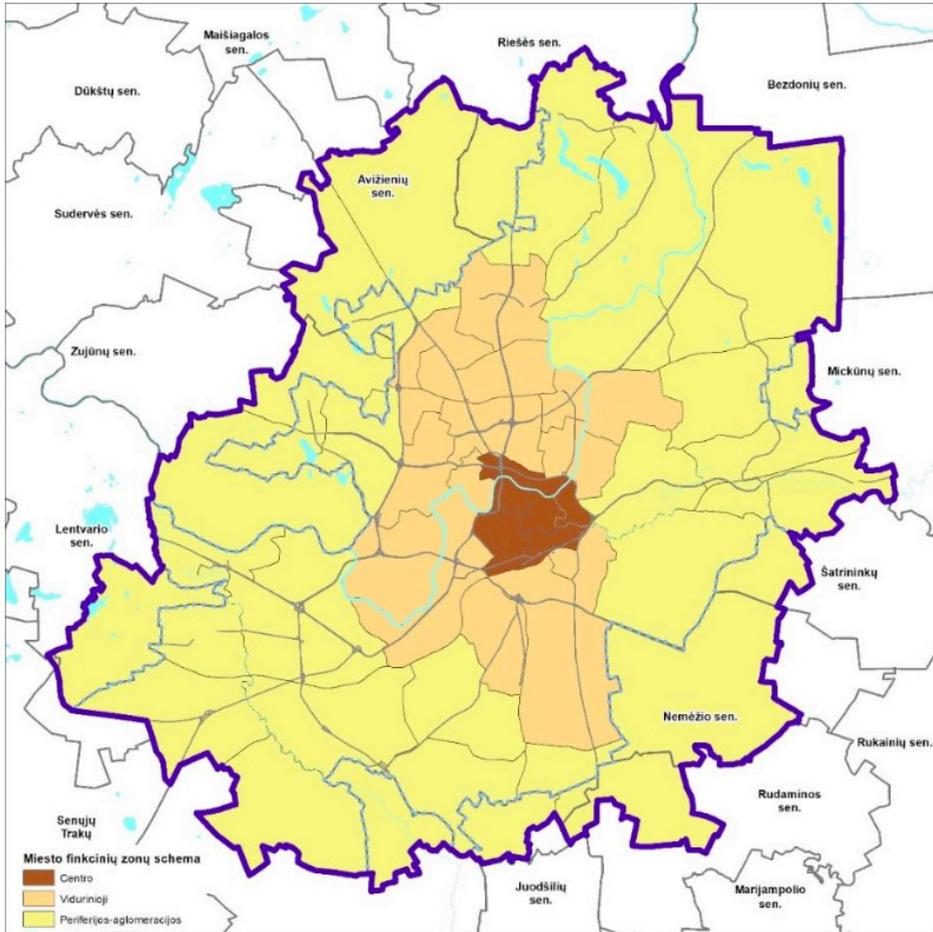
An analysis of the existing bicycle flow forecasting methodologies in the scientific literature shows that they require deep scientific knowledge to perform calculations, as well as detailed data on existing bicycle flows from databases. However, engineers involved in the design of bicycle infrastructure usually have neither the appropriate scientific level of education nor access to bicycle flow data bases. Most often, such bases do not exist in cities at all. It has been found that one of the simplest methodologies for forecasting bicycle flows in a city is the sketch planning methodology, since its use requires freely available data and simple calculations. Taking this into account, the article aims to evaluate the accuracy of the bicycle flow forecasting methodologies developed based on the sketch planning methodology in the central and middle zones of the city. Additionally, it seeks to determine how accurately this methodology predicts bicycle flow in the middle zone of the city, both when the planned infrastructure is connected to the overall bicycle transport network and when it remains unconnected.

## 2. Methodology

### Study area

Vilnius city, according to the city's general plan, is divided into three functional zones, which differ in their specificity, building intensity and density, and the number of attraction objects (Figure 1) (Vilniaus miesto savivaldybė, 2007). The central zone of the city is the most functionally integrated zone of the city, where the number of workplaces dominates compared to the number of residences. Only 10% of Vilnius city residents live here, and the most pronounced fluctuations in daily activity are visible, due to the attraction to workplaces and departures during the evening peak. The middle zone of the city is characterised by an averagely lower degree of functional integration and a contradictory set of polyfunctional and specialized residential and industrial districts. In some neighbourhoods of the middle functional zone, along with residential function, there are also industrial function areas or residential and specialized purpose areas (for example, residential houses and medical institutions buildings predominate together). However, despite the mixed functional purpose, in the middle zone, residential purpose areas remain dominant. 64% of all city residents live in the middle zone of the city. The peripheral zone of the city is a zone of specialized districts, dominated by low-rise residential areas, pure industrial areas, scientific, educational, medical centers, garden communities. There is a deficit of labor and social infrastructure; there is low investment in the development of transportation or engineering infrastructure, which would be maintained by the city. 26% of the population lives in the peripheral

zone of the city. There are also noticeable trends when residents from the central zone of the city move to the periphery due to low real estate prices; therefore, the number of residents of the peripheral zone is gradually increasing.



**Figure 1.** Functional zones of Vilnius city. Brown – the central zone of the city, orange – the middle zone of the city, yellow – the peripheral zone of the city (Vilniaus miesto savivaldybė, 2007)

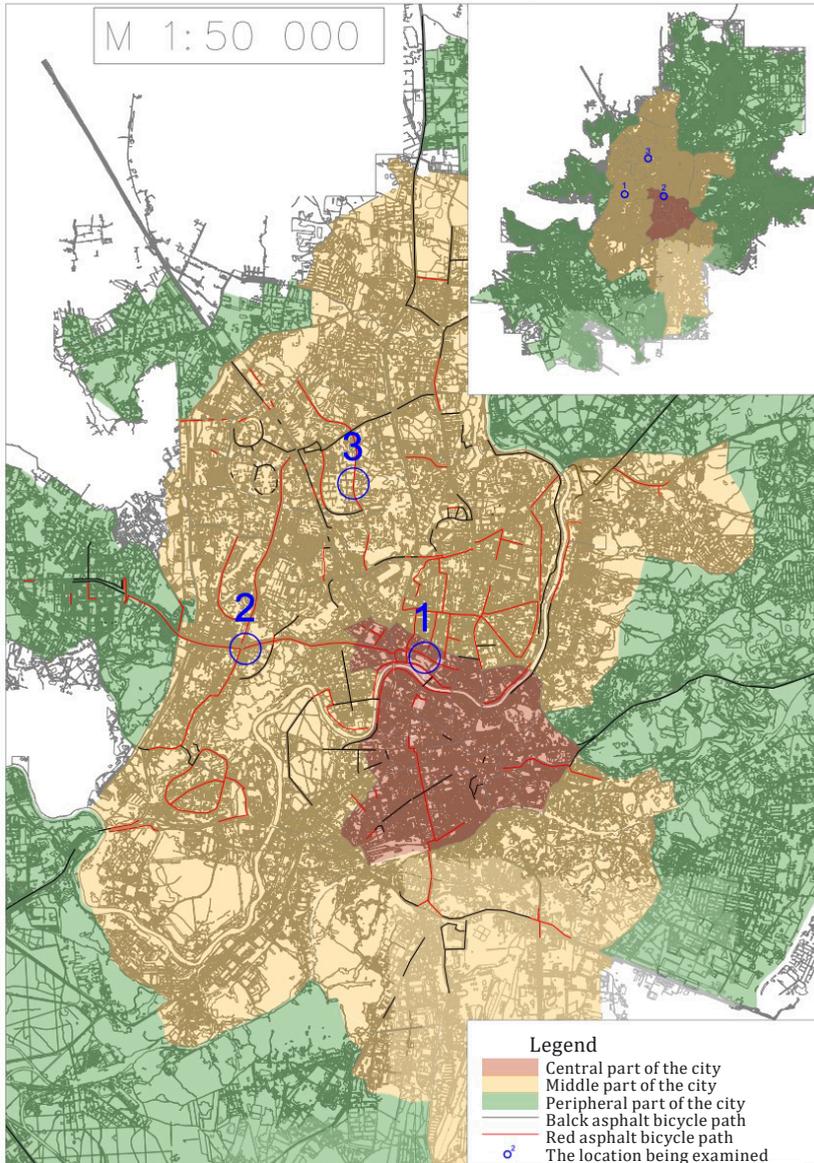
In the peripheral zone of the city, the infrastructure for car transport is not actively developed; therefore, the bicycle infrastructure is not expanded either. All resources are allocated to the development of the bicycle infrastructure network in the central and middle zones of the city, where the majority of daily trips for

transportation or other purposes occur. Taking this into account, three locations were selected for the analysis – one in the central zone of the city and two in the middle zone of the city. The locations selected in the middle zone of the city differ from each other because one location connects to the general bicycle infrastructure network, while the other one does not.

To assess the accuracy of the bicycle flow forecasting methodology of the central zone of the city, Konstitucijos Ave. (Figure 2, No. 1) located in the central zone of Vilnius city was chosen. The largest number of administrative buildings are located here and continue to be built; therefore, there is the largest concentration of workplaces, which attracts residents from middle zone neighborhoods to come here for work every day. Business establishments are developing in this zone; new offices are being built. The historical city center (old town) is not examined, as existing development allows for either a complete ban on car traffic and provision of traffic for pedestrians and bicycles, or quiet streets with mixed traffic.

In the middle zone of the bicycle traffic flow forecasting methodology, when the planned infrastructure connects to the general bicycle network, T. Narbuto St. (Figure 2, No. 2) was selected for assessment. This street connects the central business part of the city (Konstitucijos Ave.) with the most densely populated residential neighbourhoods (Viršuliškės, Karoliniškės, Justiniškės). The installation of bicycle infrastructure ensures smooth communication between residential areas and workplaces, the distance from the study area to the city center is about three kilometres.

The methodology for predicting bicycle traffic flows in the middle zone of the city, when the planned infrastructure does not connect to the general bicycle infrastructure network, S. Stanevičiaus St. (Figure 2, No. 3) was selected for the assessment. The street is located in a typical residential neighbourhood of intensive development – Fabijoniškės. Here, as in the entire middle zone of the city, the largest number of residents prevails. The district is 3–4 km away from the central zone of the city, but direct, shortest connection with the central zone of the city is not ensured. In order to get from S. Stanevičiaus St. to Konstitucijos Ave. with the existing bicycle infrastructure, it would be necessary to travel 5.4 km (Gelvonų St., Ozo St., Širvintų St., Kernavės St.), if a bicycle path were installed at the shortest distance (Ukmergės St.), it would be necessary to travel 4 km.



**Figure 2.** Study areas in Vilnius city. 1 – Konstitucijos Ave. in the central zone of the city, 2 – T. Narbuto St. in the middle zone of the city (when the planned infrastructure connects to the general bicycle network), 3 – S.Stanevičiaus St. in the middle zone of the city (when the planned infrastructure does not connect to the general bicycle network)

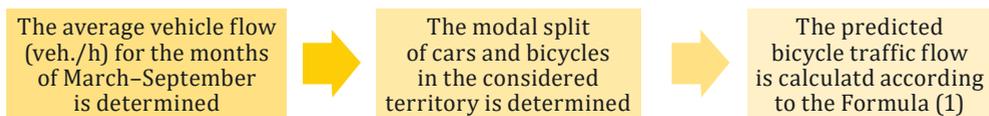
### Bicycle traffic flow forecasting

The bicycle flow forecasting methodologies in the central and middle zones of the city are developed on the basis of the sketch plan methodology. Therefore, bicycle flows are forecast based only on freely available data – population, car traffic flows, Vilnius city statistical data, and modal split data. The methodologies do not analyse how bicycle traffic changes under different weather conditions, changing terrain altitudes, changes in the bicycle infrastructure network and other factors, which are usually analysed in bicycle flow forecasting methodologies based on direct demand models. The methodology presented below analyses bicycle traffic flow during peak hours, on linear street sections.

### Bicycle traffic flow forecasting in the central zone of the city

The methodology for forecasting bicycle traffic flow in the city centre was developed based on the Griffin (2009) methodology, where bicycle traffic flows were forecasted based on vehicle flows. Modal share, also known as modal split, is a critical indicator of transportation behaviour and sustainability within a city, reflecting the percentage of travelers using different modes of transport such as public transport, bicycles, walking, and private vehicles (Flaes et al., 2016). For example, in Vilnius, according to 2022 modal share data, 43.6% of trips are made by car, 29.6% on foot, 23.7% by public transport, 1.3% by bicycle, and 1.8% by other means of transport. Since modal share shows the interaction between transport modes, the study also uses modal share data to determine the predicted bicycle flow by estimating vehicle flow.

It was also chosen to use transport flow data because cities do not always have data on workplaces in the city centre, and data on vehicle flows are usually collected in cities. The calculations use vehicle flows on the section during the warm season (March-September). Since the majority of bicycle trips are made from March to the end of September, vehicle flows are assessed accordingly at that time. Figure 3 presents the stages of the methodology for predicting bicycle flows in the central zone of the city.



**Figure 3.** Stages of the methodology for predicting bicycle flows in the central zone of the city

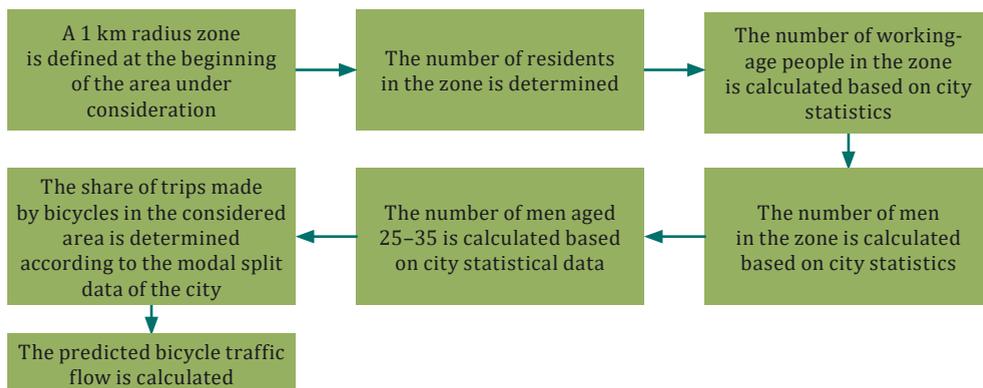
The central city area is calculated according to Equation (1).

$$tdvs = \frac{\frac{1}{n} \sum_{j=1}^n x_j dMS}{aMS}, \quad (1)$$

where  $n$  – number of months,  $x$  – flow rate,  $dMS$  – share of trips made by bicycles,  $aMS$  – share of trips made by cars.

#### Methodology for predicting bicycle traffic flows in the middle zone of the city, when the planned infrastructure connects to the general bicycle network

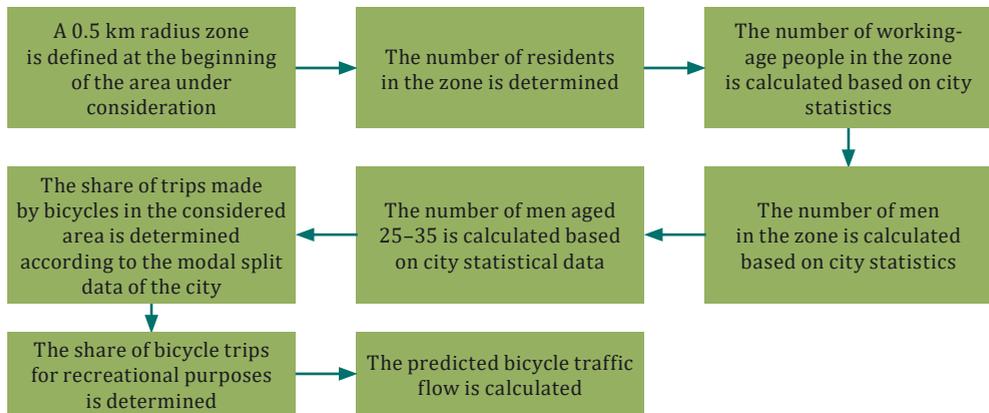
The methodology for predicting bicycle flows in the middle zone of the city, when the planned infrastructure connects to the general bicycle network, was developed based on the Turner et al. (1998) methodology, while maintaining the essential steps. However, instead of assessing the zone of influence at a distance of 3–4 km, a zone of 1 km radius is assessed. Since the planned infrastructure connects to a common bicycle network, and considering its intended purpose, the section is intended for main use, a zone of influence of 1 km radius is adopted for it. The 1 km zone of influence was chosen, and since Vilnius City Sustainable Mobility Plan provides that 1 km is the optimal distance from the place of residence to the main use bicycle routes. Turner et al. (1998) assessed the land use type. They assigned to it the number of trips that will be made from each land use type, since the study aims to determine the bicycle flow according to functional zones, the population in the territory under study, and their sociodemographic factors are assessed, not the land use type. Both the methodology by Turner et al. (1998) and the methodology presented in the study use the same data on the modal split of the territory under study. The stages of the methodology are presented in Figure 4.



**Figure 4.** Stages of the methodology for predicting bicycle flows in the middle zone of the city, when the planned infrastructure connects to the general bicycle network

Methodology for predicting bicycle traffic flows in the middle zone of the city, when the planned infrastructure does not connect to the general bicycle network

It has been established that the presence of bicycle infrastructure encourages cycling (Guo et al., 2022). However, when the infrastructure being installed does not connect to the general bicycle infrastructure network, it loses its main functional purpose. The planned bicycle infrastructure of the area under consideration should be of the main use purpose, but it does not connect to the general network. Therefore, it is more of local significance – intended for trips within the neighbourhood. Taking this into account, the zone of influence of bicycle infrastructure is reduced, and it is assumed to be located at a distance of 500 m. Additionally, bicycle trips are planned to be assessed according to their transportation purposes. The methodology stages are presented in Figure 5.



**Figure 5.** Stages of the methodology for predicting bicycle flows in the middle zone of the city, when the planned infrastructure does not connect to the general bicycle network

### Manual counts of bicycle flow

In Vilnius, data on bicycle traffic flows are not collected automatically; there are no databases or other open data sources. Bicycle flows can be measured by conducting field observations (manual counts) in a selected section or using video camera data. There are 307 traffic light intersections in Vilnius, of which 145 have video surveillance cameras installed. After selecting the analysed territories, exact locations were chosen in the city where video surveillance cameras would be installed – T. Narbuto St.-Laisvės Ave. intersection, Konstitucijos Ave.-Lietuvos Statutų St. intersection and S. Stanevičiaus St. 14 regulated pedestrian crossing. The video zone of each camera covered the installed bicycle paths. The counts were

performed by reviewing city video camera recordings at the Traffic Management Centre of the “Susisiekimo paslaugos”.

In order to verify the accuracy of the theoretical bicycle flow forecasting methodology, manual bicycle flow counts were conducted. The counts were conducted from 26 September 2023 to 26 September 2024. Since the aim of the work was to determine bicycle trips for work purposes, it was chosen to study flows on weekdays. Tuesday, Wednesday, and Thursday were chosen from the five-day work week, since after the Covid-19 pandemic, most workplaces remained with remote or blended work options. These workdays reflect employees' trips when they go to work physically.

The peak hours of bicycle traffic flows may vary depending on the functional zone of the city. Taking this into account, before the start of the manual counts, bicycle flows were analysed from 7:00–9:00 am and from 4:00–7:00 pm. When reviewing bicycle traffic flows on T. Narbuto St. and Konstitucijos Ave., it was determined that the highest bicycle flows were recorded in the morning at 7:30–8:30 am, and evening flows at 5:30–6:30 pm. When analysing bicycle traffic flows on S. Stanevičius St. in the morning hours, bicycle flows were particularly low, only a few cyclists were recorded at around 7:50 in the morning. Therefore it was decided to analyse the usual peak hour flows. When analysing bicycle traffic flows during the evening peak, it was determined that the highest flows were around 6:00 pm. Therefore, it was chosen to analyse the usual evening peak hour. In all locations examined on the selected days, bicycle flows were counted during the peak hours in the morning at 7:30–8:30 and in the evening at 5:30–6:30.

Usually, the error of manual counts is determined by comparing manually counted bicycle traffic flow data with flow data determined by bicycle counters or other devices. There are no bicycle traffic flow counters or other devices in Vilnius that would automatically calculate bicycle flows. Taking this into account, it is assumed that manually counted bicycle traffic flows have no error.

### Methodological Accuracy Assessment

The Mean Absolute Percentage Error (MAPE) is a widely used metric for assessing the accuracy of forecasting models, and many researchers use it to describe the difference between measured and predicted bicycle flows (Dadashova & Griffin, 2020; Elesawey, 2018; Jean-Louis et al., 2024; Oskarbski et al., 2021). Therefore, the mean absolute percentage error methodology was chosen to assess the theoretical and field-measured bicycle traffic flow, respectively.

The accuracy of the calculation methodology is assessed by the mean absolute percentage error (MAPE) according to the Equation (2):

$$\text{MAPE} = \frac{1}{n} \sum_{t=1}^n 100 \times \left| \frac{A_t - F_t}{A_t} \right|, \quad (2)$$

where  $n$  – number of calculations,  $A_t$  – flow amount determined by physical measurements,  $F_t$  – flow amount determined by theoretical calculations.

Also, the theoretically calculated bicycle traffic flow is compared with the manually counted average bicycle flow using SPSS Statistic software. One Sample T test will be used to check whether the averages are statistically significantly dependant, and confidence intervals will be determined. Using Cohen's  $d$  indicator, the difference in accuracy of theoretical and manually counted flows will be determined.

### 3. Results

According to the bicycle traffic flow forecasting methodology described in the methodology section, theoretical calculations of the predicted bicycle traffic flow were performed in the central zone of the city (Konstitucijos Ave.), in the middle zone of the city, when the planned infrastructure connects to the general bicycle network (T. Narbuto St.), and in the middle zone, when the planned infrastructure does not connect to the general bicycle network (S. Stanevičiaus St.).

#### Theoretical results of bicycle traffic flow forecasting in the central zone of the city

In order to forecast bicycle traffic flow in the central zone of the city, based on the city traffic flow data, average vehicle flows were determined for the months of March–September. In March, the average vehicle flow on Konstitucijos Ave. was 645 veh./h, in April – 672 veh./h, May – 725 veh./h, June – 677 veh./h, July – 682 veh./h, August – 641 veh./h, September – 658 veh./h.

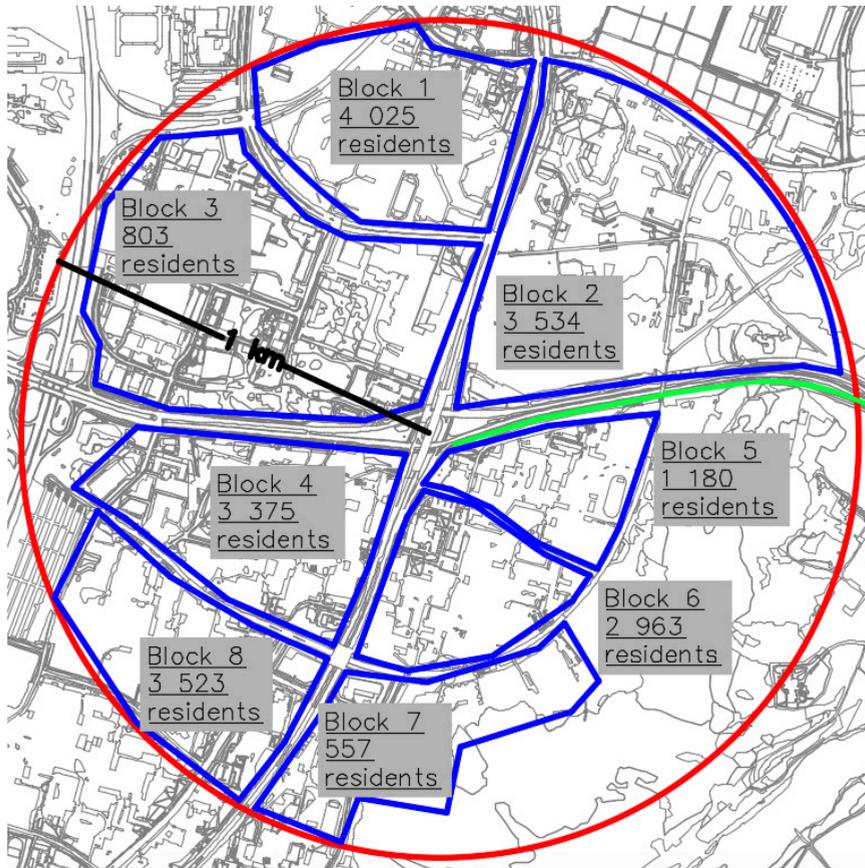
In 2022, a modal split survey was conducted in Vilnius city, and it was found that in the central part of the city 50% of trips were made by car and 2.94% by bicycle. With this data, the theoretical predicted bicycle traffic flow in the central zone of the city was calculated according to Equation (1).

$$tdvs = \frac{(645 + 672 + 725 + 677 + 682 + 641 + 656) \times 2.94}{50} = 39.4$$

According to the calculations performed, it was determined that the theoretically predicted bicycle flow on Konstitucijos Ave. should be 39 bicycles/h. The flow is calculated for peak hour.

#### Theoretical results of bicycle traffic flow forecasting in the middle zone of the city, when the planned infrastructure connects to the general bicycle network

According to the bicycle traffic flow forecasting methodology presented in the methodology section, bicycle traffic flow was calculated in the Vilnius city middle zone – T. Narbuto St.



**Figure 6.** The study area is located in the middle zone of the city, where the planned infrastructure connects to a common bicycle network (T. Narbuto St.). The 1 km area is marked in red, the blocks of the studied area and the number of residents are marked in blue, and the planned infrastructure is marked in green

At the beginning of the planned cycle path, a 1 km radius area was defined. The area was divided into blocks according to street boundaries. Using the data from the Vilnius City Population and Housing Census (2021), the number of residents in each block was determined (Figure 6). After summing up the number of residents in individual blocks, it was determined that 20 660 residents live in the area under consideration.

Then, further calculations were performed to determine the number of working-age (18–64 years old) residents in the territory under consideration. In Vilnius, data is collected on the number of residents by year of birth in individual

neighbourhoods, therefore, using this data, it was determined that working-age residents in the Viršuliškės and Karoliniškės neighbourhoods made up 57% of the total population. Accordingly, it was calculated that 11 776 working-age people lived in the territory under consideration. Although the population belonged to the working-age group, not all residents worked; therefore, using statistical data, the number of employed people in the territory under consideration was estimated. According to Vilnius City statistical data, 90% of working-age people work in the city. Accordingly, 10 599 people work in the area under consideration. It is assumed that these people travel for work purposes every day.

In order to determine the theoretical number of cyclists, it was assumed that only men travelled by bicycle. According to Vilnius city statistics, 50.2% of the working population are men. Therefore, there are 5320 men in the area under consideration.

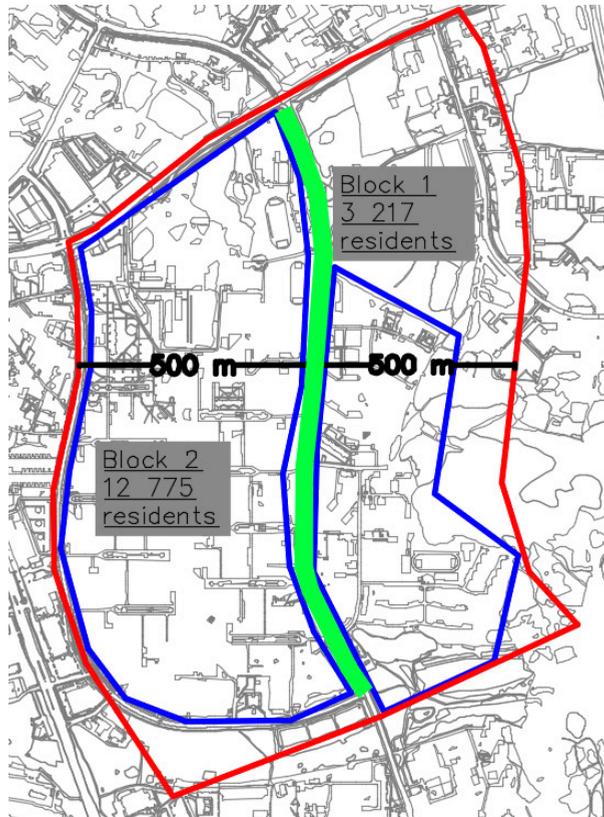
The choice to travel by bicycle is also influenced by a person's age – the older a person is, the less likely they are to travel by bicycle. According to Vilnius city statistics, 42% of all working-age men are men aged 25 to 39. Accordingly, there are 2235 men aged 25–39 in the area under consideration.

According to the Vilnius modal split study, an average resident makes three trips per day. The corresponding number of men will make 6704 trips per day.

The modal travel distribution data for Vilnius city for 2022 are grouped by neighbourhoods, so it is possible to identify the modal split in most areas or city zones. One of the neighbourhoods closest to the area under consideration and with data on trips made by bicycle is Viršuliškės neighbourhood. The share of daily trips made by bicycle in it is 1.3%. From the number of trips made by men aged 25 to 39 in the area under consideration, 1.3% is calculated. The estimate is 80.4 cyclists per hour.

#### **Theoretical results of bicycle traffic flow forecasting in the middle zone of the city, when the planned infrastructure does not connect to the general bicycle network**

According to the bicycle traffic flow forecasting methodology presented in the methodology section, bicycle traffic flow was calculated in the middle part of Vilnius city – S. Stanevičiaus St.



**Figure 7.** The study area is located in the middle zone of the city, where the planned infrastructure does not connect to the general bicycle network (S. Stanevičiaus St.). The area 500 m from the planned infrastructure is marked in red, the blocks of the studied area and the number of residents are marked in blue, and the planned infrastructure is marked in green

A distance of 500 m is set aside in parallel from the planned infrastructure. The territory falling into the 500 m zone was divided into blocks according to street restrictions. Using the data of the Vilnius City Population and Housing Census (2021), the number of residents in each block was determined (Figure 7). After summing up the number of residents in individual blocks, it was determined that 15 992 residents live in the area under consideration.

According to the statistical data of the Fabijoniškės district, it is established that 58% of the working-age population (18–64 years old) live in the studied area, which corresponds to 9275. According to the statistical data of the city of Vilnius, 90% of the working-age population are employed, which corresponds to 8348. Of

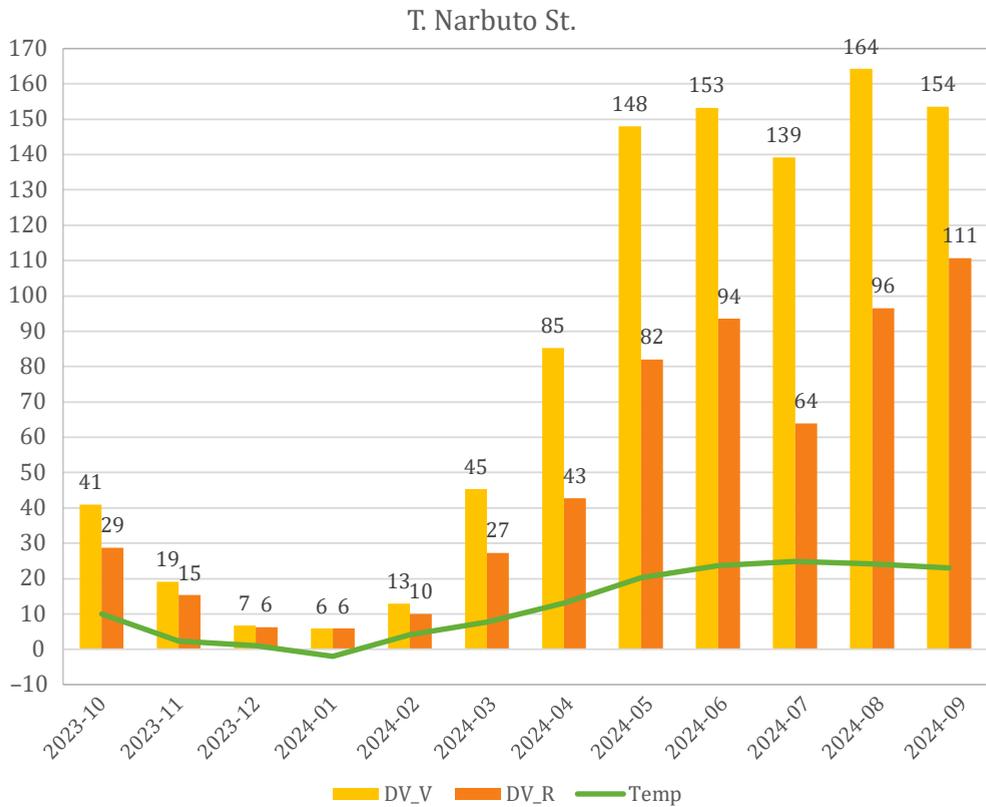
the employed population, 50.2% are men – 4190, of which 42% are men aged 25 to 35 – 1760. According to the data of the Vilnius city modal split study, one resident makes an average of three trips per day; therefore, these men will make 5280 trips per day, respectively. According to the city modal split data of the same study, the share of trips made by bicycles in the Fabijoniškės district is 0.9%. From the number of trips made by men aged 25–39 in the studied area, 0.9% is calculated, which gives 48 cyclists per hour.

Since the planned infrastructure will not ensure connection with the general city bicycle infrastructure network, and the calculation of the shortest route to the central part of the city, once created, is revised by assessing the choice of travel mode according to the purpose of the trip. According to the data of the Fabijoniškės district modal split survey, there are no trips to work in the district, and 90% of trips by bicycle are divided equally between home, educational institution and for leisure purposes and 10% of the purposes of trips are not classified. Therefore, we assume that only leisure trips are made in the area under consideration by 30%. Respectively, it is determined that there will be 14.25 cyclists per hour.

### Manual counts of bicycle flow

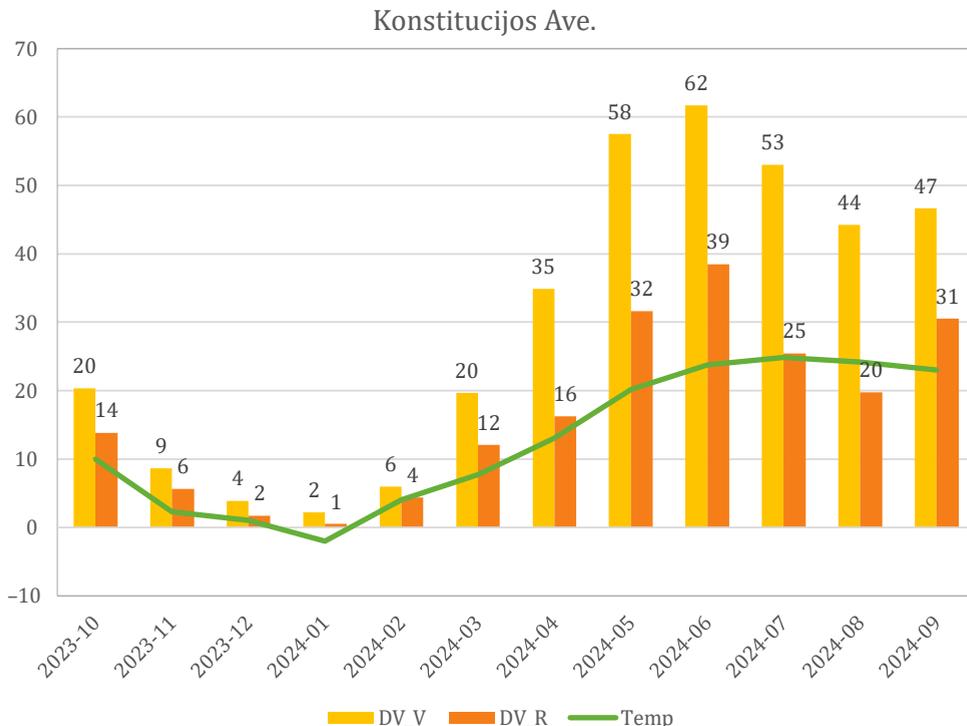
After manual counts of bicycle flows were carried out over the course of a year, data were grouped by months. Figure 8 shows the average monthly flow of cyclists during the morning and evening peak hours on T. Narbuto St.

Figure 8 shows that the morning peak flows, which reflect only trips made for transportation purposes, begin to rise in March and decrease in October. Scientific studies have also found that the largest number of bicycles is recorded in March to October (Lin & Fan, 2020). This is related to air temperature. Accordingly, the air temperature curve presented in Figure 8 shows that as the air temperature changes, so do the cyclist flows. Comparing the evening and morning peak flows on T. Narbuto St., it can be seen that the flows during the evening peak are higher than the morning peak. This indicates that bicycle trips made in the evening are not solely for transportation purposes. Analysing the morning peak flows, it can be seen that they are lowest in January and reach 6 bicycle/h, and the highest flows in September, reaching 110 bicycle/h. During the evening peak, the lowest bicycle flow is in January – 6 bicycle/h, the highest – 164 bicycle/h in August.



**Figure 8.** Average monthly flow of cyclists during the morning and evening peak on T. Narbuto St. DV\_R – bicycle flow during morning peak, bicycle/h, DV\_V – bicycle flow during evening peak, bicycle/h, Temp – air temperature, °C

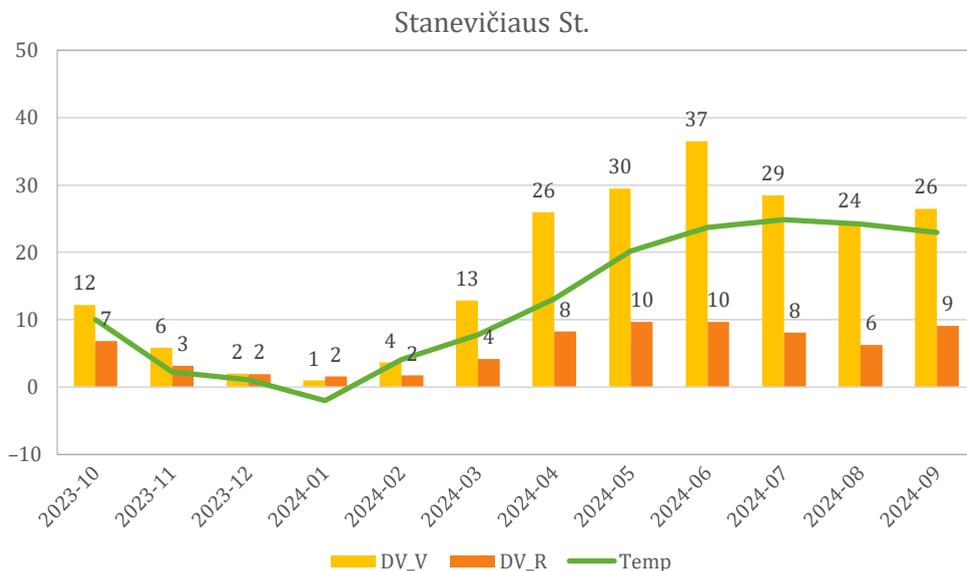
Figure 9 shows the average monthly cyclist flow during the morning and evening peak on Konstitucijos Ave.



**Figure 9.** Average monthly flow of cyclists during the morning and evening peak on Konstitucijos Ave. DV\_R – bicycle flow during morning peak, bicycle/h, DV\_V – bicycle flow during evening peak, bicycle/h, Temp – air temperature, °C

The data presented in Figure 9 show the same general trends as on T. Narbuto St., with the highest cyclist activity in the period of March–October, with lower bicycle flows during the morning peak hours than during the evening peak hours. On Konstitucijos Ave., the lowest cyclist flow during the morning peak was recorded in January, not even reaching 1 bicycle/h, and the highest flow was recorded in June – 39 bicycle/h during the evening peak hours, the lowest flow in January – 2 bicycle/h, and the highest – 62 bicycle/h in June.

Figure 10 shows the average monthly cyclist flow during the morning and evening peak hours on Stanevičiaus St.



**Figure 10.** Average monthly cyclist flow during the morning and evening peak on Stanevičiaus St. DV\_R – bicycle flow during morning peak, bicycle/h, DV\_V – bicycle flow during evening peak bicycle/h, Temp – air temperature, °C

Figure 10 shows the same trends as T. Narbuto St. and Konstitucijos Ave. The cycling season is from March to October, the morning peak is lower than the evening peak. However, the lowest bicycle flows of all the sections examined were recorded on S. Stanevičiaus St. Here, during the morning peak in January, it was 2 bicycles/h, the highest in May and June – 10 bicycles/h during the evening peak, the lowest flow was also in January – 1 bicycle/h, the highest – in June – 37 bicycles/h.

After conducting manual counts of bicycle flows, it was established that bicycle flows were affected by seasonality, and the highest flows were recorded from March to October. Therefore, the flow should be assessed from March to the end of September, inclusive. From the analysis of morning and evening peak flows, it was determined that the morning peak best reflected trips made for transportation purposes, while during the evening peak, trips made for purposes other than transportation might also occur. However, in order to form bicycle usage habits in the city, it should be ensured that bicycle trips are comfortable even if the infrastructure is used for recreational purposes. For this reason, during the analysis of the theoretical bicycle flow forecasting methodologies, the average cyclist flow is assessed by evaluating the morning and evening peaks. After conducting a

statistical analysis of natural bicycle traffic flows on Narbuto St. ( $N = 106$ ), it was determined that the March–September survey indicators fluctuated between 11 and 220 cyclists per hour, with an average of  $M = 94.151$  ( $SD = 52.619$ ). On Konstitucijos Ave. ( $N = 106$ ), the March–September survey indicators fluctuated between 5 and 84 cyclists per hour, with an average of  $M = 33.16$  ( $SD = 16.486$ ). On S. Stanevičiaus ( $N = 106$ ), the March–September survey indicators fluctuated between 2.5 and 44 cyclists per hour, with an average of  $M = 16.25$  ( $SD = 9.618$ ).

### MAPE estimation

The MAPE error was used to estimate the bicycle flow forecasting methodologies in different urban areas. It used data from theoretically calculated forecast bicycle traffic flow and average bicycle traffic flow determined by manual counts. The data are presented in Table 2.

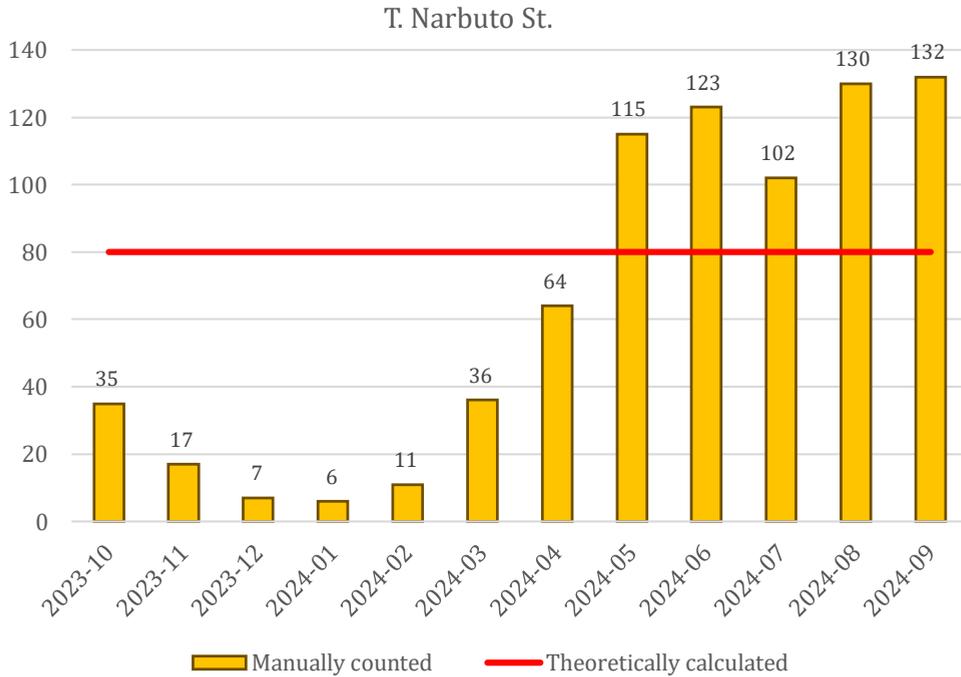
**Table 2. Manually counted and theoretically estimated bicycle flows in the studied sections**

	<b>T. Narbuto St.</b>	<b>Konstitucijos Ave.</b>	<b>S. Stanevičiaus St.</b>
Theoretically estimated bicycle flow, bicycle/h	80	39	15
Manually counted bicycle flow, bicycle/h	94.151	33.16	16.25

The data in Table 2 show that the theoretical and manual counted bicycle flows are similar in all studied sections.

Figure 11 presents the results of the theoretically calculated bicycle flow and the average bicycle flows determined by manual counts during peak hours on T. Narbuto St.

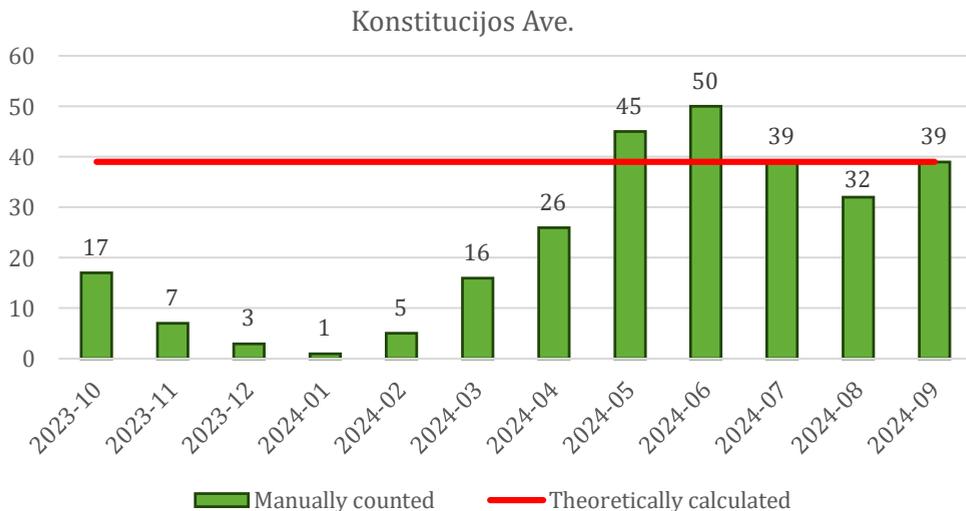
The data in Figure 11 show that the theoretically calculated bicycle flow on T. Narbuto St. falls within the naturally determined average peak hour flows in May, June, July, August, and September.



**Figure 11.** Average manually estimated peak hour bicycle flows and theoretically calculated bicycle flow on T. Narbuto St., bicycle/h

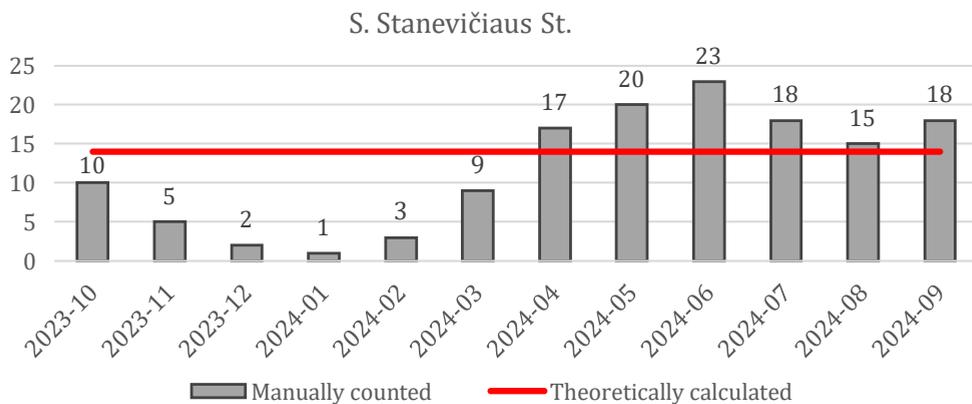
Figure 12 presents the results of the theoretically calculated bicycle flow and the average bicycle flows determined by manual counts during peak hours on Konstitucijos Ave.

The data in Figure 12 show that the theoretically calculated bicycle flow on Konstitucijos Ave. falls within the manually counted average peak hour flows in May, June, July, and September.



**Figure 12.** Average manually estimated peak hour bicycle flows and theoretically calculated bicycle flow on Konstitucijos Ave., bicycle/h

Figure 13 presents the results of the theoretically calculated bicycle flow and the average bicycle flows determined by manual counts during peak hours on S. Stanevičiaus St.



**Figure 13.** Average manually estimated peak hour bicycle flows and theoretically calculated bicycle flow on S. Stanevičiaus St., bicycle/h

The data in Figure 13 show that the theoretically calculated bicycle flow on S. Stanevičiaus St. falls within the manually counted average peak hour flows in April, May, June, July, October, and September.

The accuracy of the bicycle traffic flow forecasting methodology is calculated using Equation (2) with the data in Table 2.

According to Equation (2), the deviation of the theoretical bicycle flow forecasting methodology for the middle zone of the city when the planned infrastructure connects to a general bicycle network (T. Narbuto St.) was determined:

$$MAPE = \frac{1}{n} \sum_{t=1}^n 100 \times \left| \frac{94.151 - 80}{94.151} \right| = 15.03\%. \quad (2a)$$

It was determined that the deviation of the theoretical bicycle flow forecasting methodology for the middle zone when the planned infrastructure connects to the general bicycle network of the city (T. Narbuto St.) was 15.03%. One-sample T-test showed that the naturally measured bicycle flow averages were statistically significantly different from the theoretically calculated bicycle flow averages,  $t(105) = 2.769$ ,  $p < 0.05$ . It was found that the naturally measured bicycle flow was 14.15 higher than the theoretically calculated bicycle flow CI [4.017; 24.285]. The effect size, as measured by Cohen's  $d$ , was  $d = 0.269$ , indicating the small difference between natural and theoretical flows.

According to the Equation (2), the percentage deviation of the theoretical methodology in the central zone of the city (Konstitucijos Ave.) was calculated:

$$MAPE = \frac{1}{n} \sum_{t=1}^n 100 \times \left| \frac{33.16 - 39}{33.16} \right| = 17.61\%. \quad (2b)$$

It was determined that the deviation of the theoretical bicycle flow forecasting methodology for the central zone of the city (Konstitucijos Ave.) was 17.61%. One-sample T-test showed that the naturally measured bicycle flow averages were statistically significantly different from the theoretically calculated bicycle flow averages,  $t(105) = -3.647$ ,  $p < 0.05$ . It was found that the naturally measured bicycle flow was 5.84 smaller than the theoretically calculated bicycle flow CI [-9.015; -2.665]. The effect size, as measured by Cohen's  $d$ , was  $d = 0.354$ , indicating the small difference between natural and theoretical flows.

According to Equation (2), the percentage deviation of the theoretical methodology for the middle zone of the city when the planned infrastructure does not connect to the general bicycle network (S. Stanevičiaus St.) was calculated:

$$MAPE = \frac{1}{n} \sum_{t=1}^n 100 \times \left| \frac{16.25 - 14}{16.25} \right| = 13.5\%. \quad (2c)$$

It was determined that the deviation of the theoretical bicycle flow forecasting methodology for the middle part of the city when the planned infrastructure does not connect to the general bicycle network (S. Stanevičiaus St.) was 13.85%. One-sample T-test showed that the naturally measured bicycle flow averages were

statistically significantly different from the theoretically calculated bicycle flow averages,  $t(105) = 2.408$ ,  $p < 0.05$ . The naturally measured bicycle flow is 2.25 smaller than the theoretically calculated bicycle flow CI [0.398; 4.102]. The effect size, as measured by Cohen's  $d$ , was  $d = 0.234$ , indicating the small difference between natural and theoretical flows.

## 4. Discussion

Land use has a direct impact on the number of trips made by bicycle. The greater the diversity of land use in an area, the more trips will be made by bicycle. In a city, territories are divided into functional zones according to land use. Of these, the most important in terms of transportation needs are the middle zone and the central zone, since they respectively contain either the highest concentration of residential areas, from where the trip begins, or they contain the most places of attraction (workplaces). Often, these two functional zones in a city are separated by a transition zone, which is not built up with either residential areas or workplaces, but functions only as a transportation axis between the two functional zones. Taking this into account, it can be seen that it is important to know how to determine the transportation connections made in these different areas in order to ensure the targeted development of the bicycle infrastructure network.

There is no unified methodology in the world to predict bicycle traffic flows. Two most commonly used methodologies are distinguished in scientific literature – SD and DD. However, these methodologies are characterised by the necessity of data on existing bicycle flows in the city, the need for specific knowledge to perform calculations, and the need for software. Most often, bicycle traffic flows are predicted using these methodologies in scientific research or in organisations providing traffic flow analysis services. However, urban planning and infrastructure technical decision-making are carried out by engineers and urban development specialists, who usually do not have either the resources or specific knowledge to be able to predict bicycle flows using SS or DD methodologies. One of the most rarely analysed bicycle traffic flow forecasting methodologies in scientific literature is the sketch plan methodology. This methodology requires freely available data and established factors determining the choice of cycling, and no specific knowledge is required to perform the calculations. For these reasons, the methodology can be easily applied in practice, which makes it possible for engineers who are solving issues related to the installation of bicycle infrastructure to use it. The simplicity of the sketch plan methodology and its real-world applicability among engineers or urban development professionals make it more useful than existing bicycle flow forecasting methodologies that require detailed data and complex calculations. However, this methodology is not more accurate than the SD or DD methodologies or

any other methodologies that statistically determine cyclist behavior, where bicycle flows are adjusted with data from automatic bicycle counters in the city.

Taking this into account, the article aimed to determine the accuracy of the bicycle traffic flow forecasting methodologies, developed on the basis of the sketch plan methodology, in the central and middle zones of the city. To achieve the goal, three different locations in Vilnius were selected – a bicycle path located in the central functional zone of the city, a bicycle path located in the middle functional zone of the city, which connects to the general bicycle network, and a bicycle path in the middle zone, which does not connect to the general bicycle network. Manual bicycle traffic flow counts were conducted in the selected locations, which were used to assess the accuracy of the methodology.

When conducting theoretical studies to determine the predicted bicycle traffic flow, it was determined that in the central zone of the city, Konstitucijos Ave., the bicycle traffic flow during peak hours should be – 39 bicycle/h. In the middle zone of the city (when the infrastructure connects to the general bicycle network), T. Narbuto St., the theoretical bicycle traffic flow should be 80 bicycle/h., and in the middle part of the city (when the infrastructure does not connect to the general bicycle network), S. Stanevičiaus St., – 14 bicycle/h. After conducting manual counts to determine bicycle traffic flow on Konstitucijos Ave., T. Narbuto St., and S. Stanevičiaus St. it was found that the average peak hour bicycle traffic flow in the city center zone was 33 bicycle/h., in the middle zone of the city when infrastructure does connect to the general bicycle network – 94 bicycle/h., in the city middle zone when infrastructure does not connect to the general bicycle network – 16 bicycle/h. The MAPE method, confidence intervals and Cohen's  $d$  were used to determine the accuracy of the bicycle traffic flow forecasting methodologies. The calculations showed that the MAPE of the bicycle traffic flow forecasting methodology for the central zone of the city was 17.61%, CI [-9.015; -2.665],  $d = 0.354$ . The MAPE of the bicycle traffic flow forecasting methodology for the middle zone of the city when the infrastructure is connected to the general bicycle network was 15.03%, CI [4.017; 24.85],  $d = 0.269$ . The MAPE of the bicycle traffic flow forecasting methodology for the middle zone of the city when the infrastructure is not connected to the general bicycle network was 13.85%, CI [0.398; 4.102],  $d = 0.234$ . The Cohen's  $d$  test values show that there is a small difference between the theoretically determined bicycle traffic flows and those determined by field studies.

Usually, the accuracy of bicycle flow forecasting methodologies is assessed as a mean absolute percentage deviation (Bhowmick et al., 2023; Miah et al., 2024). However, the predicted bicycle traffic flows by Turner et al. (1998), Griffin (2009) and Krizek et al. (2006) were not evaluated with actual bicycle traffic flows, so there were no data on the validity of the sketch planning methodology. Miah et al. (2024) conducted a literature analysis of existing bicycle flow forecasting methodologies and found that the most complex computational models used to forecast bicycle

flows had the lowest MAPE, but the simpler ones had a higher MAPE. It was found that in simple models like linear regression, negative binomial MAPE was 10–40%. Dadashova & Griffin (2020) used a mixed-effects model to estimate daily bicycle traffic in Texas (USA), with a MAPE of 29%. Elesawey (2018) estimated bicycle traffic in Vancouver (Canada) using historical average methods. However, the accuracy of the estimation was poor because the effect of weather was not included. Then, using log-linear and negative binomial models, an error of about 23% MAPE was achieved. Jean-Louis et al. (2024) used a Generalized Boosted Regression model to estimate the daily number of bicycles in various parts of Germany with different levels of urbanization, with a MAPE of 27.9%.

This shows that the methodologies used by other authors had higher MAPE errors than the errors determined in the study using the sketch planning methodology. However, we cannot determine whether applying the methodologies proposed by other authors in the same locations would result in lower or higher error results. This is a disadvantage of many methodologies that the calculations are performed for specific conditions, the significance of factors is determined for specific cities, and they cannot be used in other cities. Meanwhile, the methodology presented in the study can be used in other cities because regardless of the city's statistical data or modal split data, the methodology algorithm remains the same.

The type of bicycle infrastructure in different cities is selected according to the applicable technical regulations or rules. However, most often the infrastructure type is determined by the street category or design speed. For example, Lithuanian legal regulations indicate that at a speed of 30 km/h and a car flow of less than 500 cars per peak hour, a bicycle street, a bicycle lane, a separate bicycle path or a general pedestrian bicycle path may be installed on the street. Then, the type of infrastructure is selected according to the bicycle traffic flow during the peak period – when the bicycle flow is up to 200 bicycle/h, a bicycle street or a bicycle lane is used, when the flow is higher, a bicycle lane, a bicycle path or a general pedestrian bicycle path is used. Also, knowing the predicted bicycle flow, the technical parameters of the bicycle paths are selected. The legal regulation in force in Lithuania states that a 2.5 m wide cycle path must be designed for a bicycle flow of up to 50 bicycle/h, a 3.0 m wide cycle path for 50–150 bicycle/h, and a 3.5 m wide path for higher flows. If an engineer does not know the planned cycle flow when designing a cycle infrastructure, they will not be able to correctly select the technical parameters of the width or radius of the cycle paths. Taking this into account, it can be seen that the predicted cycle flow is necessary not only to select the appropriate type of cycle infrastructure, but also for its technical parameters' selection. Therefore, the methodology presented in the study allows engineers to determine the predicted bicycle traffic flows, and then adapt them according to the current technical standards in each country where there is a visible need for it.

The bicycle flow forecasting methodologies analysed in the study can be applied in cities with a similar structure, where there is a clearly defined central part of the city, with the highest concentration of workplaces, and a middle part, with the highest concentration of residential areas. Such a structure is also identified by vehicle congestion from one part of the city to another during peak hours. If it is not clear what the functional purpose is, it can be determined by analysing the number of residential and work places in the area under consideration and based on this, determine whether the territory functions as a residential area or as an attraction with dominant work places. Vilnius is classified as a radial city structure; therefore, the methodology can be applied in radial cities. However, bicycle flow forecasting methodologies presented in the study can be applied in other cities, as they are not designed for a specific urban structure. During the analysis, it does not matter whether the city has a radial or linear structure, the most important thing is the dominant purpose in the territory – residential or work.

Following the bicycle flow forecasting methodologies presented in the article, further research on the methodologies could be conducted in other cities. Additional studies of the sketch plan methodology would help better determine the advantages of this methodology, and more precisely determine possible errors with natural bicycle traffic flows. The conducted study used the city of Vilnius as an example, where the average number of trips made by bicycle in 2022 reached 1.3%. Therefore, conducting the study in other cities with smaller or larger bicycle traffic flows, different urban structures would ensure deeper scientific knowledge. When conducting bicycle traffic flow forecasting studies in other cities based on the sketch methodology, we would suggest conducting population surveys in the analysed territories in order to obtain the latest modal split data. We would also suggest selecting locations for the analysis where bicycle traffic meters are installed, so that data on bicycle traffic flows can be compared with several data sources. Also, the methodology presented in the study can be refined through further research using other bicycle flow forecasting methods, such as GIS-based analysis, machine learning models or dynamic simulation techniques.

## Conclusions

Different land use patterns in the functional zones of the city create transport connections within the city territory. It has been established that the land use pattern is directly related to the number of trips made by bicycles; therefore, functional city zones also affect the number of trips made by bicycles. Although there is no unified methodology for predicting bicycle flows in the world, and scientists and various organisations studying traffic flows most often use the SD and DD methodologies, which are rarely used in practice by engineers. The

aforementioned methodologies are characterised by specific knowledge and resource requirements, and specialists planning bicycle infrastructure do not have such resources.

In view of this, the article analysed the developed bicycle traffic flow forecasting methodologies for the central and middle functional zones of the city, prepared on the basis of sketch plan methodology that requires freely available data and is characterised by easy calculations. Using these methodologies, the theoretically predicted bicycle traffic flow was determined in the central zone of Vilnius city, in the middle zone, when the planned infrastructure connects to the general bicycle network, and in the middle zone, when the planned infrastructure does not connect to the general bicycle network. To verify the methodologies, manual counts of bicycle traffic flows were carried out in the territories under consideration. The MAPE method, confidence intervals, and Cohen's  $d$  were used to determine the accuracy of the bicycle traffic flow forecasting methodologies. After performing the calculations, it was determined that the MAPE of the bicycle flow forecasting methodology for the central zone of the city was 17.61%, CI [-9.015; -2.665],  $d = 0.354$ . The MAPE of the bicycle flow forecasting methodology in the middle zone of the city when the infrastructure is connected to the general bicycle network was 15.03%, CI [4.017; 24.285],  $d = 0.269$ . The MAPE of the bicycle flow forecasting methodology in the middle zone of the city when the infrastructure is not connected to the general bicycle network was 13.85%, CI [0.398; 4.102],  $d = 0.234$ . Cohen's  $d$  test values showed that there was a small difference between the theoretically determined and the bicycle traffic flows identified by field studies.

The article presented methodologies for predicting bicycle traffic flows in central and middle zones of the city. The simplicity of the methodologies ensures the possibility of using them for engineers and urban development specialists, who are responsible for the design of bicycle transport infrastructure. The developed methodologies will help determine the predicted bicycle traffic flows in the planned bicycle transport infrastructure; therefore, it will be possible to correctly assess the type of selected infrastructure and technical parameters. Also, using these bicycle traffic flows, it is possible to assess the necessity of the planned bicycle transport infrastructure.

Additional research on the sketch plan methodology for bicycle flow forecasting should be conducted in other cities to deepen the existing scientific knowledge on the application of this methodology. It is also proposed to combine the sketch plan methodology with other existing bicycle flow forecasting methodologies (machine learning, GIS-based and so on) to obtain even better results.

## Disclosure Statement

We declare that we don't have any competing financial, professional, or personal interests from other parties.

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