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EVALUATION OF THE METHODOLOGY FOR DETERMINING CYCLING FLOWS IN LITHUANIA

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Abstract. Sustainable urban development is one of the most pressing issues in urban planning, and such development requires the promotion of sustainable traffic and the use of non-motorised means of transport. The main problem encountered is the lack of a methodology to easily identify existing cycling flows in the study area. Taking into account the lack of such a methodology, the paper analyses 3 methodologies for determining the bicycle flow in different land use areas of Vilnius city. A survey of the residents of the analysed areas was carried out in order to identify the factors that determine the choice of cycling trips. The study found that the proposed methodologies for determining cycling flow have a 20–40% error margin. The main factor that influences the choice to cycle is the attitude towards cycling as a leisure activity.

Keywords: bicycle flow, estimation, volume, land use, bicycle use, traffic flow.

JEL Classification: R41, R48.

Introduction

Sustainable urban development cannot be achieved without a responsible and thoughtful approach to infrastructure development. Many countries around the world are striving to make the bicycle an everyday means of transport, not only for its health benefits but also for its contribution to reducing air pollution. Although countries are investing in the development of cycling infrastructure, it is well known that long-term data on cycling flows are generally not collected. Such data are essential for the correct allocation of investment and for urban development planning.

In Lithuania, there are no data on cycling flows, nor is there a methodology to determine cycling flows in the area under consideration without manual count data collection. In view of the lack of such methodology, the article analyses three methodologies for determining the bicycle flow. The methodologies are applied in three areas of Vilnius city with different types of development – the low-density suburban residential neighbourhood – Tarande, the high-density multistorey apartment buildings neighbourhood – Fabijoniskes and the industrial land use area in Liepkalnis Street. The accuracy of the methodologies is established in the paper. To determine the factors that determine daily cycling trips, a survey of residents was conducted.

The survey showed that the proposed methodologies for determining the bicycle traffic have an error of 20–40%. The main factor that influences the choice of cycling is the attitude towards cycling as a leisure activity.

1. Literature review

1.1. Land use types

The dispersion of the population within the city is not even and constant (Juškevičius & Valeika, 2019). The type of land use in the city results in different accessibility needs. The main journeys made in the city are home-to-work and work-to-home. Depending on the type of development, the intensity of vehicles on the territory also changes. Urban industrial areas are characterised by heavy transport and cars, and journeys by public transport (PT), cycling or walking are rare in such areas. Industrial areas are generally located far from the city centre and residential areas and can only be reached by private transport. Correspondingly, low-density residential neighbourhoods are characterised by high car flows, as they are too far from the city centre and from work or education establishments to be conveniently accessible by PT, bicycle or on foot. The most convenient areas in the city in terms of transport are the high-density

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multistorey apartment buildings neighbourhoods. They are characterised by a well-developed transport infrastructure. The neighbourhoods are served by PT, there is a network of footpaths or cycle paths and a smooth street network. These neighbourhoods have a mixed mode of transport, with journeys made by car, PT, bicycle or on foot. When assessing the need for cycling infrastructure in the city, it can be seen that the type of land use has an impact on daily cycling trips. It has been extensively studied and established in the scientific literature that the type of land use has an impact on cycling accessibility (Akar et al., 2016; Oliva et al., 2018). Heinen et al. (2010) pointed out that travel distance, land use type, the presence of cycle paths and other factors are important in the choice to make a trip by bicycle, but of these, the most important factor is travel distance. Guo et al. (2022) confirms that the type of land use is a key factor in determining the purpose of a journey, with the proportion of bicycle journeys increasing in mixed land use compared to single land use areas. Mukoko and Pulugurtha (2020) found that in industrial and high-density land use areas, collisions with cyclists are more frequent due to higher travel speeds and more conflicts, while in low-density land use areas, travel speeds are slower and the likelihood of a collision is lower. It is therefore evident that the type of land use influences the choice of cycling not only in terms of changes in distances, but also in terms of the potential for conflict and the feeling of safety when cycling.

1.2. Methodologies for determining cycling flows

Collecting data on bicycle flows is a rarely used practise worldwide. Although there is a clear need to know trends in cycling flows, it is rare for countries to carry out such measurements. In most cases, cycling flows are only measured for a specific project and are not systematically stored or analysed. Lee and Sener (2020) identified four sources of data collection: manual counting (monitoring the section in question, installing bicycle counting devices), population surveys (travel diary, study area residents survey), data from apps and mobile operators (GPS data), and data from specialised apps (sports apps, bike-sharing apps). The Netherlands, as a leading country in both the number of cyclists and the development of cycling infrastructure, analyses cycling flows every year (Garber et al., 2019). They use an app in which residents mark their daily journeys for a week. This method of data collection is productive, as the city can build a digital model of cycling flows, get to know the relationship between origin and destination, and use the app data to monitor the change in trends.

The most used method for collecting bicycle flows is manual counts or automatic counts using devices (Hankey et al., 2017). Lowry et al. (2016) found that the manual counting of cycling flows has an error of up to 7%. The researchers observe a fraction of an hour and identify in which direction a cyclist travelled or estimate only the number of cyclists passed, regardless of the direction of their manoeuvre. There is a certain methodology on which days and hours of the week cycling flow counts should be performed (Lowry et al., 2016). Manual counts are also used as a baseline to compare the accuracy of the developed counting methodology (Kaziyeva et al., 2021; Fischer et al., 2022).

As technology has improved, bicycle flow manual counts have been replaced by data from software tools. Strava Metro (Lin et al., 2022; Garber et al., 2019; Kwigizile et al., 2022; Fischer et al., 2022), Mobibike (Hou et al., 2020) have been used to analyse bicycle flows. People use the Strava app to record their sports achievements. Meanwhile, the collected data helps planners to see people's favourite routes, travel times and total number of cyclists. Despite the abundance of data, only a fraction of the population uses the Strava app (Garber et al., 2019). Strava Metro data has been estimated to represent 1–5% of the total population of cyclists (Lin & Fan, 2020). The cyclists mostly do not record their daily trips, but only use Strava for long distance trips. In practise, data from mobile operators are used, which can show both the mode of travel and the origin and destination sites (Hou et al., 2020). However, data are not freely available and are often only used for strategic urban development plans.

1.3. Methodologies used to determine cycling flows

The most common methods used to determine bicycle flows per segment are direct demand, four-step demand, OD matrix estimation, agent-based simulation models (Bhowmick et al., 2022).

The direct demand model uses data on bicycle flows from the analysis area and sociodemographic factors that influence ridership, the characteristics of the bicycle network and the type of land use. It is one of the easiest and most used models as the calculations are simple. However, it does not allow for the identification of the personal characteristics of the cyclist, the psychological relationship between the cyclist and the environment, the identification of the determinants of route choice, and it is not suitable for the preparation of strategic planning documents. Nelson et al. (2021) used a direct demand model to determine cycling flows from Strava data, subsistence estimates, and population salary. In this methodology, the natural input data was important as it was the basis for the forecast. Esawey (2014) used this model to estimate the average annual number of daily cyclists. The model required data on the number of trips made per day. In the Dadashova and Griffin (2020) study the direct demand model was built using dietary and subsistence data and assessing the dependence of weather and earnings on the number of cyclists. The model was consistent with realistic weekday calculations.

Four-step demand modelling is a traditional flow forecasting model used for the preparation of strategic development plans or to analyse how build up attraction will change the traffic situation of the whole network. This model is mostly used to analyse traffic flows. The model requires information on the distribution of trips in an area, depending on population, sociodemographic data, land use; data on attractions; the choice of travel mode between origin and destination; and the choice of route based on the shortest distance or the fastest time to travel. Building such a model requires specific knowledge, data, and time. The model reflects the realistic situation in traffic and infrastructure. Jacyna et al. (2017) developed a model of the distribution of cycling traffic in the city of Warsaw, but the model only captured the existing distribution of cycling traffic in the existing infrastructure network.

The OD matrix estimation model considers only departure (origin), and arrival (destination) points and determines the fastest route in the network. For this model, all input methods can be used to obtain the origin and destination sites. The estimation of OD estimation is most appropriate for vehicles that are not affected by environmental factors. As only the origin and destination locations are relevant for the model. The OD matrix is appropriate for determining where the highest cycling flows will occur. In study by Pamuła and Żochowska (2023) such data was used to predict bicycle flow for 15 min intervals up to one hour. The study by Ryu et al. (2019) showed how potential cycling flows in the area would be distributed according to the number of people present. In study by Ryu (2020) the distribution of traffic was compared with that of cars based on the existing infrastructure network.

The agent-based simulation model requires information on the travel patterns of the population, the places visited, the duration and frequency of trips. The collected resident data becomes the digital version used in the simulations. This is one of the most difficult models to predict cycling flows due to the specificity of the input data. The model is suitable for analysing different scenarios of how a resident would move in the event of a change in the traffic or infrastructure situation and is therefore most often used for the preparation of strategic plans. Kaziyeva et al. (2021) created agent base model simulations which were very close to real cyclist's flow, the study used naturalistic surveys as a reference factor.

1.4. Factors influencing the use of a bicycle

Many factors influence the decision to travel by bicycle. Environmental factors such as weather, terrain, infrastructure, land use, and sociological factors such as gender, level of education, salary, marital status, and psychological factors such as self-identification as a bicycle user. An analysis of the literature shows that respondents are always asked about their age, gender, educational level, and salary. A study by Md Oakil et al. (2016) found that having a child in the family and a greater distance from the workplace encourages people to give up their daily cycling trips, while moving closer to the workplace encourages more cycling trips. Akar et al. (2016) found that people with higher incomes make longer journeys and consequently live in a more peri-urban location. Sottile et al. (2019) found that young men tend to cycle more than women, and families with children cycle less than families without children. Higher income groups are less likely to cycle. Acharjee and Pratim Sarkar (2021) found that the choice to ride a bicycle decreases with increasing age. They also found that attitudes towards bicycle as a means of transportation are very important.

The literature review describes complex processes for obtaining and evaluating cycling flow data, which require additional software, manual counts data and depth knowledge of how to process and analyse the data. The models described are suitable for city strategic plans creation, but there is a lack of a simpler methodology that can be understood not only by academics but also by urban planners and engineers. In view of the lack of such methodology and the problems it poses for planners, this paper analyses the possibility of applying a new methodology. The methodology presented is based on data that can be easily accessed by any planner – vehicle traffic flows, number of residents and information about city modal split. The emergence of such a methodology can help to more effectively determine the need for bicycle paths and their technical parameters in the main urban areas – multistorey apartment buildings neighbourhood, suburban residential neighbourhood and in industrial areas. The aim of the study is to determine the precision of the proposed methodologies and to determine whether it is appropriate to apply the same methodology to calculate the cycling flows in all urban areas.

2. Methods

The methodology described in this chapter is used by urban planners and engineers to determine cycling flows in areas where manual count data are not available or the project period does not allow for such surveys, e.g., cold seasons. The methodology has been applied in 3 different land use areas to determine which methodology reflects the real situation with the most accuracy. As there are no long-term measurements of cycling flows in Vilnius, Strava Metro data was used to compare the results obtained.

2.1. Study area

To identify cycling flows 3 areas of Vilnius city, with different types of land use were selected.

The first area is a low-density, suburban residential neighbourhood – Tarande. From Figure 1 it is seen that Tarande is located 8.4 km from the city centre and is

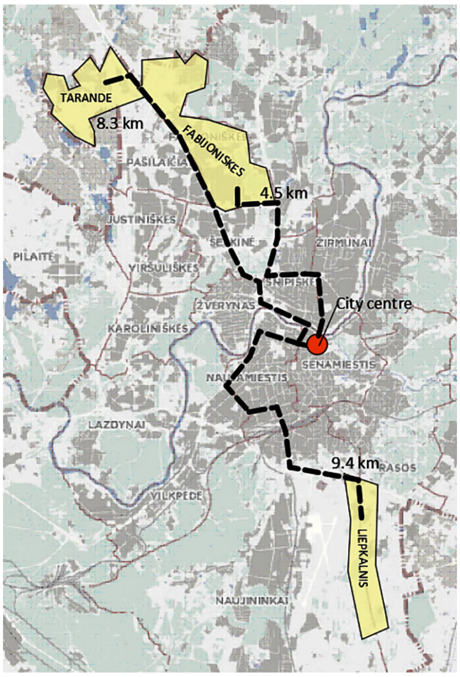

Figure 1. Study areas in Vilnius city

dominated by single-family houses. It is served by only one PT route, so the main mean of transport in the neighbourhood is car. According to Vilnius city statistics, 59% of the Tarande neighbourhood population is between 20 and 60 years old and about 24% are children under 15 years old.

The second area is a part of the high-density, multistorey apartment buildings neighbourhood- Fabijoniskes, bounded by Fabijoniskes St., S. Staneviciaus St. and Ateities St. The Fabijoniskes neighbourhood is located 4.5 km (Figure 1) from the city centre and is dominated by multistorey apartment buildings. The area is served by 12 PT routes. The neighbourhood is accessible by both private and PT. According to Vilnius city statistics, 52% of the population is between 20 and 60 years old and approximately 17% of the population is under 15 years old.

The third area is an industrial land use area in the peripheral zone of the city – Liepkalnio Street. Liepkalnio St. area is located 9.4 km (Figure 1) from the city centre and is predominantly an industrial area, but also contains few multistorey apartment buildings and single-family houses. The area is accessible mainly by car. There are 3 PT routes in the area, but these only connect to the station in the old town and areas further away. There are no routes that provide access to jobs in the city centre. Mostly garages, logistics companies and road maintenance companies operate in the Liepkalnis St. area.

2.2. Determining bicycle flow

Three methodologies were used to determine the cycling flows in the study areas. Methodology I – cycle flows are determined by population and modal split. The number of dwellings in the study area was calculated. In the multistorey apartment building neighbourhood, the number of apartments per building was determined, in the single-family hoses neighbourhood the number of dwellings is calculated based on the number of plots of land and the identification of the one or two-flat houses. It is assumed that one family lives per dwelling. According to Lithuanian statistics, one family consists of 2.17 people. Using this data, the population of the areas under consideration was determined. As the population of the areas is of different ages and only adults of working age make daily trips, the number of people of working age in the residential areas under consideration was determined using the statistical data on the composition of the population. The Liepkalnio St. area attracts only the working population of the city, therefore it is assumed that all working and living people travel here. The working age population is between 20 and 60 years old. The number of daily trips made in the area is not evaluated, as the technical parameters of the cycle paths are selected based on hourly traffic and a resident makes only one trip at a time. The proportion of bicycle trips in the Vilnius Sustainable Mobility Plan (Vilniaus darnaus judumo planas [VDJP], 2018) is 0.7%, so it is estimated how many of these trips will be made by people living in the area.

Methodology II VDJP cycle flows are derived from existing vehicle traffic flow data. Traffic flow data for the study areas were obtained from traffic flow reports for Tarandes St. and Liepkalnis St., for Fabijoniskes neighbourhood traffic flow was obtained from publicly available data. According to the VDJP, 45.1% of all trips in the city are made by car, 0.7% – by bicycles. The vehicle flow is used to deduct the cycling flow in the areas.

Methodology III – cycle flow is determined by manual counts. Cycle flows were monitored for one hour during the morning or evening peak hour. The hourly period was chosen considering that the average journey time in Vilnius is 29 minutes and therefore it is likely that cycling flows should be recorded during the observation period. The weather conditions at the time of the observations were satisfactory, with positive temperatures and no precipitation. On 02/01/2023, between 5–6 p.m., the weather was good. Natural observations were carried out on Tarande St. at the entrances to the A2 road. On 03/01/2023, 7.00–8.00 a.m. Natural observations were carried out at the intersection of Fabijoniskiu St. and Gelvonu St. 03/01/2023 5–6 p.m. Natural observations were carried out at the intersection of Liepkalnio St. and Usos St.

Strava Metro data was used to verify the results of the methodologies applied. In their study Lee and Sener (2020) reported that Strava Metro data is matched by up to 5% of all bicycle users. If the number of users captured by Strava Metro is taken into account, Strava Metro's 100% data would exceed the working age population in the study areas. In Vilnius, there are no long-term measurements of cycling flows or data on trends in cycling flows. In this context, it is estimated that the Strava Metro data reflect the total cycling population. Using the second methodology, the vehicle flow reports were carried out in different time periods and therefore the Strava Metro data is used for the same time periods as the collected data. In Tarande traffic flows were measured in 06/2021, in Fabijoniskes in 08/2021, in Liepkalnio St. in 06/2019 the Strava data was compared for the same period. Manual cycling flow counts were taken in the cold season, 01/2023, and are therefore compared with Strava Metro data 01/2021 (01/2022 data were not yet available during the study period).

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

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

where: n – number of calculations; A_t – Strava Metro bicycle flow on the analysed street according to Strava Metro data; F_t – bicycle flow on the analysed street calculated using described methodologies.

2.3. Factors influencing cycling

To determine what factors influence the choice of cycling in different built-up areas of Vilnius, a survey of residents was carried out. An electronic questionnaire consisting of 20 questions related to sociodemographic characteristics and factors influencing the choice to cycle was developed. The links to the questionnaire were shared in the Facebook groups of the Tarande residents, Fabijoniskes residents and Liepkalnis residents. A survey for Liepkalnis St. area was also sent to 20 businesses located on this street. The survey was carried out from 8/12/2022 to 23/12/2022. The survey was based on the factors identified in the literature review (Guerreiro et al., 2018; Heinen et al., 2010; Barberan et al., 2017) that influence cycling, such as age, gender, education, income, bicycle ownership, distance to the place of work, whether the bicycle is a mean of transportation or a mean of recreation, etc. Statistical analysis of the survey results was carried out using SPSS Statistic. The Chi-Square Test was used to test whether the attitude towards cycling as a leisure activity is related to a small proportion of daily trips made by bicycle.

3. Results

Table 1 shows the results of the bicycle flow estimation in the areas of Tarande neighbourhood, Fabijoniskes neighbourhood and Liepkalnio St. area according to the applied methodologies.

The results of the applied methodologies presented in Table 1 show that in the Tarande neighbourhood the calculation error using Methodology I is 40%, in Methodology II it is 100%. In the Fabijoniskes neighbourhood the calculation error using Methodology I is 20%, Methodology II is almost 88%. In the Liepkalnio St. area Methodology I – 80%, Methodology II – 40%. Methodology III, manual count, was carried out during the cold season, when only a very small proportion of the population makes trips by bicycle, so a comparison of the results with Strava Metro data shows that the Strava data almost correspond to the real situation of the population's bicycle use – the bicycle is not seen as a means of transport by the majority of the population.

Table 1. Results of bicycle flow determination

Territory concerned	Tarande	Fabijoniskes	Liepkalnis
Number of workplaces	–	–	305
Number of dwellings	817	6564	90
Number of inhabitants (2.17 in dwelling)	1773	14 244	196
Number of people of working age	1046	7406	196
Number of trips during evening peak hour	1046	7406	286
Date of traffic flows measurement	06-2021	08-2021	06-2019
Vehicle flow during the evening peak hour, veh./h	626	513	870
I method			
Number of bicycles (VDJP-0.7), units	7	52	2
Strava, units	5	65	10
MAPE, %	40	20	80
II method			
Number of bicycles (VDJP-0.7), units	10	8	14
Strava, units	5	65	10
MAPE, %	100	87.69	40
III method			
Date	02-01-2023	03-01-2023	03-01-2023
Time	17.00-18.00	7.00-8.00	17.00-18.00
Number of bicycles (VDJP-0.7), units	0	3	0
Strava, units in 2021 January	0	5	0
MAPE %	–	40	–

Table 2 shows the results of the survey, which are the most important determinants of the choice to cycle. The survey was carried out in Tarande neighbourhood with 96 respondents, in Fabijoniskes neighbourhood with

128 respondents and in Liepkalnis St. area with 90 respondents. Most respondents were 35 and 45 years old (37.5–50%). In the residential neighbourhoods, most respondents were women (58.39–64.1%), and in the industrial land use area – men (73.3%). In all the analysed areas, the educational level of the respondents was mainly higher (71.9–80.2%).

Table 2 shows that the highest number of bicycles was owned by residents of the Tarande neighbourhood, 82.3%, as it is a low-density residential neighbourhood and therefore residents mostly have a place to store their bicycles. Overall, the results show that 66.7–82.3% of the respondents have bicycles. However, irrespective of bicycle ownership, 76.6–87.5% of respondents never make daily trips by bicycle in the warm season and 89.1–93.3% in the winter. The highest number of daily trips by bicycle in summer is made by residents of Fabijoniskes neighbourhood – 23.4%, the lowest by residents of Tarande neighbourhood – 12.5%. Correspondingly, winter trips decrease in Fabijoniskes to 10.9%, in Tarande to – 7.3% and in Liepkalnis St. area to 6.7%. Irrespective of the type of development of the area, all respondents mainly see cycling as a leisure activity (82.8–94.4%). However, the respondents in the low-density residential neighbourhood (Tarande) stand out the most, with 94.8% of respondents seeing the bicycle as a leisure activity. The majority of respondents from residential neighbourhoods (57.8–59.4%) indicated that they would make daily trips by bicycle if their employer encouraged them to do so by paying a bonus or giving them a day off work, but respondents from Liepkalnis St. area (industrial land use) indicated that the incentive would have no impact on their mode of travel (70%). A higher proportion of respondents indicated that they are concerned about climate change (73.3–84.4%), but a lower proportion of respondents would agree to use a bicycle to reduce climate change (44.8–53.3%). Factors influencing the choice of cycling were analysed, such as weather conditions, terrain, clothing, transporting children home, but the results were distributed in a circular way, and it is not possible to identify one factor that would have the greatest influence on the choice. For all respondents, the choice of travel mode is mainly influenced by convenience (56.7–75%) and least influenced by cost (0–3.1%).

The analysis of the survey results related to the use of bicycles for daily journeys showed that most trips are

Table 2. Population survey results

		Tarande (n-96)		Fabijoniskes (n-128)		Liepkalnis (n-90)	
Question/statement	Variable	Frequency	Percent	Frequency	Percent	Frequency	Percent
I have a bicycle		79	82.3	90	70.3	60	66.7
How many times a week do you cycle to work in the warm season.	Never	84	87.5	98	76.6	78	86.7
	1–2	7	7.3	10	7.8	6	6.7
	3–4	3	3.1	14	10.9	6	6.7
	5	2	2.1	6	4.7		
How many times a week do you cycle to work in the cold season.	Never	89	92.7	114	89.1	84	93.3
	1–2	4	4.2	4	3.1	3	3.3
	3–4	3	3.1	8	6.3	3	3.3
Bicycle is mean of transportation or leisure activity.	Leisure	91	94.8	106	82.8	75	83.3
	Transport	5	5.2	22	17.2	15	16.7
If your employer encouraged you to cycle to work, would you cycle?	Yes	57	59.4	74	57.8	27	30
	No	39	40.6	54	42.2	63	70
I care about climate change.		77	80.2	108	84.4	66	73.3
I would cycle more for climate change.		43	44.8	68	53.1	48	53.3
I don't cycle because of the weather.		43	44.8	68	53.1	48	53.3
I don't cycle because of the terrain.		43	44.8	60	46.9	60	66.7
I don't cycle because of need to change clothes.		27	28.1	62	48.4	27	30
I don't cycle because I have to pick up my children after work.		43	44.8	22	17.2	12	13.3
What determines the choice of what you travel with?	Duration	35	36.5	20	15.6	39	43.3
	Price	3	3.1	12	9.4	0	0
	Convenience	58	60.4	96	75	51	56.7

made by bicycle by people aged between 24 and 45 years old, with men tending to make twice as many trips by bicycle as women. Higher income groups are more likely to make trips by bicycle compared to lower income groups. Most cycling trips are made if the distance to the workplace is between 3 and 10 km. The Fabijoniskes neighbourhood has cycle paths, so it was assessed whether the presence of infrastructure is related to the number of trips made, but the Chi- Square Test results X2 (1, N = 128) = 1.76, p = .184 showed that the presence of infrastructure is not statistically related to the number of trips made by bike. The Chi-Square Test was used to test the hypothesis that attitudes towards cycling as a leisure activity are related to a small proportion of daily trips made by bicycle. In all three areas, the Chi-Squared Test showed attitudes towards cycling as a leisure activity are statistically significantly related to a small proportion of trips made by bicycle, Tarande X2 (1, N = 96) = 10.88, p = .001; Fabijoniskes X2 (1, N = 128) = 35.96, p = .001; Liepkalnis X2 (1, N = 96) = 11.07, p = .001.

4. Discussion

The city has different types of land use areas and the needs and methods of access within them are different. In Vilnius, there are no long-term measurements of cycling flows, and the individual data collected during projects are not aggregated or analysed. Methodologies for measuring cycling flows are available in the scientific literature, but these methodologies are characterised by the need for baseline data on cycling flows and the need for specific expertise to carry out calculations. There is a lack of a methodology for determining cycling flows that can be used by urban planners with freely available data and that is easy to understand and apply. The paper analyse 3 methodologies for determining bicycle flows, the methodologies have been applied in three Vilnius city urban areas with different types of land use – in low-density suburban residential neighbourhood Tarande, in high-density multistorey apartment buildings neighbourhood Fabijoniskes in industrial land use area Liepkalnis St.

The MAPE method was used to determine the accuracy of the methodologies, with results of 20–40%. According to Lewis (1982, p. 40) results in the range of 10–20% are accepted as good prediction, results in the range of 20–50% are accepted as satisfactory prediction. The application of Methodology I to the determination of bicycle flow in low-density areas is with 40% accuracy, which is an acceptable method of determining flow according to the MAPE methodology. The application of Methodology I for the determination of cycling flows in areas of high-density is within 20% accuracy, which is a good method of determining flows according to the MAPE methodology. The application of Methodology II for the determination of cycling flows in areas of industrial land use is accurate to 40%, which is an acceptable method of flow determination according to the MAPE methodology. The accuracies obtained from the methodologies are not >10%, which would be accepted as a high-accuracy flow detection methodology, but these results are due to the absence of long-term monitoring of cycling flows and the realistic alignment of the cycling flow with the Strava Metro domains. Given the absence of long-term cycling flow monitoring data in Vilnius, it is suggested to use the methodologies discussed in the paper until the availability of long-term cycling flow data.

The accuracy of the methodologies shows that for low-density and high-density neighbourhoods Methodology I, which determines bicycle flows from population data, is the most appropriate methodology to measure cycling flows, as it has an accuracy of 20–40%. Estimating bicycle traffic from population data is much more accurate than estimating it from vehicle counts. In residential areas, especially with high-density, there is a greater choice of travel methods, it is possible to make trips by PT, car, on foot or by bicycle. In areas of low intensity, trips are mostly made by car, less by public transport, and very rarely by foot. Therefore, the evaluation of vehicle flows to determine bicycle flows does not show the actual number of cyclists, because trips are made in the territories not only by cars.

In industrial land use areas Methodology II, which determines bicycle flows from vehicle flows, is the most appropriate methodology to apply as it has an accuracy of 40%. In these areas, bicycle traffic cannot be estimated from the population data, due to their land use, they have a low population and a high number of jobs. Primary areas are distant from the central part of the city at such distances that it is difficult for a cyclist to overcome (about 10 km), so they are exclusively accessible only by vehicles.

The survey found that the majority of respondents have bicycles but use them for leisure rather than for daily trips. In all three studied areas, the Chi-Squared Test results showed that attitudes towards the bicycle as a mean of leisure are statistically significantly associated with a small proportion of trips made by bicycle (Tarande X2 (1, N = 96) = 10.88, p = .001; Fabijoniskes X2 (1, N = 128) = 35.96, p = .001; Liepkalnis X2 (1, N = 96) = 11.07, p = .001). This result explains why in Vilnius city, despite the development of cycle path infrastructure, there is still a low number of daily trips made by bicycle. Residents see the bicycle as a means of leisure, so they do not use it for transportation purposes. Also, the survey data showed that comfort is the most important thing for the respondents when choosing a vehicle. Until the population's attitude towards bicycles changes, the city will not record a higher number of bicycle trips. Local authorities should encourage the use of bicycles, as they would receive direct benefits due to lower transport infrastructure costs, improved air quality, reduced noise, as well as employers, as this would improve the physical well-being of their employees, which also affects psychological well-being, could shorten the time of arrival to workplace time. The survey aimed to find out which factors are the most important determinants of the choice to make daily trips by bicycle, but neither weather, terrain nor picking up the children after work had a significant influence on the choice. One of the potentially important factors influencing the choice to cycle was the need to carry extra clothing, but the results showed that less than half of the respondents were not influenced by this. Climate change was important to the majority of respondents, but fewer would give up their cars to stop it. The majority of urban dwellers make their daily journeys by car as it is the most convenient means of transport. The survey results also show that convenience is the most important factor for respondents, followed by duration and lastly cost, which is also reflected in the proportion of journeys made by bicycle.

In the light of the results of the survey, it is proposed to use the methodologies discussed in the paper to determine cycling flows in cities where daily cycling trips are up to 1% of modal split and where the population uses cycling as a leisure activity. It is also appropriate to apply the methodology in areas where there are no cycle paths and where cycling flows cannot be determined by manual counts. The methodologies proposed in the paper can be used to determine the bicycle traffic in the study area with an error of 20–40%.

Zhao et al. (2021) found that cycling trips decrease with distance from the city centre, which is in line with our results, as Fabijoniskes is located about 5 km away from the city centre and has the highest proportion of people cycling. Similar results were obtained in the experiment by Kaziyeva et al. (2021), as it can be seen that neighbourhoods closer to the central part of the city have a higher proportion of inhabitants using bicycles for their daily trips. Our findings support Sottile et al. (2019) results, where it was found that the identification of the bicycle as a means of transport is directly related to the number of trips made by bicycle.

This research may have limitations due to the lack of long-term bicycle flow data in Vilnius city, comparing the results with Strava Metro data, as only a part of the city's population uses the app. It would be appropriate to conduct the study in the warm season, when it would be possible to perform live measurements of bicycle flows and compare the obtained data with Methodology I and Methodology II.

Conclusions

Sustainable urban development can be achieved by assessing people's transport needs and shaping their new travel behaviour. However, this cannot be achieved without data on the current travel patterns of the population and the reasons behind these choices. The literature analysis has showed that there is a lack of an easy methodology for determining cycling flows based on freely available data that cities usually have, such as population size, modal split and vehicle traffic flow data. The study applied three bicycle flow methodologies to determine bicycle flows in different land use areas of Vilnius city. It was found that in residential areas, the most appropriate methodology to apply is the methodology where the bicycle flow is determined from the number of inhabitants and the modal split of trips, the accuracy of this methodology in low-density neighbourhood is 40%, in high-density neighbourhood – 20%. In industrial land use areas, it is most appropriate to determine cycling flows from traffic flow data, the accuracy of this methodology is 40%. The population survey showed that most of the daily cycling trips are made in the residential areas. And the low proportion of trips made by bicycle is statistically related to the attitude towards the bicycle as a leisure activity.

The results of the study may be useful for urban planners to identify cycling flows in areas where no data on cycling flows exist and to use the methodologies to select cycle paths with the required technical parameters.

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Contribution

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Miglė Zabielaitė-Skirmantė. The first draft of the manuscript was written by Miglė Zabielaitė-Skirmantė and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Disclosure statement

The authors declare that they don't have any competing financial, professional, or personal interests from other parties.

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