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Sustainable Transport: An Efficient Transportation Network—Case Study

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Abstract: The article describes sustainable transport principles and guides that can lead cities towards a more efficient transportation network. The authors also show good practice used in different urban areas, such as London and Copenhagen. Furthermore, Vilnius was analyzed for its sustainable transport rules and mobility. The authors took into consideration components such as public transport indicators, car use and the number of trips made by bicycle and by pedestrians. Additionally, solutions such as shared space, developing cycle routes and public transportation networks, dividing different transport modes, reducing distance and the need to travel, policy shifts and technological innovation are proposed. Moreover, already taken actions are also verified. The article, additionally, shows guidance for Vilnius, so it could be possible to develop a sustainable traffic network in the city. All analyses and guidance were based on using geographic information system (GIS) tools which allowed the authors to obtain the most reliable results. The artefacts are presented by means of a combination of graph theory algorithms in order to obtain sustainable transport using the example of a part of Vilnius City.

Keywords: road network; sustainable; transport policy; GIS; graph theory

1. Introduction

Properly designed transportation systems should meet mobility and people requirements and also provide safety and eco-friendly vehicles [1]. According to the World Commission on Environment and Development, mankind should strive for sustainable development to meet the needs of the present without compromising the ability in order to meet the requirements of future generations [2,3]. An important role in the sustainable development of space is played by the transport system. It plays a role in the sustainable development of space, because transport provides access to economic and social opportunities for all communities [4]. People living in the individual areas shall aim to develop sustainable transport systems, in particular road networks, which will enable them to achieve appropriate level of growth both in the economic, social and environmental spheres [5,6]. However, we have to admit that it is the environmental aspect and the related need to overcome natural barriers that is one of the challenges we face when creating a transport network [7]. Moreover, Lithuanian researchers emphasize that modernization of transport infrastructure “should ensure sustainable mobility, communication of individuals and establish effective relations of business agents while providing support for the national economy” [8]. Transport (communication) accessibility is considered to be an important determinant of sustainable development for agglomerations and cities [9–11]. Not only clearly technical and surface aspects should be considered in the field of transport, economic conditions of the area; peoples' expectations and optimal solutions that would be environmentally friendly and would direct the transportation towards sustainability should be also taken into account. In the field of planning the most important feature is road safety, especially for cyclists and pedestrians. Safe infrastructure has to be provided for those types of transport and that means the physical separation of people from the road area and, if this is not possible, car speeds have to be reduced and education about road safety has to be provided from an early age. Urban planners who are taking care of transport have to have not only technical knowledge, but also, they need to demonstrate ingenuity and innovation. Moreover, the way the transport looks in a specific city also depends on the efficiency of local government units [12,13]. This form of city planning practice can lead to sustainable transport.

On the other hand, the sustainability of transport in the cities is linked to high-quality implementation of innovative systems and to the need to gain public trust [14]. Planning of non-motorized transport depends on combining infrastructure improvement with education [15]. The perspective of the social dilemma sees the trend of continuous increase in the use and density of cars (more vehicles with fewer people covering longer distances on proportionally shorter roads) as a result of the unfortunate preference for short-term profits by car users at the expense of long-term losses to society [16]. A transport system can increase the efficiency and quality of life of a community if it is properly planned and managed, while at the same time the development stimulates transport demand [17]. Environmental protection requirements currently applied by companies promote improvements to already established systems [18].

The main goal of the article is to show the development of the transportation network in Vilnius and compare it with two chosen models (London and Copenhagen). Moreover, the authors would also like to analyze the studied city in relation to sustainable transport assumptions. The development of a transportation network is inevitably connected with the city's development [19]. Its growth means the same for a transportation system that can be implemented according to the highest standards. The transportation network can be also changed and modified in older parts of the city. This improvement should not only concern surface replacement but also a change in traffic, so it can be adjusted to peoples' needs [20]. The authors will indicate how it can be done in Vilnius.

2. Literature Review

Firstly, the idea of sustainable development [21] was focused on multi-annual problems [22] associated with environment and climate change [23]. The debate considering sustainable city development is today based on the idea of creating compact cities to provide them with balanced development [24]. In the case of passenger transport, social requirements are the main factors influencing sustainable transport indicators. [4]. On the other hand, Goldmana and Gorhamb [25] Goldmana and Gorhamb claim that, in order to be effective, a sustainable transport policy has to avoid the trap of the common transport policy of ignoring the larger systems in which transport activities are located.

A sustainable transport system mainly focuses on planning, politics and used technologies. Its main objective is to ensure efficient transit of goods and the high quality of transportation services. Besides, sustainable transport development is based on such city planning which would create urban areas free from cars and friendly for pedestrians and cyclists. Bike-sharing systems are getting more and more popular in large cities.17] as they are one of the most sustainable mean of transport in the urban area [20]. They are viewed as a cheap, efficient and healthy means of navigating dense urban environments [26]. Furthermore, transport in those cities should be based on public transportation means [27]. Professor David Banister, from the University of Oxford, has developed a paradigm, which presents sustainable transport rules that should be obtained in city planning [14]. Those principles are:

1. Reduced travel needs
2. Transport policy shift

3. Distance reduction
4. Technological innovation that would increase efficiency [14].

The first sustainable transport principle—reduced travel need—means that travelling has to be substituted by providing such technological solutions that could reduce these needs to a minimum. In this rule Banister notes the importance of the relationship between transportation and ICT (information and communicationstechnology), especially the growing importance of online shopping. The second sustainable transport principleimplies a strategy change (Table 1) which means that car use levels should be reduced in favor of walking and cycling. An increasing number of communities in the United States are trying to improve the sustainability of their transport systems by shifting routine vehicle trips to walking and bike usage. [28]. Furthermore, Banister [14] proposes a new road hierarchy where pedestrians and cyclists are at the top of the sustainable transport pyramid, then in the middle there is public transport and car users at the bottom. This goal can be achieved by slowing down the city traffic and creating a separate area adjusted for public transport. Additionally, road payments should be also implemented (for example: paid entrance to the city centre and the old town). Moreover, the change of the roadway definition is also part of this principle that says the street is not only a car area. It should be perceived as a space with green modules which is also used by people (cyclists and pedestrians) and public transport means. This maxim encourages creative street use at different times of the day. For instance, during the weekend some roads can be transformed to street markets or can become fun zones. Those ideas encourage people to change their way of perceiving transport and they should be combined with a properly designed strategy for the best space use. The bicycle is a desirable form of transport, because it's environmentally friendly and economic in maintenence. Also, bikes have other positive effects: they are seen as a mean to stay healthy and in a good shape [29].

Table 1. Contrasting Approaches in Transport Planning. Source: [14].

The Coventional Approach (Transport Planning and Engineering)	**An Alternative Approach (Sustainable Mobility)**
Physical dimensions	Social dimensions
Mobility	Accessibility
Traffic focus, particularly on the car	People focus, either in (or on) a vehicle or on foot
Large in scale	Local in scale
Street as a road	Street as a space
Motorized transport	All modes of transport often in a hierarchy with pedestrians and cyclists at the top and car users at the bottom
Forecasting traffic	Visioning on cities
Modeling approaches	Scenario development and modeling
Economic evaluation	Multicriteria analysis to take account of environmental and social concerns
Travel as a derived demand	Travel as a values activity as well as a derived demand
Demand based	Management based
Speeding up traffic	Slowing movement down
Travel time minimization	Reasonable travel times and travel time reliability
Segregation of people and traffic	Integration of people and traffic

The third sustainable transport principle is about distance reduction. Its intention is to create mobility inside city districts that can lead to a shift in use of transportation modes for those that are environmentally friendly (vehicles), but also walking and cycling. Districts should be planned in a way that enables residents to use different services (housing, commerce, recreation, education) which can decrease the need to travel. It is recommended, in accordance with the principles of sustainable space development, to create "green urban islands" without car traffic, and to link them with each other to enable safe foot and bicycle traffic [30].

The fourth sustainability rule states that new technologies must be implemented which can make transport more efficient. Transport is responsible for 26% of global CO_2 emissions and is one of the few industrial sectors where emissions continue to rise [31]. The role of technology is incredibly important and is inextricably linked to transportation, because it has a direct impact on its performance. The most sustainable solution would be if each transport mode would use the latest technologies, innovative engine construction, alternative fuels and renewable energy sources [32–34]. The priority in the glorious quest for sustainable is the development of green cities [35]. New solutions should also include reduction of noise generated by vehicles and ensure easy access to every part of the city in reasonable time. New vehicles should be environmentally friendly. Moreover, this principle is a combination of efficiency and drivers' behavior change towards more rational behavior; eco driving combined with following the traffic rules— especially the speed limits.

To sum up, the idea of sustainable transport is to keep the hierarchy of traffic participants. The most privileged group should be pedestrians, because they are the most defenseless and endangered group. The second group is cyclists, then the public transport network. The inclusion of bikes in a comprehensive planning framework seems to be a favourable approach which may lead to changes in urban transport [36]. At the very bottom of the classification are car users, because they are the most problematic community—it is they who often cause traffic jams and block the streets (Figure 1).

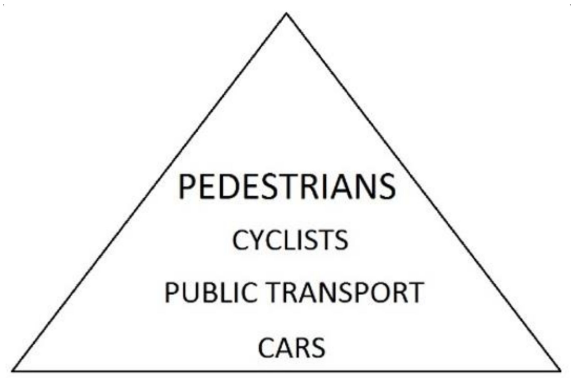

Figure 1. Sustainable Transport Pyramid.

Sustainable transport rules that are described above are the key to make the change in the way of thinking about spatial planning which is attractive for residents. Transport planning should involve people in creating and decision making processes so that they would understand occurring changes. It has to be remembered that social acceptation is a fundamental value to implement any reform successfully. GIS software can be used to achieve this goal.

3. Materials and Methods

Sustainable transport is seen as a global concept [37–39]. Its main idea is to strive for efficient communication which is economically advantageous and minimizes the harmful impact of vehicles on the environment. It focuses on both the control of harmful emissions and the promotion of sustainable means of transport such as public transport, bicycles or car sharing [40]. This type of transport and its paradigms assumes the reduction of the destruction of urban space due to the dominance of individual car transportation [41].

To reach these goals, the authors conducted their studies on many levels. At first, model cities with sustainable transport networks were presented. Then Vilnius the transportation system was analyzed, and finally the authors indicated sustainable transport solutions for this city.

While creating the proposed solutions for Vilnius, the authors used GIS tools that allow for transportation network modeling [42,43]. Thanks to that it was possible to create maps that show how the existing transportation system can be transformed into a more sustainable form. The research covered the city of Vilnius, which is the capital of Lithuania. In Figure 2 the research area on the map of

Europe is marked. ArcMap software was used to visualize the test results. The graphical algorithm [44] from the graphic theory was used to develop a model of optimal and decongested transport on a selected part of Vilnius City. The algorithmic solutions used to develop the graph concept were used to design new bicycle routes and stations. The authors used a set of combinations of new roads and stations in order to obtain an optimal combination that solves the problem of finding the shortest routes (Fleury Algorithm), the Chinese letter carrier (Dijkso Algorithm) and the salesman (Hamilton cycle) issue and also network reliability situation. Sustainable transport using graph theory algorithms has been used by many scientists [45–53].

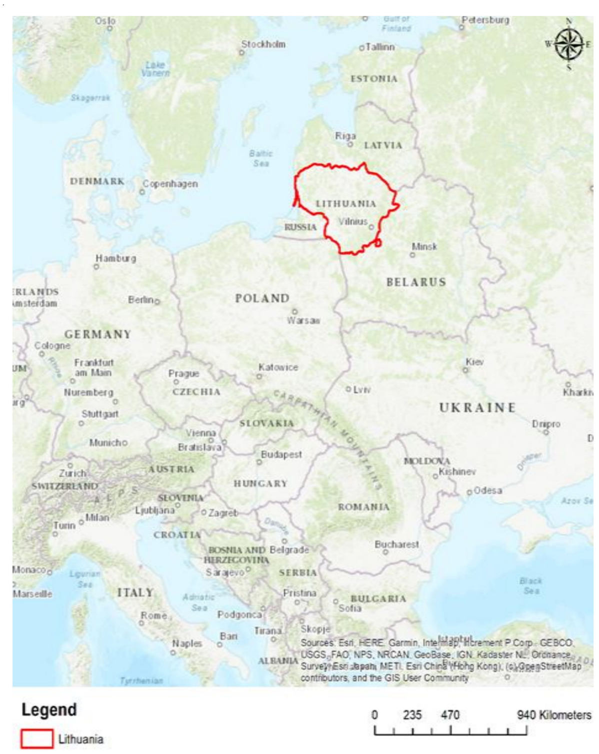

Figure 2. Research Area.

4. Results and Discussion

4.1. Examples of Model Transport Networks

Public transport development: in Copenhagen the number of public transport modes was increased by 1200 bus stops, 40 train and S-train stations. Furthermore, there was also a new metro line built. Moreover, public transport means have priority over car users. That kind of approach gave the result of increasing by 8% the number of metro passengers between years 2008 and 2009. When the number of stops was increased, the number of passengers has grown as well [54].

Bicycle paths development—in Copenhagen the number of cycling tracks was increased to 350 km [55]. Additionally, the city has many cycling facilities such as green "waves"—which enables bike users to move around the town during rush hours without stopping—and green cycle routes which divide cyclists from infrastructure. Additionally, many intersections were redesigned to give priority to cyclists—stop lines for cars were moved 5 m behind. Furthermore, blue cycling routes were implemented in places with the biggest number of accidents to reduce the risk [56]. In London, thanks to creating a public transport and city bike network (Barclays Cycle Hire), the use of cars was limited. This result was also achieved by many social campaigns [57]. Sudden changes in horizontal and vertical geometry and cross-section are ominous for cyclists. Such risks can be minimised by safety audits or by using good design practice in the initial design phase [58].

Shared space—on Kensington High Street (London), although it is one of the busiest places (40,000 vehicles drive there daily), street signs, barriers for pedestrians and any other limits were removed. The central part of the area was used as parking for cyclists, which encouraged Kensington High Street users to move around freely. In Covent Garden, thanks to Seven Dials Monument Trust activity, which fought in the 1990s for restoration of one of the most characteristic monuments (Seven Dials), not only was the monument restored, but also a space not limited by any signs or regulations was created, although it is a very busy place. Traffic is slow here, and jams are seen rarely. What is more, for 16 years there have been no serious accidents [59].

Paid entry to the city center: in London the amount of greenhouse gases was reduced thanks to paid entry to the city center which discouraged car users. In turn, cheap public transport encourages people. Moreover, Prime Minister Boris Johnson's campaign, called Charge Point, encourages citizens to use electric cars, because there are free charging points in London. That action caused an increased number of sales and registered electric cars. The results from the Transportation Report for London 2013, presented in Figure 3, confirm the above creatures [57].

Year	Rail	Under-ground /DLR	Bus (including tram)	Taxi/ PHV	Car driver	Car passenger	Motor cycle	Cycle	Walk	All modes
	Millions of trips									
1993	1.3	1.4	2.1	0.3	6.6	3.6	0.2	0.3	5.2	20.8
1994	1.3	1.5	2.1	0.3	6.7	3.6	0.2	0.3	5.2	21.1
1995	1.3	1.6	2.2	0.3	6.6	3.6	0.2	0.3	5.2	21.2
1996	1.4	1.5	2.3	0.3	6.7	3.6	0.2	0.3	5.2	21.5
1997	1.5	1.6	2.3	0.3	6.7	3.6	0.2	0.3	5.3	21.7
1998	1.5	1.7	2.3	0.3	6.7	3.6	0.2	0.3	5.3	21.9
1999	1.6	1.8	2.3	0.3	6.9	3.6	0.2	0.3	5.4	22.4
2000	1.7	2.0	2.4	0.3	6.8	3.6	0.2	0.3	5.4	22.6
2001	1.7	1.9	2.6	0.3	6.8	3.6	0.2	0.3	5.5	22.9
2002	1.7	1.9	2.8	0.3	6.8	3.5	0.2	0.3	5.5	23.1
2003	1.8	1.9	3.2	0.3	6.7	3.5	0.2	0.3	5.6	23.4
2004	1.8	2.0	3.3	0.3	6.6	3.4	0.2	0.3	5.7	23.6
2005	1.8	1.9	3.2	0.3	6.5	3.4	0.2	0.4	5.7	23.4
2006	1.9	2.0	3.1	0.3	6.5	3.6	0.2	0.4	5.8	23.7
2007	2.1	2.1	3.3	0.4	6.5	3.8	0.2	0.4	5.8	24.5
2008	2.2	2.1	3.8	0.3	6.1	3.4	0.2	0.4	5.9	24.6
2009	2.1	2.2	3.9	0.3	6.2	3.5	0.2	0.5	6.0	24.8
2010	2.3	2.1	4.0	0.3	6.1	3.7	0.2	0.5	6.1	25.3
2011	2.4	2.2	4.1	0.3	5.9	3.7	0.2	0.5	6.2	25.5
2012	2.6	2.4	4.1	0.3	5.9	3.7	0.2	0.5	6.3	25.9
Percentage change										
2011 to 2012	*8.5*	*8.2*	*-0.8*	*9.1*	*-1.0*	*-1.0*	*4.8*	*1.2*	*1.3*	*1.5*
2002 to 2012	*51.9*	*23.5*	*45.9*	*19.0*	*-13.7*	*3.1*	*-12.8*	*63.2*	*12.6*	*11.8*

Figure 3. Number of Journeys Made in London Using Different Means of Transport Between Years 1993 and 2012. Source: Report [57].

In many European cities support for public transport and cycling in daily mobility is considered to be an effective way to reduce air pollution, traffic jams and carbon dioxide emissions [60]. Planning and transport experts encourage various sustainable transport alternatives, such as using public transport, walking and cycling as affordable transport options to counteract the negative effects of car use for all [61]. The development of more sustainable transport requires the adequate establishment of four pillars: efficient land-use and transport management; fair, efficient and sustainable financing; strategic infrastructure investment; and attention to neighbourhood design [62]. Urban planning can create more efficient and environmentally friendly municipal freight transport systems. The use of innovative ICT (information and communication technologies) and ITS (intelligent transport systems), a change in the mentality of logistics managers and public-private partnerships can promote urban logistics policy measures [63]. Worldwide, several cities are striving for more sustainable urban transport systems in order to reduce accidents, congestion, air and noise pollution, and to improve social interaction, the ability to live and the value of amenities [64].

Figures 4 and 5 show the benefits from the solutions used in Copenhagen. Growth in the number of people cycling to work or educational institutions and feeling safe in traffic can be observed.

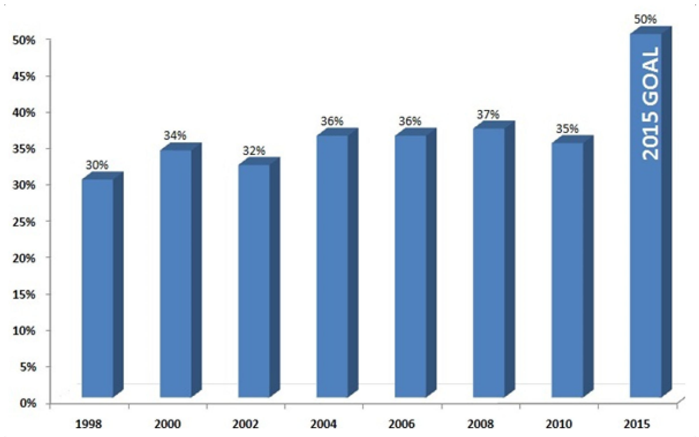

Figure 4. Percentage of People Cycling to Work or Educational Institutions in Copenhagen Between Years 1998 and 2010 and the Goal for 2015. Source: Report [55].

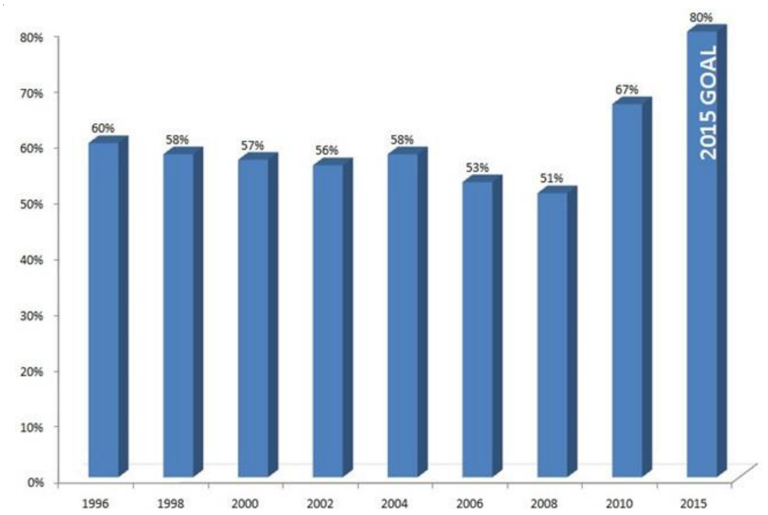

Figure 5. Percentage of People Cycling to Work or Educational Institutions in Copenhagen Between Years 1998 and 2010 and the Goal for 2015. Source: Report, [55].

Thanks to an efficient network of public transport and cycling routes in Copenhagen, car use has decreased so much that in 2010 up to 47% of citizens did not own car and 58% rode their bike to work or school on a daily basis [65].

4.2. Transport in Vilnius

Can sustainable transport be found in Vilnius? Peripheral regions in post-socialist countries appear to be particularly underinvested in terms of their transport, including at the local and regional level [7]. The authors focused on analyzing Vilnius for use of sustainable transport principles. Both already taken actions and problematic areas were analyzed. Additionally, new solutions were proposed, because efficiency of the transportation system is extremely important due to the growing scale of demands concerning mobility. Primarily, it has to be said that the main problem in Vilnius, from which difficulties in the transport department result, is the urban sprawl (uncontrolled growth of urban areas) that is inconsistent with a compact cities strategy promoted by the EU [66,67]. An attempt to show places (areas) with problematic transportation zones was taken by the scientists from Vilnius Gediminas Technical University. By using GIS tools they have managed to elaborate a model, which divides the city into 51 TAZ (traffic analysis zones) and specifies their efficiency [68]. During creation of this model, accessibility from the city center to different zones, population density and the number of jobs in the zones, density of public communication network and the number of daily trips in each zone were taken into consideration. To perform the necessary calculations, scientists used a modified Bogart and Ferry model [69].

The research results carried out by Jakimavičius and Burinskienė [68] in search of sustainable communication in Vilnius show that there are efficient communication zones, but there are only two of them: Santariškės and ŽemiejiPaneriai. In contrast, zones like Centras I, Centras II, Lazdynai, Karoliniškės, Antakalnis, Senamiestis, Šnipiškės and Naujamiestis were considered as zones having serious problems such as a lack of parking space and constant traffic jams. Abnormalities were also identified in Verkiai, Dvarčionys, Valakupiai, A. Paneriai and Tarandė zones. Moreover, sustainable transport principles about reducing the number of cars and promoting walking and cycling along with using public transport means are not completely implemented in Vilnius. Jakimavičius and Burinskienė [70] in one of their articles proposed a scenario saying that despite a growing number of cars in Vilnius, it would be possible to introduce a certain degree of sustainable transport rules if cars would be more efficient and use alternative energy sources. However, as they admit themselves, that kind of scenario is hard to accomplish. At Lithuanian motorway intersections, various traffic and safety engineering solutions are applied intensively [71]. On the other hand Klibavičius and Paliulis [72] demonstrated that the number of vehicles is similar to the statistical distribution of the data defined as such: the arrival of different vehicles at roundabouts is close to Poisson distribution.

Transport indicators for Vilnius in Figure 6 show a comparison between 1995 and 2005. It can be observed that despite an average of public transport passenger growth of 3.7% a year, there are still 17% fewer people using this type of transportation than in 1995. Nevertheless, there is in total more trips made by pedestrians, bicycles and public transport than those made by car (Table 2).

The number of people owning a car in Vilnius has been increasing by 3% per year since the 1990s. The reason for this situation could be the improving economic situation in the country. However, it should be noted that there are less people that use cars than those who choose public transport; in turn, this group is smaller than people travelling on foot and cycling (35.1% of city dwellers in 2005).

Unfortunately, forecasts for 2025 predict a growing trend in car and fuel use [68]. That is why measures to improve the communication network have to be taken in Vilnius to help the city in endeavoring to establish sustainable transport rules.

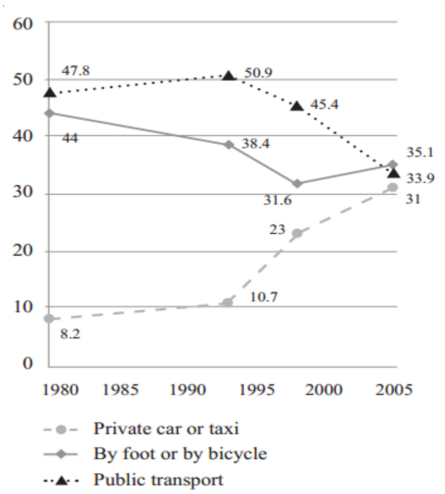

Figure 6. Travel in Vilnius by Chosen Means of Transport.

Table 2. Transport System Indicators in Vilnius. Source [68].

Indicator	1999	2005
Street network density (km/km^2)	1.9	2.4
Public transport density (km/km^2)	0.55	0.62
Bicycle paths networks density (km/km^2)	0.10	0.16
Average traffic flow in peak hours (aut./h)	1275	1521
Percentage of trucks in average flow	3.4	2.4
Average speed in peek traffic flow (km/h)	37.5	29.3
Modal split		
-pedestrian trips %	31.3	34.8
-trips by bicycles %	0.3	0.3
-trips by public transport %	45.4	34.2
-trips by car %	23.0	30.7
Maximum number of public transport passengers in peak hours	5300	3600
Transit of trucks in peak hours %	21.3	13.2
Number of traffic accidents for 1000 inhabitants	1.07	1.77

4.3. Sustainable Transport Solutions for Vilnius

Metro lines construction: Vilnius is supported by 456 km of trolleybus lines that carry 400,000 passengers per day. Besides that, citizens use buses which carry 300,000 passengers daily. This means that 33.9% of people from urban and suburban areas, consisting of 900,000 residents (540,000 living in Vilnius), use public transport. However, because of the overload in the city center, average speed in this area is about 20 km/h, which successfully scares people away from using public transport [68]. That is why the city government decided to study the usefulness of new means of transport, including a metro (Figure 7). Research conducted in the years 2006–2008 shows that 57% of responders opted for creating a metro while only 20% of them supported tram building. For the metro case, an organization called Vilnius Metro was created. The association is active in informing people about new solutions and held negotiations with investors so that a metro could be built from private resources [73].

Figure 7. Metro Construction Plan in Vilnius. Source: [73].

After the analysis of model solutions in selected cities and presenting the sustainable transport assumptions, the authors introduce possible solutions thanks to which transport in Vilnius can be treated as sustainable.

The map below presents a possible solution for the expansion of a bicycle network in a selected location in Vilnius. It is a neighborhood with a large transportation route, residential buildings and a park/forest. The possibility of linking the places where housing is located with the traffic routes will allow residents to easily change from bicycle to bus. Designation of bicycle paths and places from which bicycles can be rented in recreational areas should encourage the use of green spaces.

What is important in the proposed solution (Figure 8) is that it combines walking, cycling and public transport. The use of public transport is often uncomfortable due to the long distance to the stop. The connection between the stop and the place from which people can rent a bicycle can encourage them to use public transport. Parking in cities is associated with looking for a place and parking fees. That is why choosing public transport or bicycles relieves the traveler from looking for a place to leave the car. Some bike sharing systems reward their users if they leave the bike at the station. This saves them a fee for using a bicycle. Therefore, it is necessary to make bicycle stations available in attended places, as well as in places close to the living areas.

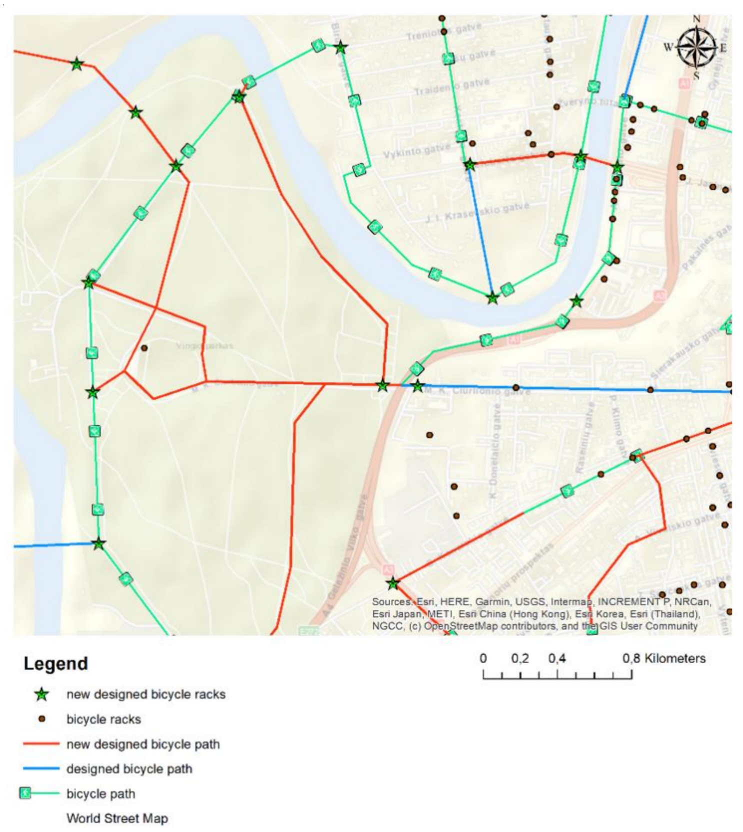

Figure 8. Results of the Analysis.

As shown in the maps above, changes can be made to the existing transport system, thanks to which it can be said that the transport in Vilnius would be sustainable. In presenting these proposals, the rules of sustainable transport contained in the Pyramid of Sustainable Transport (Figure 1) were respected. Finding the optimal solution for the Fleury, Dijkso, Hamilton cycle algorithm while maintaining apex and edge consistency required the development of many variants and testing them in order to achieve a system where algorithms have solutions. In this way, we minimized costs and maximized functionality and usability. The limitations include natural and cost barriers. We can assume that we are looking for the cheapest possible network with a predetermined reliability, or we are looking for a network with a fixed cost and the highest possible reliability. Of course, the more lines (edges), the greater the reliability. On the other hand, however, building any connection costs money. Additionally, it is assumed that the solution you are looking for has an Euler cycle, which means that there is a road that starts and ends at the same point and requires you to walk on each street exactly once. The graph is a full graph, which means it has at least one Hamilton cycle. Since the graph has a finite number of vertices, there is one (not necessarily the only one) in the set of Hamilton cycles that has a minimum sum of edge weights. We start from any vertex. Each successive edge we pass on is selected from the edges coming from the vertex we are currently in. If it is possible, removing the selected edge should not cut the graph into two "pieces". If we manage to reach the vertex from which we started and go through all the edges, the resulting path is an Euler cycle. The problem of finding Hamilton's cycle is similar to the problem of the combo-chainer being "difficult" due to the longtime of known algorithms. If the Hamilton cycle does not exist in the tested graph, then in that case we may even have to check all possible permutations of the vertex set to make sure that such a cycle does not exist. We want to design a network with the required reliability, the cost of which will be as low as possible. So, we are looking for a graph with n vertices and as few edges as possible, whose vertex consistency or edge consistency is k.

5. Conclusions

In Hamilton–Baillie's opinion, a different and better solution is creating shared and integrated spaces that bind different forms of transport in one piece [59]. This means the removal of signs, lanes, traffic lights, etc. and letting people spontaneously shape the traffic rules. However, it has to be remembered that this kind of solution may be achieved only by cooperation of people and local government combined with an approach change. There is a common opinion that residents of the suburbs are bound to use individual forms of transportation, and public transport does not meet their needs [74].

To sum up, Vilnius is a place where two city models (compact and traditional urban sprawl model) collide. This is because Vilnius is developing both in terms of sustainable transport (Santariškės and Žemieji Paneriai zones), but there are also zones like Centras I, Centras II, Lazdynai, Karoliniškės, Antakalnis, Senamiestis, Šnipiškės and Naujamiestis that have serious problems with traffic.

However, change in city transportation characteristics towards more sustainability, like in the Banister paradigm, is a long process. Both the model and infrastructure for traditional transport systems were developed many years ago. That is why the whole infrastructure and land use planning in Vilnius require gradual changes. Moreover, the starting point for every city should be different, because it depends on individual factors such as the political situation, local conditions and available funds. This is the reason why Vilnius has to work on its own solutions (based on those already existing and functioning efficiently in the world, e.g., Copenhagen and London) leading towards sustainable transport.

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