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Sustainable Urban Transport—Why a Fast Investment in a Complete Cycling Network Is Most Profitable for a City

Piotr Wałdykowski [1,*], Joanna Adamczyk [1] and Maciej Dorotkiewicz [2]

[1] Department of Landscape Architecture, Institute of Environmental Engineering, Warsaw University of Life Sciences, 02-787 Warsaw, Poland; joanna_adamczyk@sggw.edu.pl

[2] Municipal Roads Authority of the Capital City of Warsaw, Sustainable Mobility Department, 00-801 Warsaw, Poland; m.t.dorotkiewicz@gmail.com

* Correspondence: piotr_waldykowski@sggw.edu.pl

Abstract: The development of safe cycling as a mode of transport is an important objective of the transformation towards sustainable mobility in European cities. A significant number of European cities are faced with the need to implement the assumptions of the European Green Deal, of which the promotion of sustainable urban transport is a part. The article presented a simulation of the Perfect Cycling City Model in real conditions that inspired the design of two scenarios for the fast development of bicycle routes in a key transport network area in Warsaw. Scenario 1 assumes building subsidiary bicycle routes and links between the main routes. In Scenario 2, the development of all optimal cycling links at the local level is assumed. An increase in cycling participation is expected in both scenarios. The comparison of projected costs of each scenario indicated that building a complete network of connections is more profitable in terms of increased cycling participation and could counter the dominance of private car use. For this to happen, measures encouraging individuals combined with improved safety and convenience of cycling around the city must be undertaken.

Keywords: sustainable transport; cycling network; European Green Deal (EGD); the Perfect Cycling City Model; Warsaw

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1. Introduction

Under the UE (European Union) Action Plan on Urban Mobility adopted in 2009, the goal of European cities is to implement Sustainable Urban Mobility Plans. As part of the implementation, measures are taken to reduce private car traffic dominance in the public space. This objective is reflected in using alternative high-efficiency and low-emission transport means [1]. In this context, the bicycle is treated as an essential means of urban transport [2].

A frequently adopted sustainable transport strategy in European cities is to ban cars from city centers [3]. A high-profile debate on automobile traffic restrictions has continued in Germany for more than 25 years [4]. The Netherlands, Denmark, and Germany are examples of countries successfully introducing sustainable urban transport [5]. In 2016, the number of bicycles used in Copenhagen exceeded the number of cars for the first time in the history of bicycle traffic research [6]. Despite positive trends in increasing interest in bicycles, the share of cars in daily commuting in European cities is still significant, e.g., Amsterdam—19% [7], Copenhagen—29% [8]. In recent years, in response to climate change, the European Union has launched the European Green Deal initiative, aiming at 90% emission reduction by 2050 [9]. One of the ways to implement the EGD assumptions is a sustainable transport policy expected to reduce transport-related pollution in cities. In this context, the Climate Friendly Transport Mode is defined as cycling by city dwellers [10]. Cycling can help alleviate the undesirable effects of transport, such as traffic jams, air pollution, and noise [11].

Across Europe, the commuting activities included in urban functions have been neglected for decades [12]. Today, due to excessive congestion and pollution, radical measures are required. For example, in Warsaw, the share of cars in residents' daily traffic is higher than in the cities mentioned above—38.6% [13]. Cycling is significantly limited due to insufficiently developed cycleways and the failure of the existing bicycle networks to meet the basic standards for safety, consistency, and directness (e.g., CROW—the technology platform for transport, infrastructure, and public space [14]). Using an incomplete network of cycling links leads to reduced satisfaction of all its users [15], including car drivers. Studies conducted by the Department for Transport UK [16] show that moving on mixed traffic roads is too hazardous for 66% of adults, including 71% of women. The main barrier to more widespread cycling is the perceived traffic danger of cycling [17,18]. Sensitivity to perceived conflict (danger) can determine whether people will use a route [19]. Safety, comfort, continuity, and speed form the strongest drivers for the uptake of cycling and could encourage new cyclists [19]. The possibility of accidents, especially, has a negative impact on the demand for cycling travel [5]. Intersections and discontinuities of cycle routes are considered an important safety and flow problem [19]. In countries with a high cycling culture, the availability of cycling infrastructure is not a major problem and yet in surveys, the group of environmental barriers to cycling highlights the fact that continuity of cycle paths is the main factor facilitating cycling in both active cycling (74%) and non-active cycling groups (77%) [20].

The benefits of walking and cycling as a means of everyday transport are numerous and well documented [21,22]. The growing popularity of the bicycle in urban environments calls for the development of well-organized cycling networks [23,24]. Including the networks in the urban transport infrastructure encourages residents to use bicycles as a means of transport [25–27] and physical activity [28]. For bicycle users, the total length of the cycling network is less important than continuous connections to major destinations that can be reached effectively and safely [29]. However, in terms of convincing both the users and decision-makers, evidence shows that strict urban policy measures such as changes to infrastructure, services, prices, or engineering are not, by themselves, sufficient to influence the mindset of decision-makers and potential users regarding modes of transport [30]. The main compelling argument in support of change implementation is high profitability in terms of social benefits that exceed costs [31].

In Warsaw (Poland), the lack of care and organization of the bicycle network dates back to the political changes after 1989. Despite positive steps taken by the city authorities in recent years, the development of bicycle infrastructure is relatively slow. Despite a 9% annual increase in the bicycle network length [32], the route discontinuity problem has not been solved yet.

Cycling network planning is most often a task under the general transport infrastructure development plan [33] and the key elements modelled are nodes/junctions and links [34]. A systemic solution is rarely considered for cycling networks. The network design is usually original and results from local construction standards. The lack of network continuity is noticed only locally, at points where cyclists are forced to share the space with cars or pedestrians [35].

Network optimization models are developed to balance the benefits to cyclists and potential dis-benefits to car [36] or determine the profitability of routes depending on their length and the location of nodal points [37]. Network models aim to eliminate network discontinuity and may consider solution variants depending on the costs of the investment project scope [33]. In the current literature on bicycle services in the city e.g., [38], attention is paid to the Cycling or Bicycle Level of Service (BLOS) modelling. The organization of connections offered by the network is extended by assessments of bicycle routes based on indicators determining route quality, e.g., surface quality, lighting, and capacity, which are used in various methods of bicycle network quality assessment [38].

In this article, the authors focused on the fundamental problem of ensuring the continuity of cycle routes in an actual city. The authors proposed to base the cycling network development in Warsaw on the British Columbia Cycling Coalition (BCCC) Perfect Cycling City Model [39]. The model provides a theoretical justification for building optimal cycling links, complementing the existing cycle routes, taking into account the growing number of users, and the project cost. This simulation aims to give an idea of what the organization of a complete cycling network could be like compared to that in the European cities with a long cycling tradition, such as, for example, Copenhagen. The study's first objective was to develop scenarios for cycling as a mode of transport in a large European city—Warsaw. Two scenarios were prepared, each with different costs, but meeting the goal of route continuity and increased capacity. From the users' point of view, this would mean increasing the efficiency, safety, and convenience of getting around the city. The second objective was to compare the benefits to cyclists and the costs of such an investment. The adopted approach is not new, but still challenges some European cities similar to Warsaw.

This paper aimed to test the hypothesis about a simple BCCC model application as a method of complete cycling infrastructure cost estimation and provide arguments that justify the acceleration of network development for cycling continuity and the safety and comfort of its users.

2. Characteristics of the Study Area

Warsaw has been implementing measures of sustainable urban transport since 2009. The measures undertaken are based on the strategic document "The transportation system of Warsaw: sustainable development strategy up to 2015 and successive years, including the sustainable development plan for Warsaw's public mass transport system" [40]. The strategy includes measures for improving the safety and efficiency of moving around the city while limiting its harmful impact on the natural environment and enhancing the residents' quality of life. One of the provisions is devoted to the bicycle traffic system as a viable alternative to motorized traffic. The existing system of cycle routes in Warsaw is developed hierarchically, divided into city-wide and local routes. The planned density of cycling routes should reach 0.65 km/1000 inhabitants at the route length of 900 km [40]. On the other hand, Amsterdam's total length of cycling routes is 767 km [41], which is 1.07 km/1000 inhabitants. The difference may result from the larger population of Warsaw (1.76 million [42] vs. 0.821 million [43]). Significant progress on cycling is thus going to be made. However, although the route length increases consistently, the routes are not integrated, thus ensuring neither continuity nor directness [32]. At the same time, the city residents' interest in using bicycle transport is increasing. In recent years, the number of cyclists in Warsaw has grown three times as fast as the length of cycle routes. This suggests that intensifying investments in new routes [32] and striving for integrated, continuous cycling links are justifiable.

Warsaw's traffic has been monitored since 1969 and documents preference changes. The first increase in bicycle participation was observed between 1998 and 2005, with a bicycle share of 1.1% [44]. In 2015, 3.1% of trips were completed by bicycle [13]. In subsequent years, further growth in cycling participation was observed: 4.5%—2017; 7.54%—2019; approximately 8.85%—2020 [45]. At the same time, the use of automobiles increased from 32.9% in 1998 to 38.6% in 2015 [13]. The increase in bicycle use is interpreted as a direct effect of the extension of the cycling network, which is consistent with social trends of healthy lifestyles [32].

In the latest study of bicycle traffic before the COVID-19 pandemic, the maximum values in Warsaw were up to 2850 bicycles/5 h, which translates to 567 cyclists/h. A survey conducted by the Warsaw Barometer after [45] revealed that only 2% of city's inhabitants ride a bicycle every day, 7% declare that they are willing to ride a bicycle every day, and 41% are willing to use a bicycle. This 41% of respondents should be treated as a target group in the urban transport cycling planning. The more so because today, most cyclists (2019—70–99.5%) ride their bikes on pavements [45]. Pavement use by cyclists helps avoid the hazards of moving on the road but intimidates pedestrians and creates areas of potential conflict.

The research area in this study was the central part (the city) of Warsaw and adjacent districts (Figure 1).

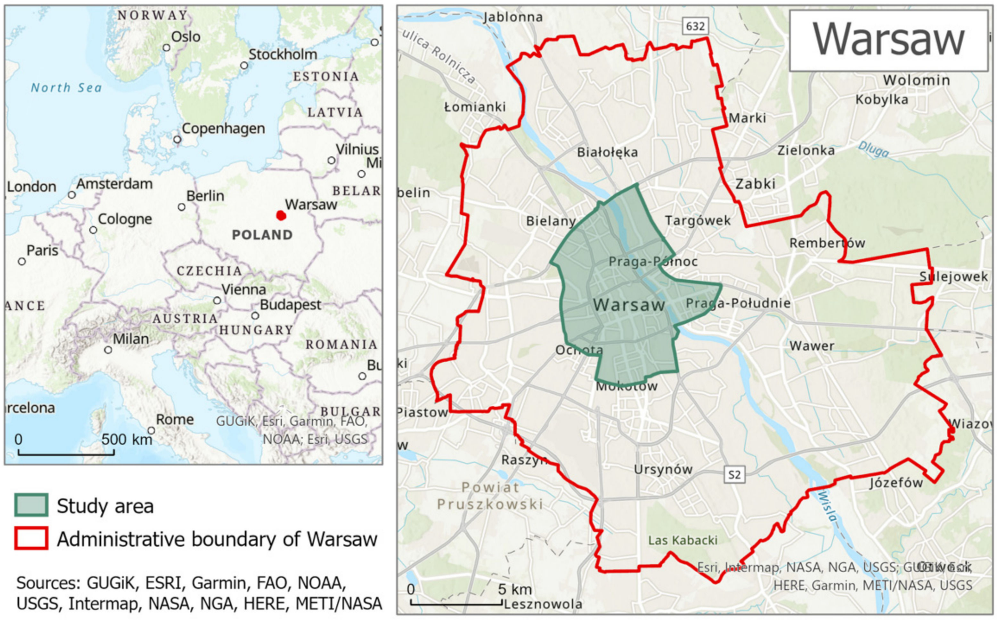

Figure 1. Location of the study area in Warsaw.

This area is crucial from the point of view of the city's transport links. The boundaries of the study area discussed in this article are streets of significant importance for the urban transit, which, intersecting with other streets, create clear transport junctions. Inside the analyzed area, which is cut by the approximately 1-km-wide Vistula valley, there is the very center of the city with a characteristic urban spatial structure (with multi-family housing and service and commercial space). After the destruction of Warsaw during World War II, the city was spatially reorganized to widen its primary arterials. As a result, there are local, less wide streets from densely built-up quarters concentrating service and commercial activity. The development structure on the right side of the river looks slightly different, with older downtown buildings from the first half of the 20th century and industrial development being currently converted into residential and service areas. As the city spreads on both sides of the Vistula, there are ten river bridge crossings; some are included in the city's outer ring roads and two railway bridges. Six bridges, key to the city transit and bicycle traffic, are located within the area under analysis. The study area also includes one vehicle bridge crossing planned to be completed in 2024. Intensive development and high population density characterize this area (Figure 2), with workplaces, transport hubs, shops, cultural institutions, etc. In Warsaw, motor traffic is the dominant mode of travel (destination traffic) throughout the week, and without investment, more people will turn to cars. Leisure cycling is observed mainly on weekends.

The most crucial problem of Warsaw's bicycle transport is that cycle infrastructure does not join together. The longest routes go within the main arterial road boundary. The streets with a lower level of use do not create well-developed connections; the links are short and can take few users. New routes, built in the newest housing estates, are not connected to the existing cycle network. Some of the new solutions provided during road renovation in some sections ensure no route continuity. Locally vital cycle lanes and contraflow bike lanes are designed in older parts of the city, where cycle tracks are separated from car traffic. They are most often the result of social initiatives and not the priorities resulting from municipal planning. The construction of new separated routes in older housing estates is met with reluctance by the residents afraid of losing on-street/pavement parking spaces. The situation related to the restrictions on introducing car traffic in the intensively built-up city is similar to that of many other European cities. In Warsaw, however, there is a lack of political will and public support for a shift away from the prime position cars hold in the city center.

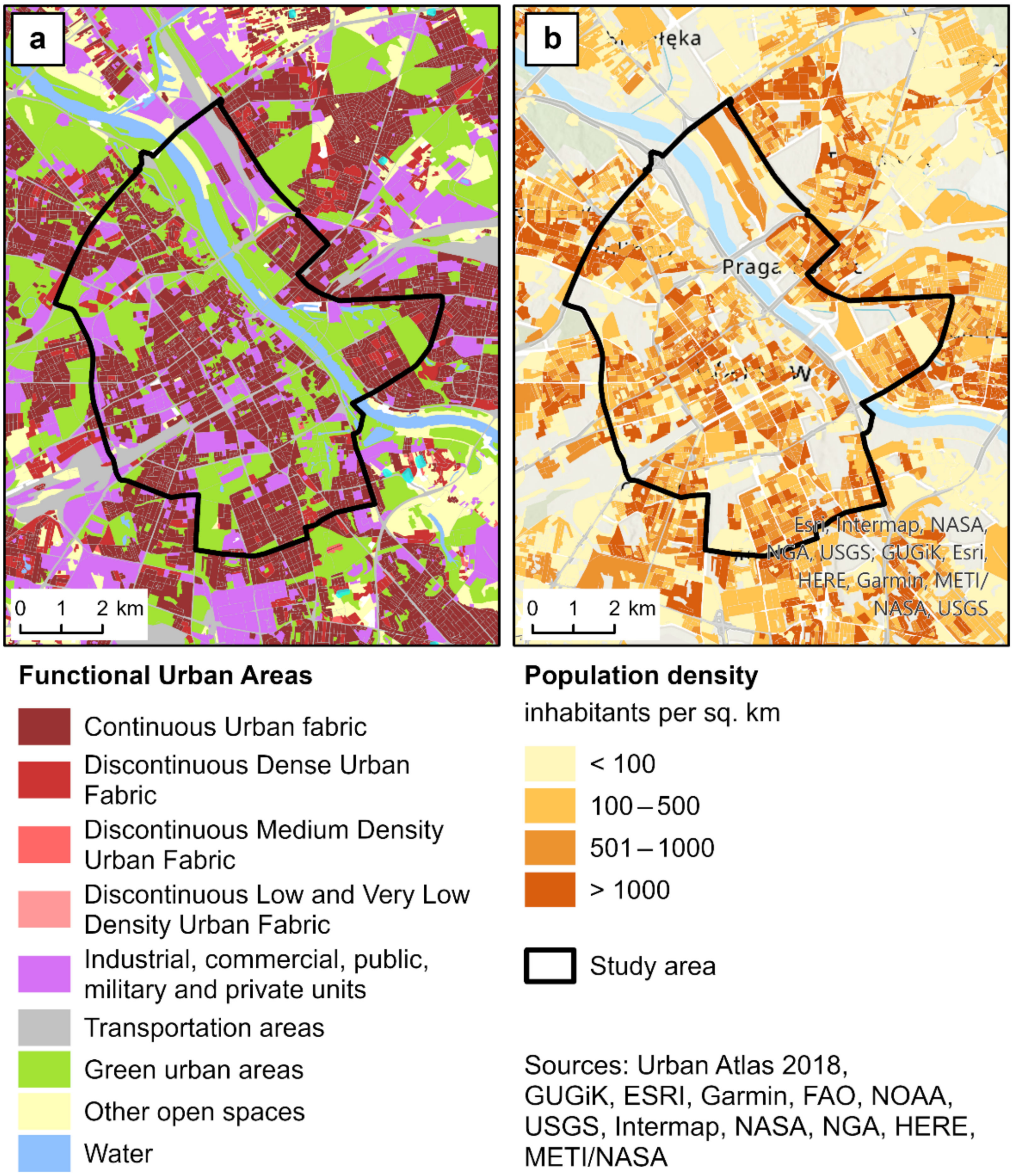

Figure 2. (**a**) Functional Urban Areas [46] and (**b**) population density [47] in the study area.

The total length of existing bicycle routes in Warsaw in 2020 [32] is 680.35 km. Compared to the most bicycle-friendly cities in Europe, the situation is not too bad, but the differences are visible in the density of cycle networks per unit area and also in bicycle mode share in daily commuter trips (Table 1).

Table 1. Cycle network characteristics for Warsaw, Amsterdam, and Copenhagen against the bicycle share in daily trips.

	Warsaw	Amsterdam	Copenhagen
Total length of the network, km	680.3 (2020) [1]	767 (2021) [2]	416 (2019) [3]
Density of cycle networks, km/km^2	1.32 (2020) [1]	no data	4.53 (2006) [4]
Bicycle share in daily trips, %	8.85 [1]	35 (2017) [5]	28 (2018) [6]

[1] [32], [2] [41], [3] [48], [4] [49], [5] [50], [6] [51].

3. Materials and Methods

3.1. The BCCC's Perfect Cycling City Model

On a supra-local scale, a well-functioning cycle network should be characterized by high coherence and directness, ensuring access by bicycle both to essential destinations for targeted traffic and the possibility of public recreation under convenient conditions. Therefore, the objectives of the theoretical simulation of the expansion of Warsaw bicycle routes were as follows:

- providing potential users with access to a safe bicycle network
- ensuring the most effective access using the main routes and local streets of significant transit importance
- determining the relation between the costs incurred and the expected increase in the number of bike users

For this purpose, the Perfect Cycling City Model developed by the British Columbia Cycling Coalition—BCCC (after [39,52]) was used, which helps trace the relationships between the intensity of bicycle route use (traffic intensity) and the two most important qualitative aspects of connections within bicycle networks (route length and coherence).

Theoretical assumptions of the method based on the Perfect Cycling City Model [39] assume performing a simulation for a square city with a grid of six by six routes, spaced every 1 km. Within the thus created road network, the routes begin and end at the intersection points of these roads (nodes). Thus, in the model defined this way, there are 36 nodes between which cyclists travel. A total of 100 cyclists move between each pair of nodes in both directions. This means that if one route with a length of 5 km is built in the Perfect City, it serves six nodes from which one can get to five more nodes. Thus, such a route can serve 3000 people, where 600 people use the 1 km route.

Similarly, if all routes (Figure 3b), i.e., six north-south routes and six west-east routes, were developed in the Perfect City, this would give a total of 60 km of cycle routes with 36 nodes. All the routes would create a complete set of links between nodes (street intersections). A total of 1260 links (35 × 36) would be created, which would be used by 126,000 cyclists (126,000/60 km = 2100 cyclists/km), three and half times as many as in the case of a single route.

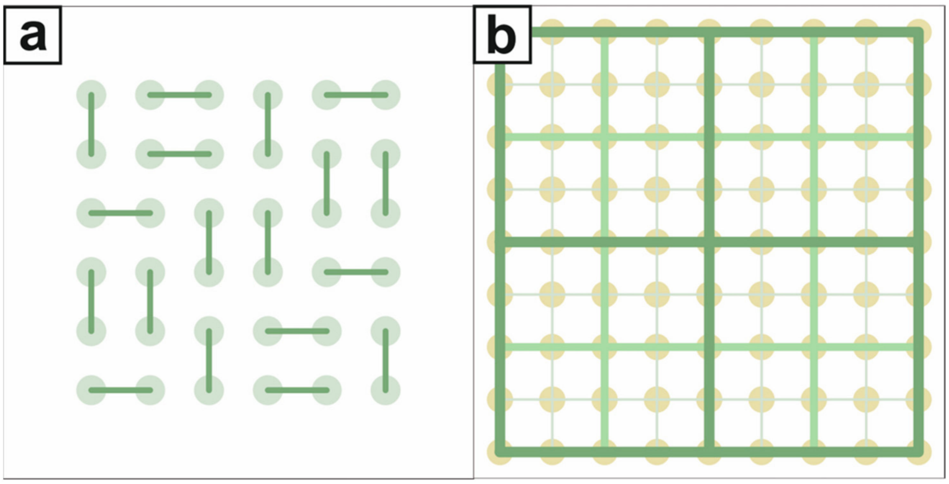

Figure 3. Square shaped Perfect City in two variants: (**a**) with local routes that are not interconnected city-wide, (**b**) with a full system of cycling links.

Another variant of the BCCC Model (Figure 3a) shows sections without links to the routes connecting all nodal points. Individual stretches are also part of the bicycle routes network, but their start and end points become nodes without connection to other routes. Such a layout of routes illustrates local cycling connections that do not spread over the whole city (this situation is very similar to the case studied as part of this work).

The BCCC method compares network alternatives from the point of view of investment costs per one cyclist. The comparison is presented in Table 2 with the following assumptions: construction of one section of the route costs $1000. It is worth noting that the method does not include the calculation of costs of construction of junctions (route crossings) and other cycling infrastructure.

Table 2. Comparison of theoretical models included in the Perfect Cycling City Model [39].

	Variant a	Variant b
Total length of cycle routes (km)	18	60
Number of junctions	36	36
Number of connections	36	1260
Number of cyclists (current and predicted)	3600	126,000
Kilometers of cycling routes per 1 cyclist	200	2100
Cost of extending the existing network ($)	36,000	1,260,000
Cost of extending the existing network per 1 cyclist ($)	36	1

3.2. Adaptation of the Perfect Cycling City Model in Warsaw

The BCCC method [39] is a simple simulation illustrating the profitability of the rapid creation of cycling infrastructure. Lack of continuity of cycling routes is particularly noticeable in cities that start implementing cycling solutions. The authors adapted the BCCC method to an actual situation in a real city, which has a poorly developed cycling network of continuous connections. An important methodological challenge was adapting the simple BCCC method to complex conditions in Warsaw. The rapid construction of cycling routes is intended to support the existing city policy on developing a complete cycling network.

The practical application of the BCCC Perfect Cycling City Model [39] assumptions requires broadened model adaptation to the real situation in the city. As in the theoretical model, we assumed that each node, i.e., the intersection of cycle routes, can also be treated as the beginning and end of individual route sections. The length of the route sections will vary from that in the Perfect Cycling City Model. Real cities are not square, and the distances between nodes (intersections) are not equal. The number of movements can similarly be represented by the product of the number of nodal points. The routes have different transport conditions, e.g., the number of starting points (housing estates) and endpoints (workplaces) and will be unevenly loaded by the users. However, also in this situation, as in the Model, the target solution should be a complete network of bicycle connections, enabling movement within the city using all available routes and nodes. Not all links are as important as in the theoretical model.

The BCCC Model [39] was adopted as follows:

1. The real city does not meet the assumptions of only one variant of the theoretical model. At least two variants of the BCCC model are applicable here, i.e., the partial variant (more often) and the variant of the maximum link network (less frequently).
2. Road sections vary in length, so nodes also occur at unequal intervals. It was assumed that these sections must not be shorter than 90 m. Separate traffic nodes are real intersections in the city's transport system.
3. The numbers of current and potential bicycle users were compared to the data collected from the automated traffic measurement [45] and the forecasts for the development of the bicycle route network [28], the completeness, directness, and safety of which, among other factors, are to translate into an increase in the number of cyclists.
4. The application of the valuation method took into account the actual costs that the city would incur if the investment were made:

a. Sections of cycling routes vary in construction costs, depending on location, e.g., separated cycling lanes and traffic lanes.
b. Construction costs also apply to junctions (crossings of cycling routes and crossings with other roads). Costs vary according to the size of the junction and the importance of the transport links (local or city-wide importance).

From the entire route network in Warsaw, its central part was selected for key importance in city transit. This criterion was also used when selecting the routes to be developed. The development of the network was assumed in two stages. The starting point was the current condition of the network. It is incomplete, and the cycle routes are located along main arterial roads and streets or within traffic lanes. Off-street routes in Warsaw are mainly recreational, and their nodes form intersections, which, as in the BCCC method [39], are the beginning of new routes.

Further analysis was aimed at presenting scenarios for building the missing links. The existing network of bicycle routes was supplemented with new routes keeping in mind the real possibility of creating cycle connections. Scenario 1 assumes that the existing routes will be supplemented only along the main passageways.

Scenario 2 is for supplementing the network with vital local connections. Bicycle lanes and contraflow lanes are also included.

The two network variants satisfied the cyclists' needs to a different extent. Therefore, they were compared to determine the maximum use of routes and the analysis of the bicycle infrastructure within a cost-benefit framework.

The cost estimate calculated for both network extension variants was based on the data from the bicycle infrastructure projects submitted to the Warsaw City Hall under the Participatory Budgeting process. The values were converted to US dollars according to the current exchange rate for illustrative purposes. Investment costs depend on the route type and are given per distance unit (1 km). For the nodes, the level of node complexity was considered. The costs of the existing and planned routes calculated separately for the off-street routes (bicycle paths, shared walking, and cycling routes) and the routes designated within the existing streets (on-street bicycle lanes, contraflow lanes). For valuation, the costs of off-street 2.5-m-wide paths were calculated separately, and in the case of the on-street lanes, the costs of painting the markings were taken into account. The costs of new junctions varied depending on the spatial extent—the complexity of cycling solutions on large junctions is more significant than simple street intersections), the number of joining lanes—if more than four streets intersect, construction costs are also higher. Both scenarios consider the maximum feasible scope of building crossings over the Vistula, recognizing that it is still crucial for connections despite a significant increase in investment costs in bicycle infrastructure.

The obtained picture of investment costs was evaluated regarding the network development scenarios and network users. The maximum variant of the route development (Scenario 2) was estimated based on the Warsaw Cycling Report [32]. According to the report, 41% of the city's inhabitants (adjacent areas excluded) declare the willingness to ride a bicycle. It is worth noting that in Copenhagen, the same percentage, 41%, corresponds to the overall share of cycling commuters, and for people living and studying exclusively in Copenhagen's central districts, it is 62% [53]. For the scenario according to which only main cycle routes (Scenario 1) were to be built in Warsaw, with routes of local importance excluded, it was assumed that only some of potential users would be interested. This corresponds to the assumption made in the Model BCCC [39] about the number of users increasing proportionally to the increasing number of cycling connections. Therefore, by proportion, the share of interested users was determined to be 14.5%, according to the following formula

$$\text{NuS1} = [(\text{NuS2} - \text{NuC}) \times \text{RelS1}]/(\text{RelS1} - \text{RelS1})$$

NuC—Current number of users

NuS1—number of new users in Scenario 1
NuS2—maximum number of new users in Scenario 2
RelC—number of current connections
RelS1—number of new connections in Scenario 1
RelS2—number of new connections in Scenario 2

4. Results

The current condition of the bicycle network and the two scenarios of its development are presented in Figures 4a–c and 5a–c. Figure 4a–c describes the connection points (routes intersections) within the network. "Large" nodes refer to cycle route junctions connecting 5–6 roads, with tram passageways and more than one lane in each direction. Standard intersections are typical crossings, connecting minor streets in up to four directions.

Figure 4. (**a**) Existing cycling network and proposed connections and junctions: (**b**) Scenario 1, (**c**) Scenario 2.

Figure 5. Existing cycling network (**a**) and proposed connections: (**b**) Scenario 1, (**c**) Scenario 2, by bicycle route category.

Currently, in Warsaw (Figure 4a), the network of bicycle routes is incomplete; thus, some nodes are not intended to be intersections, but the endpoints of the routes. There are large junctions on the outskirts of the study area, which include intersections within large arteries. Inside the study area, smaller nodes dominate. As part of the design work for the cycle route network in Scenario 1, the routes and nodes along primary roads were added (Figure 4b), leaving incomplete links to local roads. In Scenario 2, all necessary routes and nodes, both standard size and large (Figure 4c), were added.

Figure 5a–c shows the routeing system by solutions used depending on the road importance. There are four main types of bicycle routes: located along the main roads, other roads, traffic lanes/contraflows, and leisure routes. The leisure routes go mainly along the Vistula River and city park zones. Therefore, it is possible to consider connecting them to the system of other cycle routes in Warsaw without extending the existing recreational routes.

Figure 5a shows the current system of the routes. Most of the existing network elements are based on the connection to the main roads and recreational routes, which are long routes that connect city districts and the banks of the Vistula River. The number of nodes in the current cycling network within the analyzed area corresponds to the main routes across the city but is incomplete. To make the network complete, the missing links were added under Scenario 1, and new links were introduced along the main roads (Figure 5b). In Scenario 2, the network was supplemented with routes along other roads and road lanes (Figure 5c). The particular concentration of the road lanes is achieved in the very center of the city and some districts adjacent to the city center (also on the right side of the Vistula River) with quarters of compact development.

The calculation of the investment costs (Table 3) shows that supplementing the connections between the current parts of the network for main routes will result in only 17 nodes and a 36 km extension of the route network. This means a marginal increase (of 12,062) in the number of connections. However, by supplementing the network to the full extent, the length of routes will reach 295 km (an extra 134 km), and the number of nodes will be 461 (an increase of 222 nodes compared to current conditions), which will provide 136,067 connections (an increase of 97,603).

Table 3. Scenario 1 and Scenario 2 vs. the existing route network.

	Existing Cycling Routes	Scenario 1 Main Routes	Scenario 2 Full Network
Total length of cycle routes (km)	161	197	295
Number of junctions	239	256	461
Number of connections	38,464	50,526	136,067
Number of cyclists (current and predicted)	35,883	259,830	735,608
Share of Warsaw population (%)	2	14.5	41
Kilometers of cycling routes per 1 cyclist	4.5	0.8	0.4
Cost of extending the existing network (billions $)		9.3	19
Cost of extending the existing network per 1 cyclist ($)		35,942	25,832

Only 2% of the city's population [32] use the current connections regularly, i.e., 35,883 bicycle users. Assuming the expansion of the road network by supplementing the connections and a slight extension to it, the network will be used by a larger group of cyclists (14.5% of inhabitants). In Scenario 1, the cost of expanding the network amounts to $9,338,001,000, which is $36,000 per cyclist. In Scenario 2 (the construction of a complete network of bicycle connections in the study area), where increased interest in cycling is assumed (max 41% of the city's population), despite far higher costs ($19,002,000,000), the cost per one bicycle user is reduced to $26,000.

The implementation of Scenario 1, despite a lower increase in network length, is quite cost-intensive because it mostly requires the construction of complex nodes (junctions) and off-street routes (walking and bicycle routes, cycle paths) and the adaptation or construction of all crossings across the Vistula River. This investment model corresponds to the current policy of the city authorities. Its advantage is the ability to fill gaps in the network. However, the analysis shows that significant investment will not translate into the residents' interest in cycling (up to 14.5%) even if the number of connections rises to 50,526.

Implementing the complete network of bicycle routes also considers the costs of complementary links on the main routes. Building additional local routes (98 km long) on existing roadways (cycle lanes/contraflow lanes) will be less costly than the main routes.

If following the assumptions of the CROW [14], the safety and directness of links are improved (increase in the number of connections up to 136,037), and it can be assumed that cycling will become attractive to all potential users. The more significant number of users will guarantee a better distribution of the investment costs per cyclist.

5. Discussion

Following the network design principles, the network has to satisfy the conditions of coherence, safety, directness, convenience, and attractiveness [14]. Fulfilling the CROW assumptions is a global canon. A bicycle is perceived as an equal and innovative element of urban transport, the use of which should be daily and safe [54]. The Dutch success is based primarily on network coherence. A study from 1981 on the use of high-quality cycle routes built in The Hague and Tilburg clearly showed that their efficiency is low despite the investment in quality. The routes did not connect, so cyclists did not use them as assumed [55]. Suppose the layout of the links is well thought out and allows reaching a destination as quickly as possible. In that case, using a bicycle may also seem attractive outside the recreational season. Cyclists who can reach the destination over a shorter distance and in a shorter time will be willing to do so regardless of weather conditions after [56]. Currently, the literature devotes much space to indicators defining the optimal urban cycling solutions in terms of Bicycle Level of Service indicators [38]. Attention is paid to the quality of the infrastructure and the comfort of cycling. With the assumed bicycle network, users' preferences for the choice of routes are examined [57,58]. These indicators are based on the expected quality of infrastructure and cycling comfort. They can also be a valuable hint for upgrading already applied solutions, such as the long-discussed separation of routes from car traffic and the width of routes [59].

It is difficult to discuss all conditions for choosing a route in Warsaw since many routes fail to provide continuous cycling connections within the route network. Therefore, this article focused primarily on the first stage of improving the quality of the routes. However, it should be noted that a correctly performed extension of the cycle route network, even based on the best theoretical premises, is not the only factor increasing the number of users. What is needed is public education and infrastructural changes to de-prioritize car use and, above all, incentives to change the way of thinking about the everyday use of a bicycle, not only for recreational purposes. In Europe, introduced in 2009, the Strategies for the Sustainable Development of the Transport System were to aid in reaching this goal [40]. These documents focus on the city's policy on dedicated bus lanes, free parking of electric vehicles, and cycling promotion activities. In the current European Union Strategy provisions, the interest in transport policy has deepened to reduce the emissions due to transport by 90% before 2050 [60]. All large and medium-sized cities should put in place their own sustainable urban mobility plans by 2030, and the largest 100 cities should achieve climate neutrality. According to the current EU policy, the goal of sustainable urban transport policy should be to increase safe cycling route share, the length of which, in the case of cities declaring more than 2300 km of cycle routes, should double in the space of next ten years to reach 5000 km of safe cycle routes. The development of bicycle routes, i.e., cycle lanes, cycle tracks, cycle highways, and cycle streets, should be accompanied by necessary parking racks, docking stations, bicycle-sharing schemes, rental services, and support measures: information, signage and wayfinding, and bicycle maintenance and repair facilities. Although Warsaw is not among the cities with the highest share of bicycle routes, each year, it increases the length of bicycle routes and other infrastructure in line with current trends [32].

Conclusions resulting from the practical application of the Perfect Cycling City Model [40] show a method to achieve the goal faster than expected, considering the rate of investments in leader countries. Spanish Sevilla is living proof that the accelerated implementation scenario is possible [61]. Sevilla is considered a poster city for sustainable transport, and in newspapers, it has been named "The cycling capital of southern Europe". The quick introduction of a complete network of bicycle routes increased the number of daily users (from 6000 to 70,000, 2003–2015), the share of commuter trips reached 6%, and all trips by bike rose to 9% [62]. These values are far from Danish or Dutch results (e.g., Copenhagen—all cycling trips 28% [51], all commuter trips 41% after [53]).

Nevertheless, it is far above the average in Spain, where only 1.6% of the population declares a bicycle to be their primary transport mode, and almost 50% say it is a car [43]. Despite different climates (snow, frost, and ice in winter), insufficient length of routes, and all imperfections of the cycle network, the cycling share in Warsaw between 2010 and 2019 increased from about 1% to 7.54% [32]. The cycling system introduced in 2012 contributed to an increase in the number of users from 53,000 to 901,000, and the number of public bicycles grew from 1050 to 5701 [45]. In the survey, however, only 2% of Warsaw residents nominated the bicycle as their daily mode of transport, and only 7% said they were ready to ride a bicycle every day [32]. Warsaw seems to have great potential for a complete network of connections. The current rise in cycling interest results from the increased length of the route network from 275 to 645 km in 2010–2020 [32]. This suggests that with the complete network, a scenario in which all residents declaring any bike use (41%) [32] become interested in cycling is highly probable. The COVID-19 pandemic increased cycling popularity. According to the latest report, in 2020 in Warsaw, bicycle use increased by 17.4% compared with 2019 [45]. A similar trend was observed, for example, in Germany, where, in 2020, bicycle sales rose by 35% compared with previous years. The German government plans to significantly double bicycle traffic by 2030, increasing the daily trip distance from 1.5 to 3 km/cyclist [62]. In the context of long-term efforts on the cycling community to build a complete network of bicycle routes in Warsaw, this idea has received public support as confirmed by the submitted proposal and request for funding under Participatory Budgets in various city districts. The Participatory Budget is part of the city's investment funds allocated to projects proposed and voted for by the citizens. The proposals received by the city authorities confirm the need to extend the existing network of bicycle routes at the local level.

6. Conclusions

This study provided important arguments supporting the development of a complete network of bicycle routes in Warsaw. First, Warsaw is an excellent city for the fast implementation of such a project. The growing interest in cycling, the city authorities' policy advocating cycling and the construction of new bicycle routes confirm this goal. City bicycle rentals are top-rated. The idea of building a complete network of bicycle routes is becoming an increasingly clear necessity in Warsaw to improve the safety of both cyclists and pedestrians. Finally, reducing the share of cars on city streets should be a priority to bring Warsaw closer to cities with a sustainable transport system.

The added value of the present study is the practical method of estimating the efficiency of fast cycling infrastructure implementation in the context of social benefits. The fast implementation of the complete network of bicycle routes, despite high costs, is profitable due to the expected increase in cycling participation. The cost in the scenario of the complete network construction, although more expensive in terms of overall cost, only slightly exceeds the cost of building only main bicycle routes. Therefore, the authors consider implementing the method based on the Perfect Cycling City Model as possible in the conditions of an actual city. In the face of the EU policy aimed at supporting sustainable transport, implementing the complete bicycle network in cities similar to Warsaw is highly probable.

Achieving the assumptions of the European Green Deal requires consistent measures to reduce the emission of air pollutants generated by transport. One of the pillars for implementing those assumptions is increasing cycling participation. In the article, the authors chose not to pay attention to social education necessary to achieve this goal, analyze cyclists' preferences, or analyze other mechanisms that administratively limit the participation of cars in individual transport. However, it is worth emphasizing that even the best-designed bicycle network may not be attractive without appropriate social awareness. Moreover, the lack of a secure and fully connected cycling network fails to provide arguments in the social debate about the benefits of using a bicycle in everyday transport.

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