Journal of Transport Geography 35 (2014) 120–129

Contents lists available at ScienceDirect

Journal of Transport Geography

journal homepage: www.elsevier.com/locate/jtrangeo

What about people in cycle network planning? applying participative multicriteria GIS analysis in the case of the Athens metropolitan cycle network ☆

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ARTICLE INFO

Keywords:
Metropolitan cycle network planning
Cycling infrastructure
Participative multicriteria GIS analysis
Cyclists' views
Cycle route choice

ABSTRACT

The bicycle is gaining ground as an inexpensive, fast, healthy, and enjoyable mode of transport, but the development of cycle infrastructures appears to be a necessary prerequisite for supporting further growth in cycling rates. Thus far, few studies have developed comprehensive methodologies for the prioritisation of cycling infrastructure investments, and the role of end users has been underestimated in this process. The unique relationship that cyclists develop with the bicycle itself, their co-cyclists, bicycle facilities, and the urban environment as a result of sensory, kinaesthetic, symbolic, or even political reasons can assist in designing cycle facilities that are more efficient and closer to fulfilling the needs and desires of users. We propose a comprehensive four-step methodology for cycle network planning, which both accounts for the city structure and the zones in which higher cycling demand is possible and uses participative multicriteria GIS processes to incorporate cyclists' views with regard to choosing the cycle network segments. Our case study is Athens, Greece, where cycling facilities are few and heavily fragmented, although cycling demand has recently grown. This methodology may be useful for cities attempting to introduce and prioritise cycling infrastructures because it focuses on determining where cyclists would prefer to cycle to make such investments more successful in attracting users.

1. Introduction

The bicycle is one of the most attractive ways to travel in a city as it is inexpensive, does not pollute, and consumes little energy; moreover, under certain traffic conditions, it may be faster than other means of transport (Heinen et al., 2010). Bicycling has also been linked with a different, environmentally-friendly, healthier, more enjoyable and creative lifestyle, especially among Millennials, the generation born between the early 1980s and the early 2000s (see ifmo, 2013; Sakaria and Stehfest, 2013). At a policy level, the bicycle is currently recognised as one of the important pillars in the strategy for sustainable mobility in Europe (ECMT, 2003) and the US (Pucher et al., 1999, 2011). During the last two decades, the development of cycling infrastructure in urban areas has been emphasised. In Berlin, the network of separate bicycling facilities increased from 271 km in 1970 to 920 km in 2008; in Paris, the bike lane network more than tripled during the last 10 years, reaching 399 km; and in Portland, Oregon, the number of bikeway miles (lanes, paths, and boulevards) has increased by 247% since 1991 (Pucher et al., 2010).

Many studies have shown that cycle infrastructure is, indeed, a necessary prerequisite for the expansion of bicycle use. Buehler and Pucher (2012a) recently confirmed that cities in the United States with a greater supply of bicycle paths and lanes have significantly higher bicycle commute rates, even when controlling for land use, climate, socioeconomic factors, gasoline prices, the availability of public transport, and cycling safety. The importance of cycle infrastructures has also been emphasised by: Dill and Carr (2003) in their study of 43 large cities across the United States; Barnes et al. (2006) in Minneapolis-St. Paul, Minnesota; Pucher and Buehler (2006) in a comparison of cycle use rates in Canadian and US cities; and Handy (2011) in Davis, California. Moreover, Milakis (in press), in his research on Patras, Greece, found that the development of cycling facilities is likely to strengthen citizens' sense of having the means, ability, and opportunity to use bicycles for their mobility needs.

☆ Title adapted from the classic work of Torsten Hägerstrand '*What about people in regional science?*' (Hägerstrand, 1970).

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http://dx.doi.org/10.1016/j.jtrangeo.2014.01.009
0966-6923/

Although the development of cycling facilities is associated with increased levels of cycle use, few studies have developed comprehensive methodologies for cycle network planning and the prioritisation of cycling infrastructure investments in particular. Thus far, research interest has focused primarily on investigating (a) route choice criteria of cyclists and (b) the factors affecting bicycle use. In the first category, studies have employed revealed or stated preference methods to explore the effects of criteria such as the class and physical characteristics of the roadway, the bicycle facility type, the slope, the number of cross streets, and the number of stop signs or traffic controls on cyclists' route choice decisions (see, e.g., Stinson and Bhat, 2003; Titze et al., 2008; Sener et al., 2009; Menghini et al., 2010; Winters et al., 2011; Broach et al., 2012). The second set of studies has used multivariate statistical methods to examine the effects of parameters such as the built environment, socio-demographic characteristics, attitudes, and bicycle facilities on bicycle use (see, e.g., Cervero and Duncan, 2003; Rodríguez and Joo, 2004; Moudon et al., 2005; Pucher and Buehler, 2006; Zahran et al., 2008; Parkin et al., 2007; Zhao, 2013).

The results of these surveys are extremely useful in designing cycle networks, but they cannot offer a complete answer to the following question: 'What is the optimum location in which to develop new cycle facilities?' Few recent studies have sought to answer this question, aiming to utilise demand-based approaches to determine priorities for cycle network planning. In a study for Milwaukee, Wisconsin, Rybarczyk and Wu (2010) developed a 'Demand Potential Index' (DPI) of bicycle facilities incorporating six factors (crime, businesses, schools, recreation areas, parks, and population) that could potentially affect demand for cycling. The selection and ranking of the factors were based on the researchers' personal experience, previous literature, the Wisconsin Bicycle Guidance Handbook, and interviews with personnel from the Bicycle Federation of Wisconsin and the Wisconsin Department of Transportation. Multicriteria analysis was then applied to estimate the DPI for each road segment. The demand indicator was also aggregated at a neighbourhood level, aiming to assist citywide planning on a greater geographic scale. In a second study for Montreal, Canada, Larsen et al. (2013) developed a 'Prioritisation Index' (PI) for cycling infrastructure investments that considers five factors: observed bicycle trips; potential bicycle trips (that could replace short car trips); suggestions by cyclists for specific segments of bicycle paths; bicycle-vehicle collision data; and the presence of 'dangling nodes', namely, bicycle facilities that end abruptly. Four of the five factors were first aggregated at 300-m grid cells and were then summarised for each cell to provide the PI. All factors were given equal weight. The fifth factor ('dangling nodes') was not used in the PI, but was used in subsequent visual analysis. The final result included the locations with the highest priority for new bicycle facilities and specific recommendations for cycling infrastructure interventions in several zones of the city of Montreal.

Although both studies suggest comprehensive cycle network planning methodologies, they did not adequately incorporate the views of end users, i.e., the cyclists themselves. In the first study, it is indicated that some interviews with cyclists were conducted during the selection and ranking of the possible demand factors (especially commercial business), but no further details regarding the methods and results of the interviews are provided. Moreover, the simple additive weighting method that is used to integrate all demand factors does not reflect real differences between factors. Weights in this case are calculated through a normalising weighting function that simply reflects a predefined ranking order of the factors, which was primarily based on researchers' personal experience, literature, and interviews with Wisconsin officials. In the second study, the views of cyclists are confined to proposals for the development of cycle infrastructure on certain road sections. These suggestions were aggregated and summarised with three other factors in the PI using equal weights. The researchers recognise the limitations of their methodology in using the same weighting for the planning criteria, but conclude that decisions regarding the relative importance of each criterion must be made by the analyst/planner.

We believe that the relative importance of each of the factors included in a cycle network planning methodology should be decided by the end users (cyclists). The unique relationship that cyclists develop with the bicycle itself, their co-cyclists, the facilities, and the urban environment for sensory, kinaesthetic, symbolic, or even political reasons (see Spinney, 2009, for a review of the 'immaterial' embodied and sensory aspects of cycling mobility, van Duppen and Spierings, 2013 for an exploration of the ways urban environments are sensed by cyclists, and Gatersleben and Uzzell, 2007, for a discussion of the affective aspects of commute cycling in comparison to other means of transport) may contribute to a design that is more efficient and closer to user needs and desires. To this end, we propose a comprehensive four-step methodology for cycle network planning, which both accounts for the city structure and the zones in which higher cycling demand is possible and incorporates the views of cyclists with respect to choosing the cycle network segments. The methodology involves multicriteria analysis with deliberation and the help of GIS software for the quantification and mapping of urban and road environment characteristics. The Athens metropolitan cycle network formed our case study, in which a total of 36 cycle routes (226 km in length) were proposed as part of the new master plan of the city.

The remainder of the paper is structured as follows: Section 2 describes the urban and transport contexts of Athens with an emphasis on cycling infrastructure and policies; Section 3 describes our methodology, step-by-step application, and outcomes; and finally, Section 4 offers a discussion and conclusions regarding both the methodology and results pertaining to the Athens metropolitan cycle network.

2. Study area

The metropolitan area of Athens, the largest urban area in the country (3,537,000 inhabitants; El. Stat., 2011), hosts 32.7% of the Greek population. This area has a hierarchical system of centres with approximately 20% of the population living, and 30% working, in the municipality of Athens. Several other secondary centres are developed in the north, south, and west (see Fig. 1 – top), and smaller centres are scattered throughout the city. The arterial network follows a radial form, and the remainder of the road network is characterised by irregularities reflecting the historical weaknesses and inconsistencies of land use and transportation planning (see Milakis et al., 2008). Although Athens has high population densities and a variety of land uses, the share of cycling trips remains at low levels (0.9%, OASA, 2007a) contrary to what we would theoretically expect (see Heinen et al., 2010). These low levels primarily result from the lack of infrastructure for cycling. According to a recent study in the third largest city of Greece (Patras), the Greeks' intention to cycle was found to be high, but a lack of infrastructure appeared to be the main deterrent for cycling, especially for women and older age groups (Milakis, in press).

Indeed, although there have been major investments in the public transport system of Athens during the last 20 years and especially on the occasion of the 2004 Olympic Games (Karlaftis et al., 2004; Frantzeskakis and Frantzeskakis, 2006), there has been no similar interest in cycle infrastructures. Any attempts to develop cycling facilities to date have been isolated, primarily stemming from local municipal initiatives, as no central strategy for cycling and sustainable mobility exists. This lack of strategy has resulted

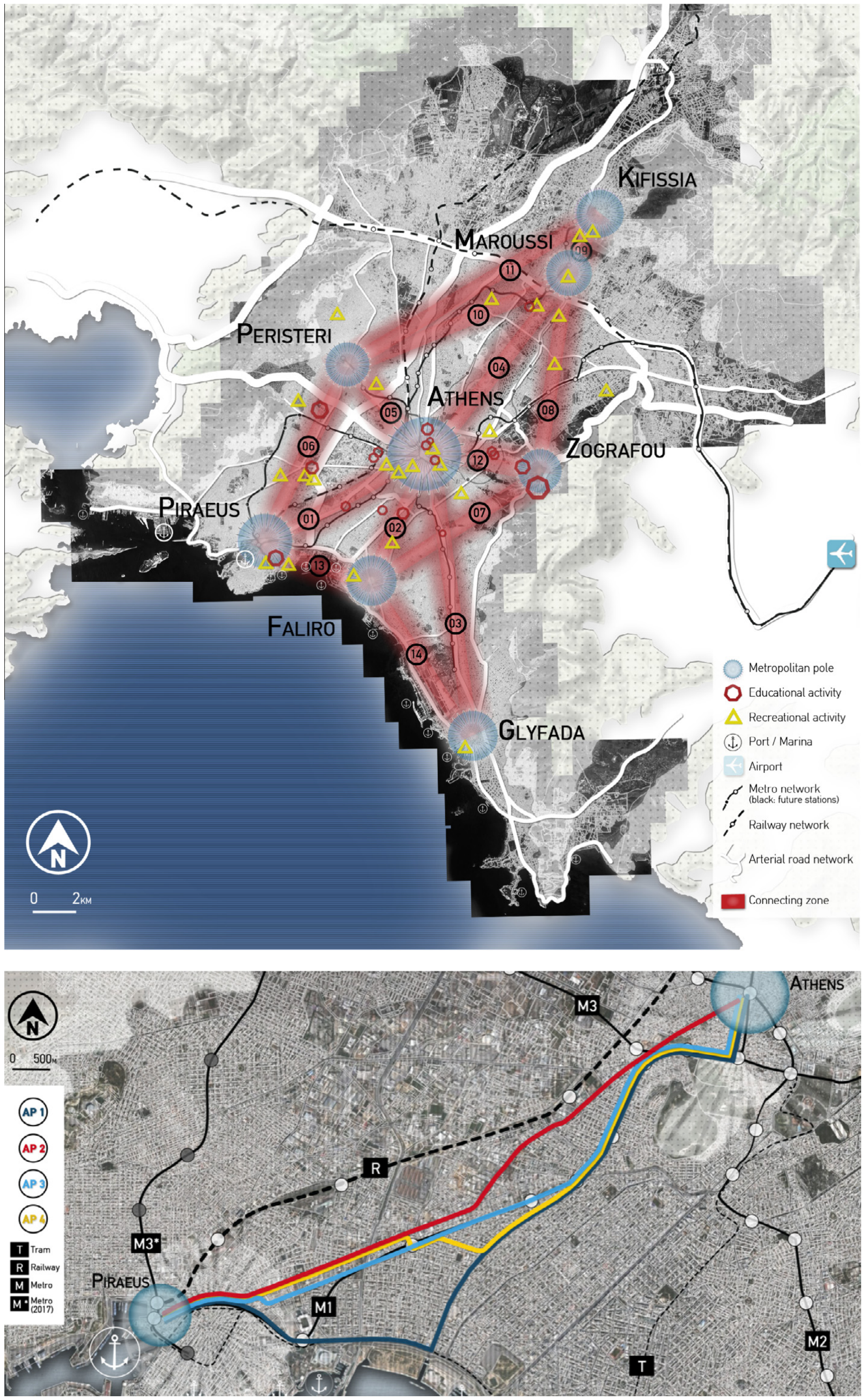

Fig. 1. (Top) The eight metropolitan poles, the 14 connecting zones where cycle routes scenarios were developed, and the spatial distribution of the educational and recreational activities. (Bottom) An example of four cycle route scenarios between the centres of Athens and Piraeus.

in a heavily fragmented cycle network in Athens (see Fig. 2 – left), consisting of 48.6 km of cycle routes scattered in 16 primarily regional municipalities (approximately 3 km of cycle route per municipality), with the longest route not exceeding 7.1 km and the shortest route being only 0.2 km. It also worth noting that the central municipality of Athens, with a population of 664,000 residents, has absolutely no cycling infrastructure. With 5.5 km of cycle routes and lanes per 100,000 inhabitants, Athens appears to be more akin to the US (e.g., Chicago, 9 km, or San Francisco, 15 km of cycle infrastructures per 100,000 inh.), Canadian (e.g., Toronto, 12 km per 100,000 inh.), or Australian (e.g., Sydney, 15 km per 100,000 inh.) examples than to those of northern European cities (e.g., Berlin, 33 km, Amsterdam, 61 km, or Copenhagen, 80 km per 100,000 inh.) (data from Buehler and Pucher, 2012b).

However, during the last five years, especially since the outbreak of the financial crisis, there are signs that cycling demand

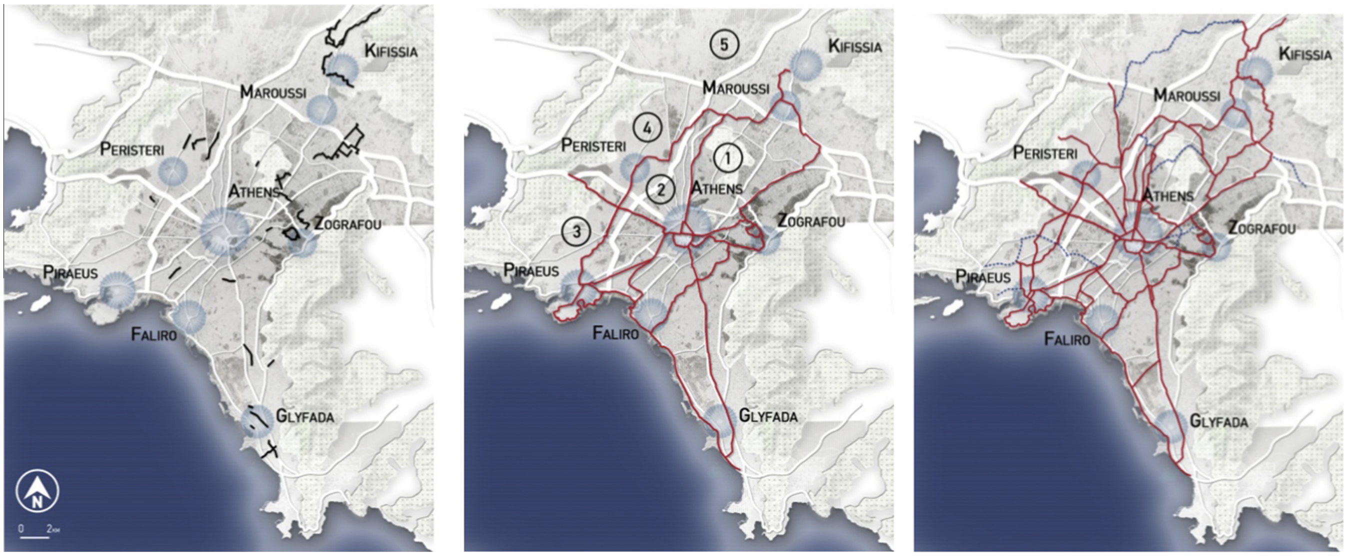

Fig. 2. The existing, heavily fragmented, cycling facilities in Athens (left), the draft cycle network plan after the application of the participative multicriteria analysis in 46 cycle route scenarios (middle, the numbers represent areas with poor spatial coverage) and the final map of the metropolitan cycle network after the spatial coverage assessment (right, phase A – continuous red line; phase B – dashed blue line).

has grown significantly. Bicycle imports have increased by 7% over the period from 2007 to 2011 (El. Stat., 2012), and Greeks appear to be particularly concerned with car use and maintenance costs (e.g., petrol, tolls, and road taxes), combined with a more positive attitude towards the environment and realisation of car-related problems (see Milakis, in press). This growth in demand is also reflected by the recent strong involvement of social groups, especially younger age groups, who have been supporting cycling through social media, events, and demonstrations, insisting that the central government develop bicycle infrastructures.

3. Methodology application and results

Our aim was to propose a legible, functional, safe, and pleasant metropolitan cycle network for Athens while avoiding a strictly top-down, expert led approach. Therefore, the views of cyclists were integrated into specific methodological procedures, contributing significantly to the final outcome of the project. Our methodology comprised four successive and interrelated steps. First, we identified the key metropolitan poles as nodes of the cycle network. Then, we developed cycle route scenarios linking the nodes of the cycle network. In the third step, we evaluated the cycle route scenarios and selected the optimal scenarios based on participative multicriteria GIS methods. Finally, in the fourth step, we assessed the spatial coverage of the cycle routes and finalised the metropolitan cycle network plan.

3.1. First step: identification of key metropolitan poles

The aim of the first step was to identify the major urban poles of Athens as the nodes of the metropolitan cycle network. Eight poles were detected based on criteria such as the following: (a) the spatial allocation of specific land uses (retail, offices, education, and leisure) that could generate/attract large numbers of cycling trips, (b) the OD matrices for total trips from the two most recent travel surveys in Athens (AM-DPGS, 1997; OASA, 2007b), and (c) the hierarchical network of centres as indicated in the Master Plan of Athens (OJHR, 1985). Obviously, this method provides a rough estimation of the potential generation/attraction poles for cycling trips. However, as the share of cycling trips in Athens is lower than 1% of total trips and as we did not have detailed OD data on these trips, the most significant urban centres appear to be good approximations of the potential main generation/attraction poles for cycling trips.

The zones connecting the metropolitan poles were defined as the areas along which specific cycle route scenarios could be developed (see Fig. 1). A maximum width of 1.5 km was attributed to each zone, thus ensuring that cycle route scenarios would meet the criterion of directness for all pairs of poles. Our objective was to make all possible connections between the major poles, unless topography or other local barriers (e.g., major brownfield sites) did not allow it. For example, we did not connect the two south-eastern poles (Zografou and Glyfada) because of the steep slopes of the road network. In total, 14 such zones were identified (see Fig. 1 – top). We subsequently conducted a closer examination of the extent to which specific categories of urban activities of special interest to cyclists were located within the zones. According to the results, the percentage rate of the urban activities found within the zones varies between 50% and 94%, with critical activities such as universities, shopping centres, and cultural poles showing high rates (see Table 1).

3.2. Second step: development of cycle route scenarios

In the second step, we developed cycle route scenarios within the 14 zones that were defined in the previous step. In a broad zone of 1.5 km, more than one alternative cycle route could be identified; thus, we followed some basic planning principles related to safety, directness, and comfort to define the initial cycle route scenarios. Additional scenarios were derived from the Greek Cyclists Organisation's early experiential cycle route proposals in Athens (Greek Cyclists, 2008). Specifically, if such a proposal existed for a specific connecting zone, then it was automatically identified as a cycle route scenario. Moreover, modifications of existing scenarios or even suggestions for new scenarios were derived from the experienced cyclists who participated in the focus group (see next paragraph). Fig. 1 (bottom) presents the four cycle route scenarios for the most important pair of poles connecting the centre of Athens and Piraeus. The blue cycle route is developed along the coastline (Greek Cyclists Organisation's proposal), the red route follows a major road artery (our research team's proposal), the

Table 1
The percentage rate of urban activities (with special interest for cyclists) found within the 14 zones connecting the key metropolitan poles (see Section 3.1) and the weights assigned to each activity type for the estimation of the accessibility to activities criterion (see Section 3.3.1).

Urban activities	Universities	Shopping centres (malls)	Cultural poles	Ministries	Linear centres	Entertainment zones	Parks/ open spaces	Hospitals	Metro & railway stations	Sports facilities
Percentage rate of urban activities located within the zones connecting the key metropolitan poles	94%	86%	83%	82%	72%	69%	65%	55%	54%	50%
'Accessibility to activities' weights	10	6	5	1	8	9	8	3	–[a]	8

[a] Accessibility to metro and railway stations was assessed as separate criterion and is therefore not included in the 'accessibility to activities' calculations.

cyan route follows a railway line (the focus group participants' proposal), and the yellow route is a synthesis of the red and cyan cycle routes proposed by our research team. Finally, 46 cycle route scenarios in 11 zones (approximately four scenarios per zone) were identified. In three zones, no alternative scenarios were defined because of geographical limitations (e.g., coastline), which also served as major advantages for a specific cycle route, particularly in the case of the connection of the three southern poles (Piraeus, Faliro, and Glyfada) along the coastline of Athens.

3.3. Third step: evaluation of the cycle route scenarios

The aim of the third methodological step was the participative evaluation of the cycle route scenarios and the selection of the optimum routes for each zone, based on specific criteria. In this manner, an initial cycle network scheme was approached. The evaluation process comprised the following: (a) the selection of the evaluation criteria based on previous literature, the research team's experience, and discussions with the experienced cyclists who participated in the focus group; (b) the quantification of the criteria for each cycle route scenario using GIS software; (c) the determination of the criteria weights by a focus group of experienced cyclists and the subsequent application of multicriteria analysis for each zone; and (d) the identification of the optimum cycle routes and the configuration of a draft plan for the metropolitan cycle network.

3.3.1. Selection and quantification of the evaluation criteria

Eleven criteria describing comfort, travel safety, directness, quality of the urban environment, and functionality were used to evaluate the cycle route scenarios. Description and calculation methods are given below and are summarised in Table 2. All data were derived from an extensive geographical information database for Athens, Greece (NTUA-SRSE, 2009), except for the location of the municipalities' centres and major urban parks (provided by the Organisation of Planning and Environmental Protection of Athens). Additional in situ inspections were necessary for the estimation of some criteria (e.g., traffic intensity and speed, natural and built environment).

Ride difficulty: this criterion describes the level of riding difficulty based on two factors: the length and slope of the cycle route. We used the sum of the products for these two factors for each cycle route section with different slopes. Previous studies (Menghini et al., 2010; Broach et al., 2012) have indicated the length and slope of a cycle route as two possible determinants of cycle route choice but did not use them in conjunction. We suggest that a cyclist's comfort depends on the length of the slope (i.e., a steep slope for a short length may be better than a moderate slope for a longer distance).

Junction density: this criterion describes the level of safety and continuity of a cycle route. Junction density was calculated as the ratio of the number of nodes to the length of a cycle route. We defined a node as the intersection of a cycle route with a road of equal or higher hierarchical level because cyclists should yield the right of way in this case. The signalised nodes were considered at the 50% level, given that at approximately half of these nodes cyclists would pass during the green period. Thus far, several studies have considered junction density to be a possible determinant of bicycle route choice (see, e.g., Stinson and Bhat, 2003; Sener et al., 2009; Providelo and Sanches, 2011; Broach et al., 2012; Winters et al., 2011).

Traffic intensity: this criterion describes the pressure and discomfort that a cyclist may feel as a result of traffic. The estimation for this variable was based on the hierarchical level of each road. Three levels of traffic volume were defined (low: 10, medium: 5, and high: 0). Motorways and primary arteries correspond to high traffic volume, secondary and collector roads to medium volume, and local roads to low volume. Traffic volume is not the only parameter used for classification of the road network. Therefore, adjustments to the traffic intensity level for specific road segments were possible based on the research team's experience and site inspections. Traffic volume has also been identified as a possible deterrent to bicycling in previous surveys (see, e.g., Sener et al., 2009; Winters et al., 2011; Broach et al., 2012; Li et al., 2012).

Traffic speed: this criterion refers to the average speed of vehicles moving next to a cycle route and therefore indicates the feeling of insecurity that cyclists feel as a result of this speed (see also Sener et al., 2009; Providelo and Sanches, 2011; Winters et al., 2011). Three levels of traffic speed were defined (low: 10, medium:

Table 2
Calculation methods and descriptive statistics for the 11 unnormalised evaluation criteria for the cycle route scenarios.

Criterion	Calculation method	Mean	SD
Ride difficulty	$\sum_1^n L_i S_i$	0.24	0.12
Junction density	$\frac{\#\text{nodes}}{\text{cycle route length (km)}}$	2.35	0.62
Traffic intensity	$\sum_1^n L_i T_i / \sum_1^n L_i$	4.75	2.57
Traffic speed	$\sum_1^n L_i V_i / \sum_1^n L_i$	4.55	2.01
Legibility	$\frac{\#\text{directional changes}}{\text{cycle route length (km)}}$	1.11	0.54
Natural environment	$\sum_1^n L_i N_i / \sum_1^n L_i$	2.80	1.58
Built environment	$\sum_1^n L_i B_i / \sum_1^n L_i$	2.25	2.55
Accessibility to activities	#Urban activities within 250 m zone from the cycle route	7.20	4.76
Centrality	#Urban centres within 500 m zone from the cycle route	4.04	1.50
Accessibility to urban parks	#Urban parks	0.84	0.80
Accessibility to metro/ railway stations	#Stations within 250 m zone from the cycle route	5.92	3.64

i: The number of cycle route sections.
L_i: The length of cycle route section i in km.
S_i: The slope of cycle route section i.
T_i: The traffic intensity next to cycle route section i. Measured as low: 10, medium: 5, and high: 0.
V_i: The traffic speed next to cycle route section i. Measured as low: 10, medium: 5, and high: 0.
N_i: The presence of natural elements along the cycle route section i. Measured as important: 10, medium: 5, and little importance: 0.
B_i: The quality of the built environment along the cycle route section i. high: 10, medium: 5, and low: 0.

5, and high: 0) based on the hierarchical level of the road. Motorways and primary arteries correspond to high traffic speed, secondary and collector roads to medium speed, and local roads to low speed. As with traffic volume, adjustments to traffic speed level for specific road segments were possible based on the research team's experience and site inspections.

Legibility: this criterion describes how easily a cycle route is mentally imprinted in the minds of cyclists. High legibility makes a route more user-friendly and makes cyclists less dependent on technical assistance (e.g., maps, GPS). We calculated this criterion as the ratio of the number of directional changes (deviation from a straight line) to the length of the cycle route. Broach et al. (2012) have similarly identified directional change as a possible deterrent to the use of a bicycle facility.

Natural environment: this criterion describes the degree of the presence of natural elements (e.g., streams, coastline, forests, urban parks) along a cycle route. Beyond aesthetic pleasure, the presence of trees and green spaces has a positive effect on the comfort of cyclists, especially in hot climates (see also Providelo and Sanches, 2011; Winters et al., 2011). Three levels of contact with natural elements were defined (important contact/next to large urban parks, streams, coastline, and forest: 10; medium contact/ beside small urban parks or streets with dense hedgerows: 5; or little contact/along a road with no or minimal presence of green spaces: 0).

Built environment: this criterion describes the quality of the architectural environment along a cycle route. Three levels were defined based on our research team's evaluation (cycle routes in high-quality architectural environments, including historic buildings, well-designed street furniture, and architectural landmarks: 10; cycle route in medium-quality architectural environments including pedestrian and traffic calmed streets: 5; or cycle routes in low-quality architectural environments, i.e., roads with no or minimal visual stimuli: 0).

Accessibility to activities: this criterion refers to the number and type of urban activities served by a cycle route and is consistent with the concept of 'busy neighbourhoods' as possible cycling motivators according to Moudon et al. (2005). We calculated how many urban activities fall into a buffer zone of 250 m from the cycle route and then assigned weights (on a scale of 1–10) to the various urban activity types, providing bonuses to those of high interest for cyclists (see Table 1).

Centrality: this criterion indicates the number of urban centres served by a cycle route. We first identified the location of the centre for all 83 municipalities in the Athens' metropolitan area and then calculated how many of them fall into a buffer zone of 500 m from the route. We decided to extend the buffer zone from 250 m of the accessibility to activities criterion to 500 m, as municipal centres may offer greater attraction to cyclists because of the higher intensity of activities.

Accessibility to urban parks: this criterion describes the number of urban parks (suitable for cycling) that a cycle route approaches. All parks with cycling facilities or areas designated for cycling were included in this criterion.

Accessibility to metro/railway stations: this criterion describes the number and type of metro and railway stations that a cycle route serves. We assumed that a higher number indicates greater possibilities for bike and ride trips (see also Martens, 2004). We calculated the number of stations that fall into a buffer zone of 250 m from the cycle route and then assigned weights to the various stations based on their hierarchical level (metropolitan: 1.5, regional: 1.0, and local: 0.5).

The values of all 11 criteria were calculated for 46 cycle route scenarios using GIS software and normalised using a simple linear value function to allow for comparisons among them (see Eq. (1)).

$$v'_{ij} = (v_{ij} - v_{\min}/v_{\max} - v_{\min})100 \tag{1}$$

where v'_{ij} and v_{ij} are the normalised and original value respectively for criterion i and cycle route scenario j, and $v_{\min}$ and $v_{\max}$ are the minimum and maximum value for criterion i. Each criterion can take values from zero to 100. A higher value indicates a more positive criterion for cyclists (e.g., a more comfortable ride, better accessibility to activities).

Descriptive statistics for all unnormalised criteria are presented in Tables 2 and 3 shows the scores for the four cycle route scenarios of the Athens–Piraeus example. According to the results, the AP1 cycle route scenario (along the coastline) has, as expected, a comparative advantage regarding traffic intensity (83), traffic speed (68), and contact with the natural environment (42) but not with regard to ride difficulty (70), built environment (36), and centrality (50). The AP2 scenario, which follows a major road artery, appears to be the most comfortable and legible route (ride difficulty-88 and legibility-100, respectively); however, it yields zero scores for traffic intensity and speed and for contact with natural elements. The AP3 scenario (cycle route along the railway line) offers good scores for centrality (64) and accessibility to metro/ railway stations (81) but shows the lowest score for the built environment criterion (35). Finally, the AP4 scenario, which is a combination of the two immediately preceding scenarios, exhibits moderate scores for ride difficulty (81) and contact with the natural environment (23) but a low score for legibility (48). None of the cycle route scenarios approaches an urban park that is suitable for cycling; therefore, all of them score zero on that criterion.

3.3.2. Criteria weighting and multicriteria analysis

Although multicriteria methods have been used extensively in the transportation context (Giuliano, 1985; Schwartz and Eichhorn, 1997; Yedla and Shrestha, 2003; Tudela et al., 2006; Macharis et al., 2009; Chow et al., 2013), only limited applications can be found thus far in cycling mobility research (see Rybarczyk and Wu, 2010). In the case of the Athens metropolitan cycle network, we applied deliberative multicriteria analysis to identify the optimum cycle route scenarios. One of the most critical issues in multicriteria analysis is the criteria weighting process. In our case, we decided to allow the prospective users of the cycle network choose the weights in the framework of a participatory planning approach. To this end, we established a focus group comprising three members of the research team and 10 experi-

Table 3
The scores of the 11 evaluation criteria (1–100 scale) for the four alternative cycle route scenarios for the Athens-Piraeus zone (see also Fig. 1 – bottom).

Cycle route scenarios in the Athens – Piraeus (AP) zone	Length (km)	Ride difficulty	Junction density	Traffic intensity	Traffic speed	Legibility	Natural environment	Built environment	Accessibility to activities	Centrality	Accessibility to urban parks	Accessibility to metro/ railway stations
AP1 (blue)	10.30	70	66	83	68	55	42	36	66	50	0	81
AP2 (red)	7.89	88	65	0	0	100	0	100	58	57	0	15
AP3 (cyan)	9.19	79	62	83	56	61	27	35	55	64	0	81
AP4 (yellow)	9.01	81	53	67	59	48	23	61	65	57	0	58

Table 4
The socio-demographic profile of the Athenian cyclists based on a sample of 428 respondents in a web survey.

Gender	%	Age	%	Education	%	Job	%	Cycle use	%
Male	83.7	<24	14.7	Primary	0.0	Employee	57.0	Every day	43.2
Female	16.3	25–34	48.8	Lower secondary	0.8	Employer	10.3	Once a week	47.4
		35–44	26.9	Higher Secondary	15.4	Self-employed	10.3	Once a month	5.6
		45–54	7.2	Higher Tech. educ.	17.5	Student	17.1	Rarely	3.8
		>55	2.4	Tertiary	30.1	Retired	0.9		
				MSc	29.7	Currently unemployed	3.0		
				PhD	6.5	Other	1.4		

Table 5
The results of the multicriteria analysis for the Athens–Piraeus zone based on cyclists' individual (left) and group weights (right). The highest scores are bolded.

Cycle route scenarios in the Athens–Piraeus (AP) zone	Cyclist 1	Cyclist 2	Cyclist 3	Cyclist 4	Cyclist 5	Cyclist 6	Cyclist 7	Cyclist 8	Cyclist 9	Cyclist 10	Group
AP1 (blue)	**57**	**59**	**58**	**53**	**58**	59	**58**	**55**	**60**	**53**	61
AP2 (red)	40	49	37	37	47	57	49	52	41	47	58
AP3 (cyan)	55	58	55	52	**58**	**60**	57	**55**	58	**53**	**62**
AP4 (yellow)	53	55	53	48	54	57	54	52	55	49	59

enced cyclists. We defined experienced cyclists as those who used bicycles as their main mode of transportation for the last two years. The Greek Cyclists Organisation assisted us in recruiting a purposive sample of experienced cyclists among its members. Apart from cyclists' experience, no other criterion, including prior knowledge or intuition about the evaluation metrics, was used to select our subjects. The participants in our workshop comprised of eight men (80%) and two women (20%), most of whom were under 44 years old (four participants 25–34, five participants 35–44, 90% in total) and highly educated (eight participants had at least a bachelor's degree, 80%). The sample is representative of the regular cycle users in Athens. Their socio-demographic profile was identified through a web survey conducted via the Greek Cyclists Organisation's website, since no such data was available for cyclists in Athens. We collected 428 responses in total and we found that regular cyclists (those who use their bicycle every day or at least once a week, 90.6% of the respondents) who participated in our survey are predominantly young (under 44 years of age, 90.4%), highly educated (at least a bachelor's degree, 83.8%) male (83.7%), employees (57.0%) (see Table 4).

In typical participative multicriteria methods, such as the multi-attribute utility (see Dyer et al., 1992; Wallenius et al., 2008), and the more recent deliberative mapping (Davies et al., 2003), participants reach a consensus regarding the weights after several rounds of discussions. In our case, consensus weights were reached after two meetings over consecutive days. In the first meeting, the research team presented and explained the evaluation criteria individually. Subsequently, a discussion session between members of the research team and the cyclists occurred to clarify the logic of each criterion. In the next step, the research team distributed a printed form regarding the assignment of weights on a 1–10 scale and a document summarising each criterion. Detailed instructions were provided for the completion of the form, with special emphasis on the metrics of the weighting scale. Based on the results of individual weighting, we calculated each cycle route scenario score per cyclist using a weighted additive value function (see Eq. (2)). The optimum cycle route for each zone was the route that was rated higher among the alternatives by most cyclists. For example, in the case of the Athens–Piraeus zone, the AP1 scenario was the optimum route based on individual weights, receiving the highest score from 9 out of 10 cyclists in the focus group (see Table 5).

$$S_j = \sum_{i=1}^{n} W_i v'_{ij} \tag{2}$$

where S_j is the score for cycle route scenario j, w_i is the individual weight assigned to criterion i, and v'_{ij} is the normalised value for criterion i and cycle route scenario j.

In the second meeting the following day, the optimum cycle route scenarios were presented to the cyclists on a Google Earth platform to help them make a direct mental connection between their weighting choices and 'real' planning outcomes. A discussion moderated by a member of our research team ensued on all optimum routes, and cyclists were then asked to reach a consensus for the final group weights. According to the results, the cyclists consider ride difficulty, junction density, legibility, and centrality to be the most important criteria, whereas traffic intensity and speed were assessed as being much lower in importance (see Table 6). Furthermore, contact with the natural environment and access to urban parks and metro/railway stations appear to play a minimal role for cyclists with regard to the metropolitan cycle network. Under the new 'group weights', scores for each cycle route scenario were re-calculated to provide the final optimum route per zone. Interestingly, in our example for the Athens–Piraeus zone, the optimum cycle route scenario switched from AP1 for individual weights to AP3 for group weights. Therefore, the cyan cycle route that follows the railway line was finally incorporated into the draft cycle network scheme.

3.4. Fourth step: spatial coverage assessment and final selection of the metropolitan cycle routes

In the fourth and final methodological step, we sought to detect and cover any poorly served areas from the draft cycle network. To this end, we applied a buffer analysis in a 500 m zone along the draft cycle network, which means that a cyclist could approach a network branch in less than five minutes with an average speed of 17 km/h. We identified five main areas with low accessibility to the cycle network (see Fig. 2 – middle) and examined whether any of the cycle route scenarios that had been rejected initially or any of the Greek Cyclists Organisation's experiential cycle route proposals would be appropriate to serve these areas. If such a cycle route did not exist, then we designed a supplementary cycle route segment. The final network consisted of 36 cycle routes totalling 226 km in length to allow the majority of Athenians to reach a network branch in less than five minutes. The cycle routes were also categorised according to their implementation priority, based on the aims of (a) obtaining an integrated and functional network, fulfilling the criterion of continuity (or arteriality, according to

Table 6
The final group weights of the evaluation criteria.

	Ride difficulty	Junction density	Traffic intensity	Traffic speed	Legibility	Natural environment	Built environment	Accessibility to activities	Centrality	Accessibility to urban parks	Accessibility to metro/ railway stations
Group weights	10	10	6	5	9	3	6	5	7	1	3

Marshall, 2005) from the beginning; (b) prioritising central over regional cycle routes; and (c) avoiding the inclusion of any two neighbouring cycle routes in the second network development phase. Several other parameters, not considered in our study, could affect the implementation priority of the cycle network segments (e.g., cost, impact on road traffic). Finally, 24 cycle routes totalling 180 km in length were included in the first phase, and 12 routes totalling 46 km in length were included in the second phase (see Fig. 2 – right).

4. Discussion and conclusion

The bicycle is gaining ground as an inexpensive, fast, healthy, and enjoyable means of transport in urban areas. The development of cycle infrastructures appears to be one of the most critical factors for the 'massification' of its use. Thus far, research interest has focused primarily on investigating (a) the route choice criteria of cyclists and (b) the factors affecting bicycle use. Few studies have developed comprehensive methodologies for the prioritisation of cycling infrastructure investments, and the role of end users has been underestimated within this process. We propose a comprehensive four-step methodology for cycle network planning that both accounts for the city structure and the zones allowing for higher cycling demand and it incorporates the views of cyclists with respect to choosing the cycle network segments. Our case study was Athens, Greece, a city with few heavily fragmented cycle facilities today; however, cycling demand in Athens has recently grown both for economic reasons and because of a greater popular awareness of the problems caused by excessive car use.

In the first two steps of our methodology, we identified the nodes of the metropolitan cycle network and developed cycle route scenarios connecting them in pairs. Given the lack of detailed OD data for cycling trips, we proceeded with a rough estimation of the potential cycling trip generation/attraction poles based on land use data, the existing master plan of Athens, and OD data for total trips. We strongly believe that cycling trip data can contribute to more precise estimations in this methodological step, especially in cities with higher rates of cycling. Therefore, our methodology would greatly benefit from future travel surveys that include detailed information on bicycle trips. In the second step of the methodology, we suggested no limitation on the number of cycle route scenarios as long as certain basic criteria are met for their drafting (e.g., safety, directness, comfort). However, we would strongly recommend a fair balance between the number of the cycle route scenarios proposed by the design team on one side and cyclists on the other to ensure that selection possibilities remain similar between them. It is particularly important that the design team seeks existing cyclist proposals. It is highly possible that such proposals exist in every city.

The third and fourth steps formed the core of our methodology, comprising the participative evaluation of the cycle route scenarios, the selection of the optimum routes for each zone based on specific criteria, and the finalisation of the metropolitan cycle network plan. A total of 11 evaluation criteria were selected based on previous literature, discussions with cyclists, and the specific characteristics of Athens. For example, ride difficulty, traffic intensity, and junction density were considered crucial for the case of Athens given the hilly topography, the high congestion levels, and the small blocks, and hence the large number of intersections along a route. Additional or even fewer criteria could be used in other cities based on local urban and transport characteristics.

We chose to invite experienced cyclists to rate the evaluation criteria because we considered it necessary that the participants have an experiential background of the sensory, kinaesthetic, and symbolic factors associated with bicycling. Thus, we believe that we can ensure a more harmonious relationship between all aspects of the cycling experience and the proposed infrastructure to serve it. Whether or not cycling frequency affects route choice preferences has been addressed in existing literature without definitive conclusions. According to Sener et al. (2009), route choice criteria that are extracted from surveys among regular cyclists may suffer from the 'road warrior' mentality bias. However, in their study of Portland, Oregon, Dill and Gliebe (2008) found that cycling regularity did not significantly influence the relative ranking of the route choice criteria, although average ratings differed between the groups of experienced and inexperienced cyclists.

The final group weights were reached after a dynamic two-day deliberation process. During the workshops, the cyclists had the opportunity to interact with the research team and with their co-cyclists in the group, requesting more information, further explanations, or clarifications on any of the workshops topics (e.g., evaluation criteria, weight-form metrics). The cyclists had also the opportunity to make direct mental connections between their weighting choices and 'real' planning outcomes on the Google Earth platform. All of these procedures allowed the cyclists to deeply understand both the scope and criteria of the cycle route scenarios evaluation before reaching consensus regarding the weights. According to Savage (1971), education and training prior or even during the application of elicitation techniques could help reduce potential biases in the responses. Interestingly, the optimum cycle route scenario in our example differed based on individual and consensus weights, reflecting the dynamics of the rate assignment process.

According to the consensus weights, the cyclists rated ride difficulty, junction density, legibility, and centrality as the most important criteria, whereas traffic intensity and speed were assessed as being much less important. Contact with the natural environment and access to urban parks and metro/railway stations did not play an important role for the cyclists. These results are consistent with the findings of previous studies showing that steep slopes (Aultman-Hall et al., 1997; Sener et al., 2009; Menghini et al., 2010; Broach et al., 2012; Li et al., 2012) and the number of intersections (Sener et al., 2009; Providelo and Sanches, 2011) have a negative influence on cycle route preferences. However, other findings are not consistent with our results. For example, several studies have shown that contact with green areas along a cycle route (Providelo and Sanches, 2011; Winters et al., 2011) or traffic volume (Aultman-Hall et al., 1997; Li et al., 2012) are important route choice criteria for cyclists. One possible explanation for these differences is that in our case, the metropolitan character of the cycle network with dedicated facilities significantly influenced the criteria ratings. Cyclists appear to prefer the metropolitan cycle routes that offer fast, direct, and safe movement to the detriment of the qualitative characteristics of a cycle route, such as the attractiveness of the urban environment. Cyclists also consider that the main objective of a metropolitan cycle network is to serve utilitarian rather than recreational needs. As one cyclist (male, 33) stated in our workshop, '*for recreational purposes, I would not choose the metropolitan network, but a city park*'. A second cyclist (female, 28) noted as follows: '*The best route for me is one that allows me to reach my destination with closed eyes, effortlessly and safely*'. These options favoured cycle route scenarios in central arteries and downgraded longer routes on secondary axes, even if the urban environment there was better. Straight routes at relatively short distances from major urban centres were also prioritised in selection. Similarly, cyclists in Montreal, Canada, suggested that future cycle facilities primarily follow busy arterials (Larsen et al., 2013). On the contrary, arterial roads received lower grades and residential streets higher grades as potential cycle axes in the case of Milwaukee, Wisconsin, when researchers applied the bicycle level of service (BLOS) method, which ranks streets according to engineering-type criteria and focuses on travel safety, such as speed limit, heavy truck traffic, and road width.

As cycling demand grows, it becomes increasingly necessary to develop comprehensive methodologies to optimally determine areas for the development of future cycle infrastructure. This infrastructure translates into cycle facilities that offer a return on investment cost by attracting the largest possible number of cyclists. To achieve this objective, we believe that the views and experiences of cyclists should be a structural component of the design process. Our method offers a balanced approach between an objective method of spatially determining cycling demand and a participatory approach for selecting the final cycle routes. This method will be evaluated after the construction of the project based on the number of users. Meanwhile, we are encouraged that cyclists have disseminated our research results to the wider public through their website, web forums, social media, newspapers, and public discussions, believing that they have decisively contributed to the design of the new cycle network of their city.

Acknowledgements

This research was funded by the Organisation of Planning and Environmental Protection of Athens. Earlier versions of this paper were presented at the Transport Research Arena Conference in Athens, Greece (April 2012), at the Institute of Urban and Regional Development, UC Berkeley (February 2013) and at the Institute of Transportation Studies, UC Davis (May 2013), so this version has greatly benefited from the audiences' comments. The authors would like to thank the 10 cyclists who participated in the workshops, Thanos Vlastos for his valuable contribution to this research, Evangelos Vafeiadis, Konstantinos Vasileiadis and George Nathenas for their research assistance, Bert van Wee and Thijs Dekker for their comments on a previous version of this paper and Athanasios Athanasopoulos for his assistance with the maps in this paper. The authors alone are responsible for the views expressed in this article and any other shortcomings.

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