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# Walking and cycling friendliness as proxies to retrofit active transport infrastructure

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**Active transport modes, such as walking and cycling, have been promoted by scientific studies and policymakers due to congestion-reduction and health benefits, and low environmental impact. However, adequate infrastructure is necessary for citizens to exercise their choice for those modes. This article presents a case study on the active mode infrastructural condition of a city which, as many others, privileged motorized modes in its growth during the 20th century. Using walking and cycling friendliness as evaluators of the infrastructural condition and a Geographic Information System environment as the calculational tool, an accessibility-based analysis was carried out that enables policymakers to identify the main issues affecting those modes and, most importantly, to pinpoint specific problems that are common to both modes. The methodological approach is scalable to any city size and is a decision-aid tool that can provide value mainly by identifying those common problems which can be efficiently addressed in future infrastructural improvements and maintenance actions. For the case study, common problems turn out to lay along large, distributor roads which fail to provide active travellers with adequate safety from traffic. Based on the results, a concrete intervention plan is proposed, for which a cost-benefit analysis was carried out.**

**Keywords:** town & city planning/transport planning/UN SDG 9: Industry, innovation and infrastructure/UN SDG 11: Sustainable cities and communities/walking & cycling

**1. Introduction**

The promotion of active transport modes, such as walking and cycling, has been a growing concern of many policymakers ever since it became clear that the current status-quo of widespread individual motorized travel could not be sustained long-term, for reasons of both efficiency and environmental impact (Huang *et al.*, 2022; Neves and Brand, 2019; Roman, 2022; Woodcock *et al.*, 2009). The scientific literature has contributed to the positive image of active modes by proving that they grant health benefits to users (Cieřla and Macioszek, 2022; Conceiçao *et al.*, 2023; de Nazelle *et al.*, 2011; Doorley *et al.*, 2019; Rissel, 2009; Rojas-Rueda *et al.*, 2013), reduce congestion (Litman, 2022; Rissel, 2009; Tight, 2016; Wang *et al.*, 2008), and have virtually no greenhouse gases emissions (Both *et al.*, 2022; Rissel, 2009). But promotion might not be enough to achieve higher shares of active modes, as the convenience of the automobile, and in some cases the social image it passes, are powerful magnets towards this mode (Faherty and Morrissey, 2014; Pisoni *et al.*, 2022). Thus, if

active mode shares in line with their potential, of circa 50% or higher (Monteiro *et al.*, 2023), are to be reached and maintained, constant investment in walking and cycling infrastructures will be necessary (Conceiçao *et al.*, 2023; Litman, 2022), as such investments do lead to active mode share increases (Buehler and Dill, 2016) (Song *et al.*, 2017). Indeed, cities such as Amsterdam or Copenhagen, which have invested heavily in active mode infrastructure, now have high active mode shares (Dixon *et al.*, 2019), close to their theoretical potential (Monteiro *et al.*, 2023).

However, owing to decades of cheap fuel and road investments in the 20th century, cities have often neglected active modes in favour of motorized modes and are now facing the need to adapt their transport infrastructure to cater for walking and cycling. Adaptation to cycling is especially demanding, as best practices (Parkin, 2018) recommend segregating cycle traffic from motorized one due to speed differences. The same reasoning advises segregating walking from cycling. Creating adequate provisions for cycling is bound to require street space, a commodity most

cities have in short supply, thus requiring careful planning and increasing the cost of the associated construction work.

Because retrofitting a transport network infrastructure to properly accommodate active modes is expensive, and is dubious whether it can be financed with extra taxes (Panagopoulos *et al.*, 2018), complete overhauls of large urban spaces are unlikely to be carried out in the short-term, making it important for policymakers to identify which parts of the urban space are in higher need of an intervention and which aspects need to be improved. Thus, proper assessment of the actual condition of the transport infrastructure for supporting active modes is important before any retrofitting or maintenance works are planned and undertaken. Since transport networks connect origins to destinations, such assessments should go beyond a mere look at the individual components of the transport networks (e.g. network arcs) and focus on the practical impact they have on active travel, as some components are more likely to be used than others.

Following the above line of reasoning, this article presents a case study of the pre-existing condition of the active transport infrastructure of the city of Coimbra, Portugal, and its impact on active travel. The two active modes, walking and cycling, were analysed following the concept of modal friendliness (Sousa *et al.*, 2019), which is essentially the average infrastructural condition a user experiences in her trips using a given mode (see Section 2 for details). Calculations were carried out on a Geographic Information System (GIS) environment, where the friendliness concept was implemented, and the output is presented in the form of friendliness maps for each mode. By looking at those maps combinedly, problematic locations and issues can be readily identified. Based on the case study results, a concrete intervention plan was designed and a cost-benefit analysis for that plan was carried out that is also discussed. The goal of the approach is to assist decision-makers in designing infrastructural maintenance and retrofitting (M&R) plans, following the actual situation on the field, its impact on travellers' routes, and taking advantage of eventual M&R synergies between walking and cycling networks that the field situation may reveal.

## 2. Literature review

Before moving on to the methodological details, it is important to review the state of the art on active infrastructure assessment methods and how their outcomes can be explored to suggest intervention measures.

Early work on pedestrian infrastructure assessment includes (Gallin, 2001; Landis *et al.*, 2001), the literature having evolved more recently to non-compensatory methods (Sousa *et al.*, 2017), that is, methods in which poor scores in one criterion cannot be compensated by good scores in other criteria (Cinelli *et al.*, 2014), and to the inclusion of infrastructural condition on walkability indicators (Corazza *et al.*, 2016; Lwin and Murayama, 2011).

Reviews can be found in Aghaabbasi *et al.* (2018), Kellstedt *et al.* (2021) and Vale *et al.* (2016). Concerning cycling infrastructure, existing assessment methods include audit tools based on global and local characteristics of the cycling network (Hoedl *et al.*, 2010; Lowry *et al.*, 2012; Pais *et al.*, 2022; Winters *et al.*, 2013), the latest also considering non-compensatory aspects. The review of Vale *et al.* (2016) has more examples.

Some articles developed tools to analyse the two active modes (Emery *et al.*, 2003; Hoedl *et al.*, 2010), the first being a walkability and bikeability indicator. These indicators, which include infrastructural condition, can provide hints at how to improve the active transport network. However, walkability and bikeability are often (but not always) holistic concepts which go beyond considerations of infrastructural condition, making it difficult to identify a clear course of action specifically for M&R actions by municipal authorities. In practice, articles which explore the impact of infrastructural insufficiencies on daily accessibility trips and use it to design intervention strategies are very scarce, especially those combining the walking and cycling modes. This research fills that literature gap by presenting a case study that reveals typical issues which can be expected to arise when such a combined "walk + cycle" approach is pursued in the evaluation of the impact infrastructural insufficiencies and what solutions can be prescribed to foster the use of active modes in an economically efficient manner.

## 3. Methodology

The assessment of a city's walking and cycling infrastructure and its impact on accessibility requires evaluating the network condition on a per component (i.e. network arc) basis, considering engineering aspects. This evaluation yields a numeric condition score for each component, which in turn can be used to estimate the impact that component has on active trips. This approach can be operationalized using the concept of modal friendliness, which was first introduced in Sousa *et al.* (2019) and has an interpretation as the average network infrastructure condition a person experiences in trips using the respective mode. Specifying to active modes, walking and cycling friendliness are, respectively, walkability and bikeability indicators which focus on infrastructural condition and accessibility trips. Walking and cycling friendliness essentially measure the average traveller experience during accessibility trips, that is, trips from residences to interaction opportunities and vice-versa, carried out by the respective mode. The reason to focus on accessibility trips is because these form a large fraction of daily trips and are modellable in GIS. Evaluation of modal friendliness is done on a GIS environment and requires three datasets: origins, destinations, and transport network. The latter must be endowed with condition information for each component, in numeric format (one dataset per mode).

Modal friendliness is evaluated for each origin by considering origin-destination (OD) trips, by obtaining the shortest distance OD routes, and calculating the average infrastructural condition

experienced by the traveller in a two-way trip. Two-way trips are preferred, as roads with one-directional traffic may force the return trip to use a different route. However, for the walking mode, the one-way trip suffices, as both trips (towards and away) have the same route. OD trips are then weighted, based on frequency, and a friendliness score can then be obtained for each origin. This can be summarized by Equation (1):

$$1. \quad MF_i = \frac{\sum_j w_j \bar{K}_{ij}}{\sum_j w_j},$$

where

$i \in \{1, \dots, P\}$ : set of origins.

$j \in \{1, \dots, Q\}$ : closest destination of type  $j$ .

$MF_i$ : friendliness score of origin  $i$  for mode  $M$ ;  $M \in \{W, B\}$  with  $W$  = walking,  $B$  = (bi)cycling.

$\bar{K}_{ij} = \frac{K_{ij}}{S_{ij}}$ , with  $K_{ij}$  the cumulative value of the product of condition by length for all components (arcs) of the  $ij$  OD shortest two-way route and  $S_{ij}$  the total length of the  $ij$  OD shortest two-way route:

$$S_{ij} = \sum_{k \in i \rightarrow j \text{ route}} l_k + \sum_{k \in j \rightarrow i \text{ route}} l_k$$

$$K_{ij} = \sum_{k \in i \rightarrow j \text{ route}} l_k C_k + \sum_{k \in j \rightarrow i \text{ route}} l_k C_k$$

$l_k, C_k$ : length and condition of route component  $k$ .

$w_j$ : weight of destination type  $j$  (a measure of destination attractiveness/frequency).

Note that the segregation by destination type happens because most destinations are urban facilities, and it is assumed the active traveller will go to the closest facility of each type. Destinations that are not of flexible nature (e.g. jobs) require a different treatment (e.g. use of job zone analysis). However, as will be argued in Section 4.1, for the case study it will not be necessary to consider jobs. The shortest route was defined in terms of distance for this article, as network databases were readily available for this impedance. Other impedances, for example, time, could be used without loss of generality. Also, there is a high correlation between time and distance for active modes (Millward *et al.*, 2013), so either impedance can be used effectively.

The GIS implementation of Equation (1) may seem intricate, but it can be done as follows (Sousa *et al.*, 2019). The discussion

below uses the ArcGIS language, but any other GIS environment can be used, provided its network analysis tools can carry out the necessary operations.

1. Endow the mode  $M$  network dataset with length  $\times$  condition information by adding a column in the associated table with the value  $K = l \cdot C$  for each component;
2. For each origin  $i$ , use the ArcGIS network analyst Closest Facility tool to obtain shortest distance routes from  $i$  to the closest facility of type  $j$ . Set length and  $K$  as accumulation variables. The cumulative values of these variables will be respectively  $S_{ij}$  and  $K_{ij}$  for the  $i \rightarrow j$  trip (towards facility). Store them in the origins feature class associated table and repeat the procedure for the return trip,  $j \rightarrow i$  (away from facility);
3. Add a column to the origins feature class associated table and fill it with  $\bar{K}_{ij}$  using the Field Calculator tool;
4. Repeat steps #2 and #3 for each facility type  $j$ ;
5. Add a final column to the origins feature class associated table and use the Field Calculator tool to implement Equation (1). This final column contains  $MF_i$ , which can then be used to obtain statistics and draw maps.

#### 4. Case study

The city of Coimbra, Portugal, is a mid-sized city with circa 104,000 inhabitants in its central area (Instituto Nacional de Estatística, 2021) and healthcare and higher education as its main economic activities. Coimbra has grown mostly in an unrestricted way and the consequent urban sprawl led to a prevalence of the automobile, whose modal share is circa 60% of total trips (Metro Mondego, 2011). Concerning accessibility-related trips, these make up 51% of total trips in Coimbra (Metro Mondego, 2011), reaching out to over 80% if commuting to jobs is added.

The pedestrian and cycling network condition indicators selected for this study were those proposed in (Sousa *et al.*, 2017) (walking) and (Pais *et al.*, 2022) (cycling). These are numeric indicators that classify the condition of each network arc on a 1–4 Likert scale (from worst to best; 4 = best), with values obtained from the ELECTRE TRI non-compensatory multicriteria method (Mousseau *et al.*, 2001). The reason for choosing the above assessment methodologies was the scalability of the data collection method, which can be applied to a city of any size, requiring only a team of inspection technicians, and the similarity of the evaluation methodology. Other condition assessment methodologies could be used instead, provided their output can be transformed onto numeric values for GIS calculations and representation.

Two condition scores were obtained for each component (arc) of each network, one focusing on traveller safety (from traffic) and the other on traveller comfort (ease of path threading, absence of irregularities or obstacles), following the ELECTRE TRI parameterizations indicated in Pais *et al.* (2022) and Sousa *et al.* (2017). Comfort and safety were found to be most important aspects in

geo-design planning of cycling infrastructure (Zare *et al.*, 2022). For completeness, the criteria used by the condition assessment method are presented here. For the pedestrian network these were: width, pavement suitability, pavement conservation, connectivity, safety from traffic, lighting, obstacle density, walking environment, and pedestrian density. For the cycling network: cycling comfort, safety from traffic, roadside conflicts, intersections, and lighting. See Pais *et al.* (2022) and Sousa *et al.* (2017) for methodological and technical assessment details.

4.1 Dataset curation and network condition maps

The origins dataset was defined as the point feature class of the centroids of a square mesh (50 m × 50 m) over the city. All centroids more than 100 m away from the walk and cycle networks were removed from the analysis, as these correspond to centroids with no inhabitants. A total of 5474 origins was obtained for the case study.

T1 The destinations datasets were available from previous projects and correspond to facilities of the types listed in Table 1, which also includes the weights applied in Equation (1).

The empirical 1-2-3 scale for weights was based on trip frequency following Monteiro *et al.* (2022). Higher weights mean trips to the corresponding destinations are likely to be more frequent. The above weights are consistent with trip frequencies per urban facility type found by Gov.UK.

Finally, a word on commuting trips is now given. Those were not considered for the following reason: a job zone analysis to Coimbra (Monteiro *et al.*, 2022) revealed that the average distance per inhabitant to jobs is circa 4400 m, which is beyond what most cyclists are willing to go regularly, according to current literature (Buehler and Dill, 2016) and certainly beyond walking range. Thus, most inhabitants in Coimbra commute using motorized modes, reducing the importance of considering job as destinations in the case study. More compact cities may require adding jobs as destinations.

F1 Figure 1 (left) below depicts the origins and destinations considered in the analysis. Concerning the walking and cycling networks datasets, those were manually drawn in the GIS and the data

needed to assess the condition of its constituent arcs were obtained from a field survey. The walking network consists of sidewalks and pedestrian crossings, whereas the cycling network is composed mostly of shared space with motorized traffic, with only a small number of cycleways, built primarily for recreation. Figure 1 (right) shows the cycling network and highlights its locations along the arterial and collector roads.

5. Results and discussion

Applying the methodology to Coimbra yields the maps of Figures 4 and 5 and the statistical figures of Table 2. The friendliness values go from 1 to 4, as mode friendliness is a (doubly weighted) average condition indicator, whose values also range from 1 to 4.

T2

It is important to emphasize that the main contribution of modal friendliness is the transformation of infrastructural scores (Figures 2 and 3), which may be difficult to interpret in practice, to a visual representation of how those scores effectively affect peoples’ trips that is easy to understand and helpful in decision-making (Figures 4 and 5).

F2 F3

F4 F5

5.1 Walking friendliness analysis

Figure 4 map the walking friendliness indicator, with condition ratings focusing on safety (left) and comfort (right), respectively. These are an updated version of the maps in (Sousa *et al.*, 2019), including the latest infrastructural improvements and a wider study area. Comparing both figures, it is seen that the safety-focused indicator,  $WF^{safe}$ , displays various spots of poor scores (red; scores of 1 to 2) that are mostly located nearby the arterial and collector roads identified in Figure 1 (right). Those are high traffic volume roads with no adequate separation for pedestrians, which is consistent with Figures 2 and 3 (left). The similarity between pedestrian infrastructure condition and  $WF^{safe}$  values is mostly general, but occasionally some differences arise, an example being the bottom south region (zone below the southernmost east/west road in Figure 1 [right]), where many sidewalks have scores of 3–4, but the region itself has lower scores. A look at Figure 1 suggests this is due to the lack of some urban facilities in this region, which forces citizens to travel north through pedestrian infrastructure in poor condition to reach those facilities.

For the  $WF^{comf}$  case, indicator values are more uniform and slightly better (2.36 vs. 2.25 average, 0.37 vs. 0.54 deviation), but in general the considerations are like those for  $WF^{safe}$ , especially in what concerns the bottom south region.

Both WF indicators register the best scores in zones with many urban facilities and well-conditioned infrastructure. However, their average values are mediocre, suggesting that a large-scale intervention is necessary on the walking infrastructure. For the purposes of decision making, a possible action might be to set a high intervention priority on pedestrian infrastructure nearby

Table 1. Facility types and weights

Weight 1 facilities ( $w_j = 1$ )	Weight 2 facilities ( $w_j = 2$ )	Weight 3 facilities ( $w_j = 3$ )
Post offices	High schools	Kindergartens
Sports facilities	Shopping centres	Primary schools
Cultural organizations	Entertainment sites	Middle schools
Universities and institutes	Primary healthcare services	Grocery stores
Elderly care centres	Pharmacies	Supermarkets
	Restaurants	Bakeries and pastries
	Parks and green areas	—

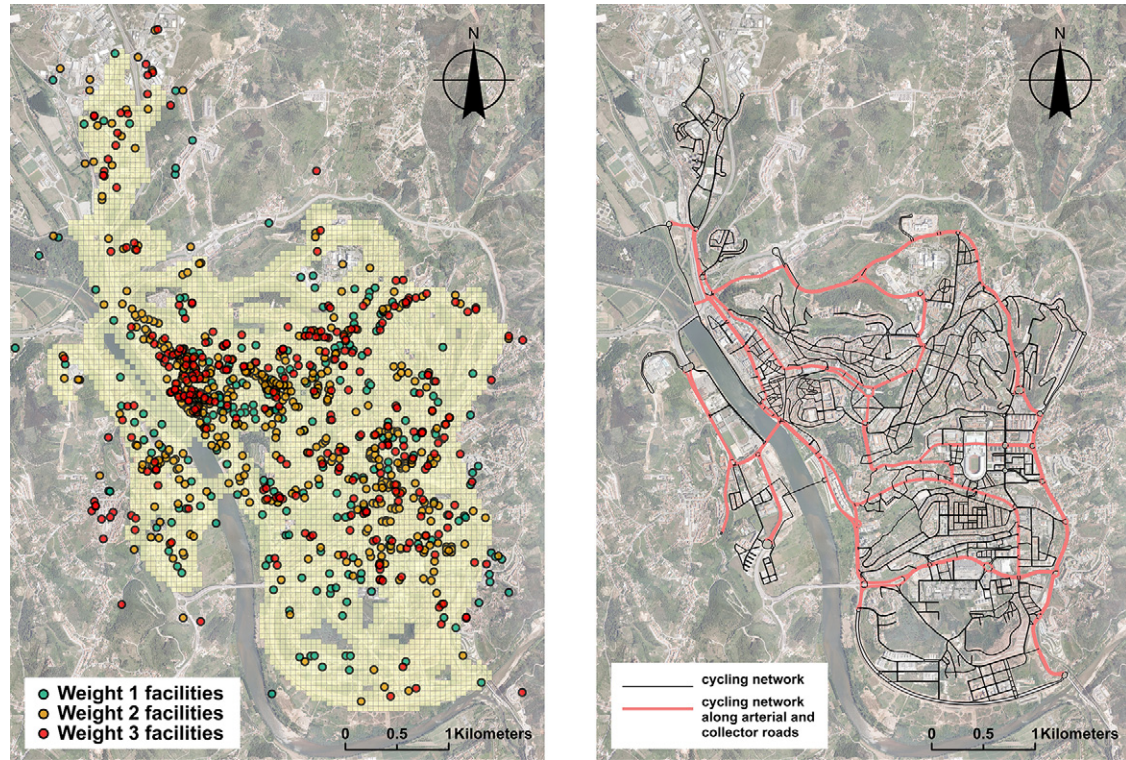


Figure 1. Left: Origin polygons and destinations. Right: cycling network and locations along arterial and collector roads

Table 2. Modal friendliness statistics

Indicator	Average	Std. Dev.
$WF^{safe}$	2.25	0.54
$WF^{comf}$	2.36	0.37
$BF^{safe}$	1.81	0.40
$BF^{comf}$	2.15	0.30

zones with bad  $WF^{safe}$  and  $WF^{comf}$  scores. But the inclusion of cycling will suggest other courses of action and therein lies the plus-value of making a combined analysis.

### 5.2 Cycling friendliness analysis

Maps for BF indicators are given in Figure 5. These results are new. Figure 5 (left),  $BF^{safe}$ , shows that Coimbra is not a safe city to ride a bicycle, which is confirmed by  $BF^{safe}$  having the worst average of all indicators of Table 2 (1.81). This is again due to segments of the cycling network positioned along arterial and collector roads that lack adequate separation from motorized traffic (Pais *et al.*, 2022). Because lack of safety is arguably the largest deterrent of cycling (Buehler and Dill, 2016; Useche *et al.*, 2019), the result help understanding why the cycling modal share of Coimbra is extremely low. It is only in the bottom south that scores are acceptable, owing to

cycleways built along the riverside. These cycleways were originally built for recreation, but even so their impact on improving cycling friendliness is very noticeable.

Turning to the comfort-focused indicator,  $BF^{comf}$ , Figure 5 (right), the situation is better, but still far from ideal. Zones with the lowest  $BF^{comf}$  values turn out to be located nearby cobbled roads, a very uncomfortable pavement for cycling.

The maps of Figure 5 show an even greater need to retrofit the cycling infrastructure than the pedestrian one, if fostering of cycling is to be pursued by municipal authorities. However, contrary to the pedestrian mode, prioritizing intervention on roads near zones with poor  $BF^{safe}$  and  $BF^{comf}$  scores may not be the best strategy because  $BF^{safe}$  has considerably worse scores. Decision-makers may want to consider addressing  $BF^{safe}$  issues first.

### 5.3 Differential analysis: WF vs. BF

Possession of WF and BF indicators allows for the creation differential maps, that is, maps highlighting differences between friendliness indicator values for the two active modes, as well as between safety and comfort weight set scores for each active mode. Differential maps are a plus-value of the combined “walk + cycle” approach and another tool that may be useful to understand the current support for

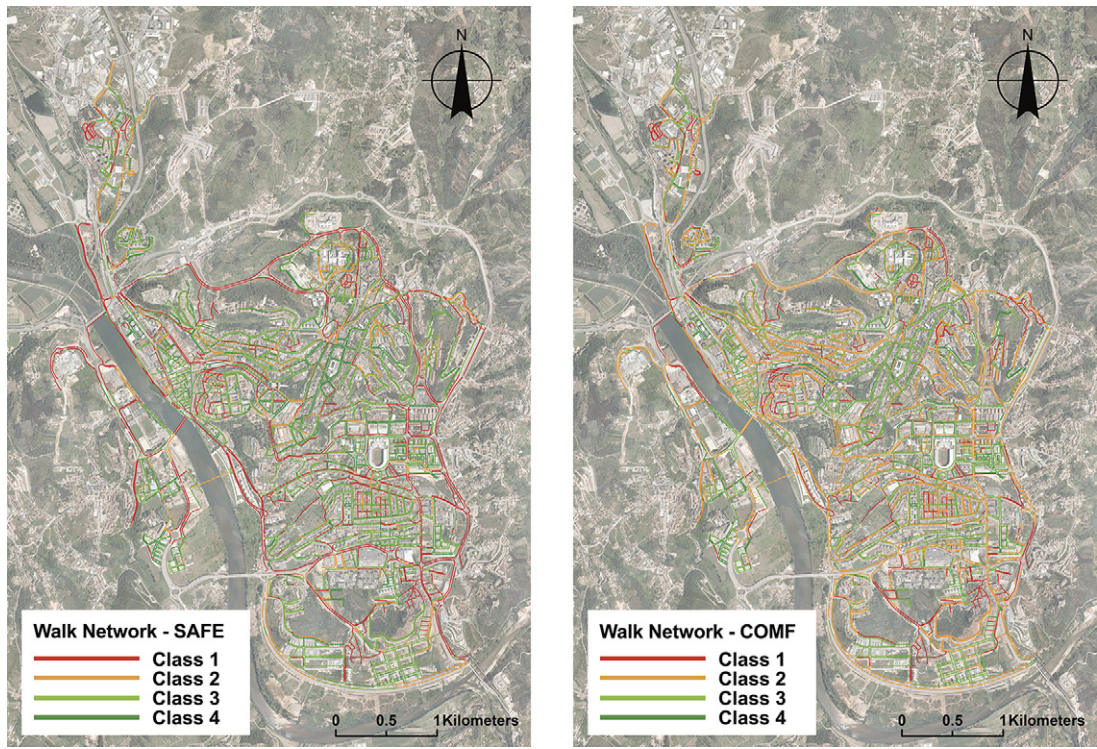


Figure 2. Left: walking network condition (focus on safety). Right: walking network condition (focus on comfort).

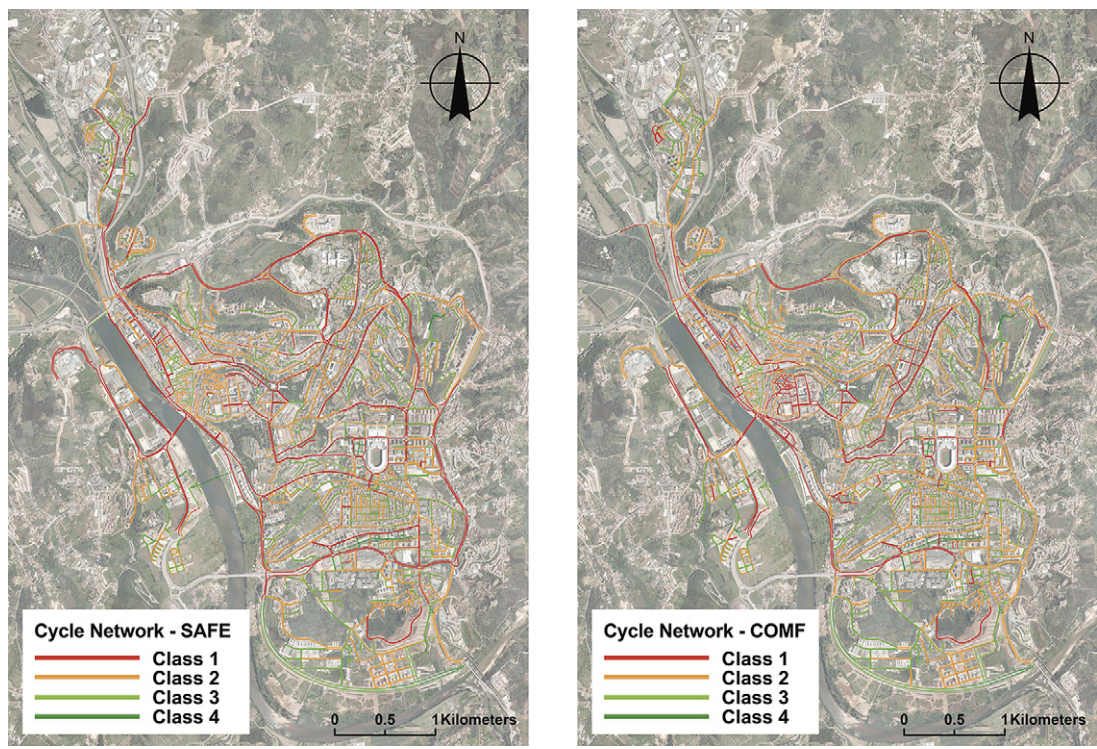


Figure 3. Left: cycling network condition (focus on safety). Right: cycling network condition (focus on comfort)

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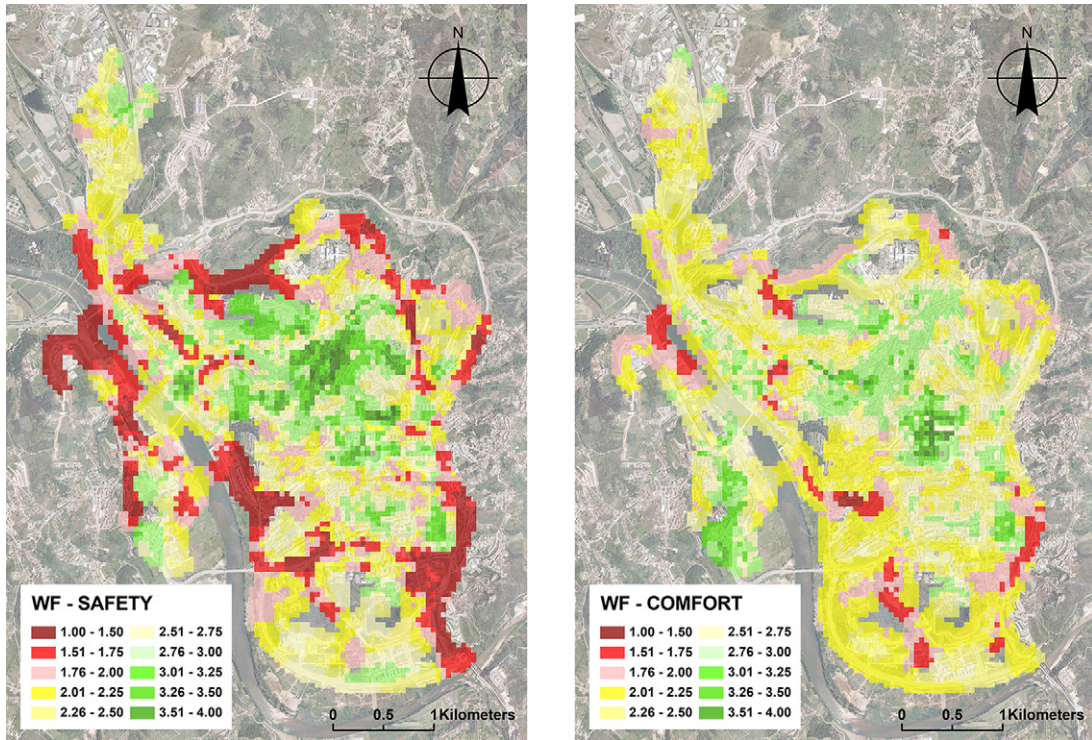


Figure 4. Left: walking friendliness indicator (focus on safety). Right: walking friendliness indicator (focus on comfort)

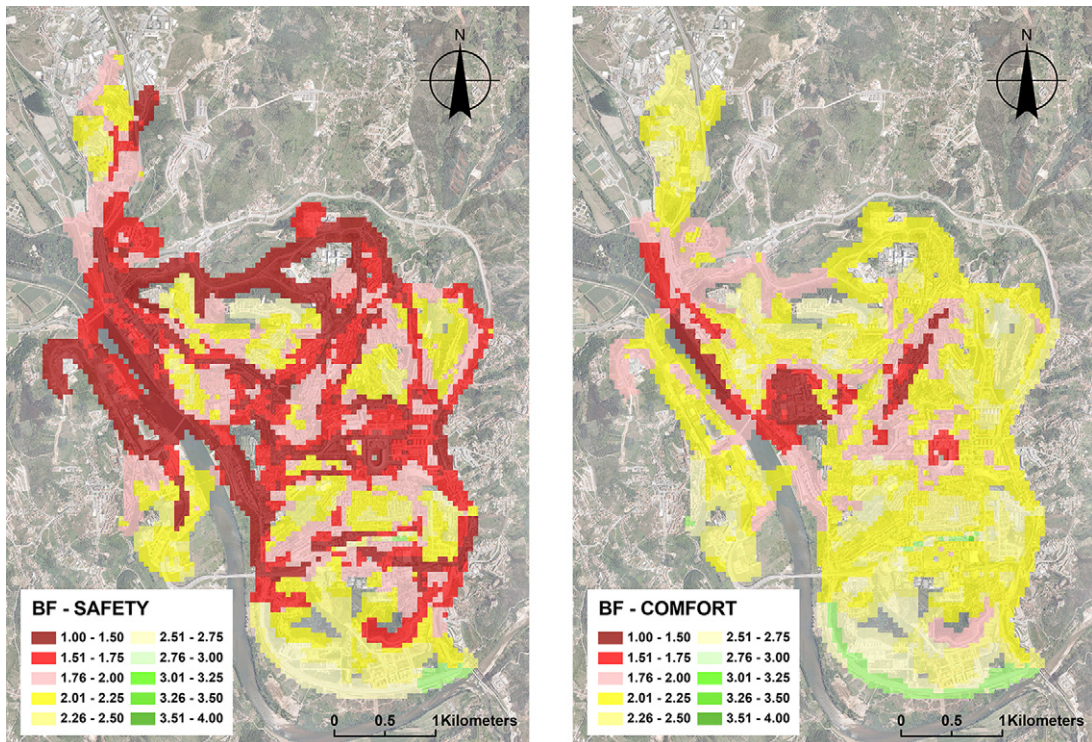


Figure 5. Left: cycling friendliness indicator (focus on safety). Right: cycling friendliness indicator (focus on comfort)

T3 active modes and plan for infrastructural improvements. Table 3 provides descriptive statistics for the two differential analyses.

F6 Figure 6 provides differential maps between BF and WF values, that is, BF minus WF. Regardless of which weight set is considered (focus on safety/comfort), the city is more suitable for the pedestrian mode, albeit more so for focus on safety (-0.45 vs. -0.21; Table 3). Again, it is only for the bottom south region that cycling has a clear advantage over walking, especially for focus on comfort, due to the aforementioned cycleways along the river-side and along a recently built, very important cycleway connecting two sides of a hill down south. The BF-WF standard deviations of 0.56 and 0.50 mean that differential scores mostly oscillate by 1 point in the condition scale, a significant, but not extreme, variation.

Table 3. Differential modal friendliness statistics

Indicator	Average	Std. Dev.
$BF^{safe} - WF^{safe}$	-0.45	0.56
$BF^{comf} - WF^{comf}$	-0.21	0.50
$WF^{safe} - WF^{comf}$	-0.11	0.37
$BF^{safe} - BF^{comf}$	-0.34	0.27

### 5.4 Differential analysis: safety vs. comfort

The maps of Figure 7 exhibit differences between focus on safety and focus on comfort friendliness indicator values for both modes. As will be argued later, these are perhaps the most revealing and useful maps for decision-making.

For the walking mode (Figure 7, left), the map shows some regions better for comfort, which nearly all lay nearby high traffic volume roads. The reason for this is that many of those sidewalks are in reasonable conservation, but have little or no separation from traffic, making them pleasant to walk but not very safe. Areas that are better for safety usually have low traffic volumes and sidewalks in worst condition.

Concerning the cycling mode (Figure 7, right), the same trend applies: regions nearby high traffic volume roads are better for comfort. For cycling this is because in the absence of cycleways cyclists must, by law, circulate sharing the road with motor vehicles. Since asphalt roads make good pavements, cyclists experience reasonable comfort. However, by sharing the road cyclists are exposed to the greatest risks for this mode, hence the low safety values. The only region that is better for safety (green spot in Figure 7, right) is an old university area, with quiet but cobbled roads, that make it more safe than comfortable to cycle there.

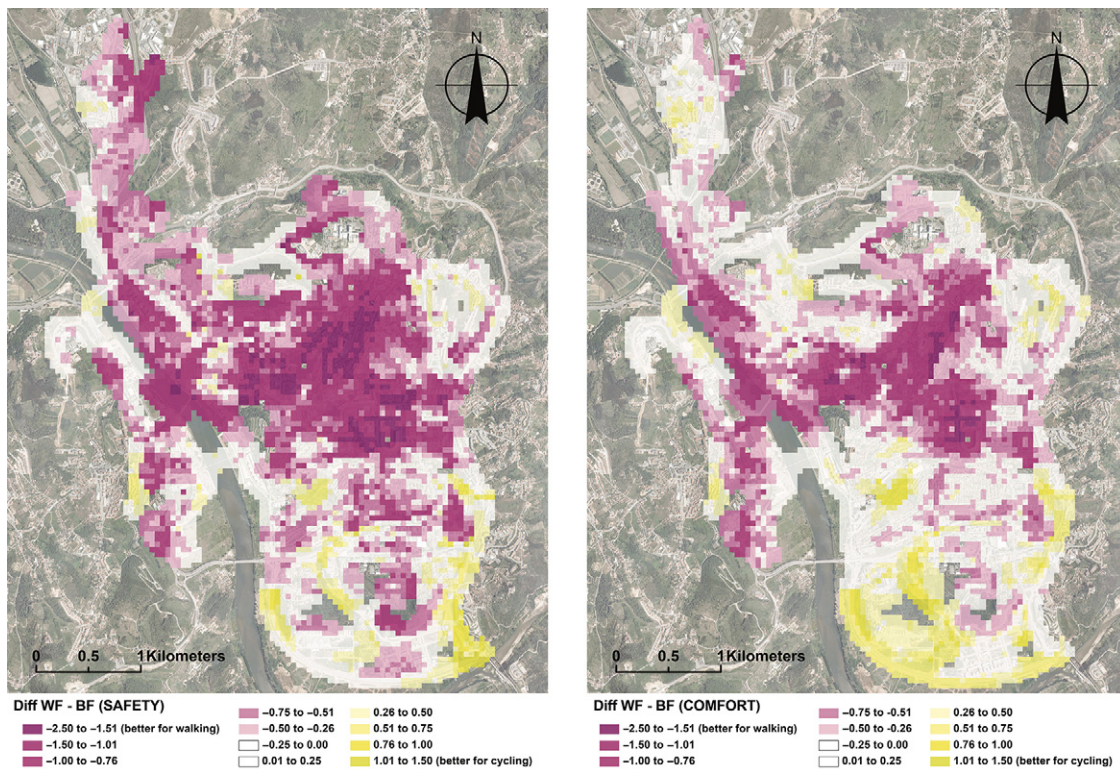
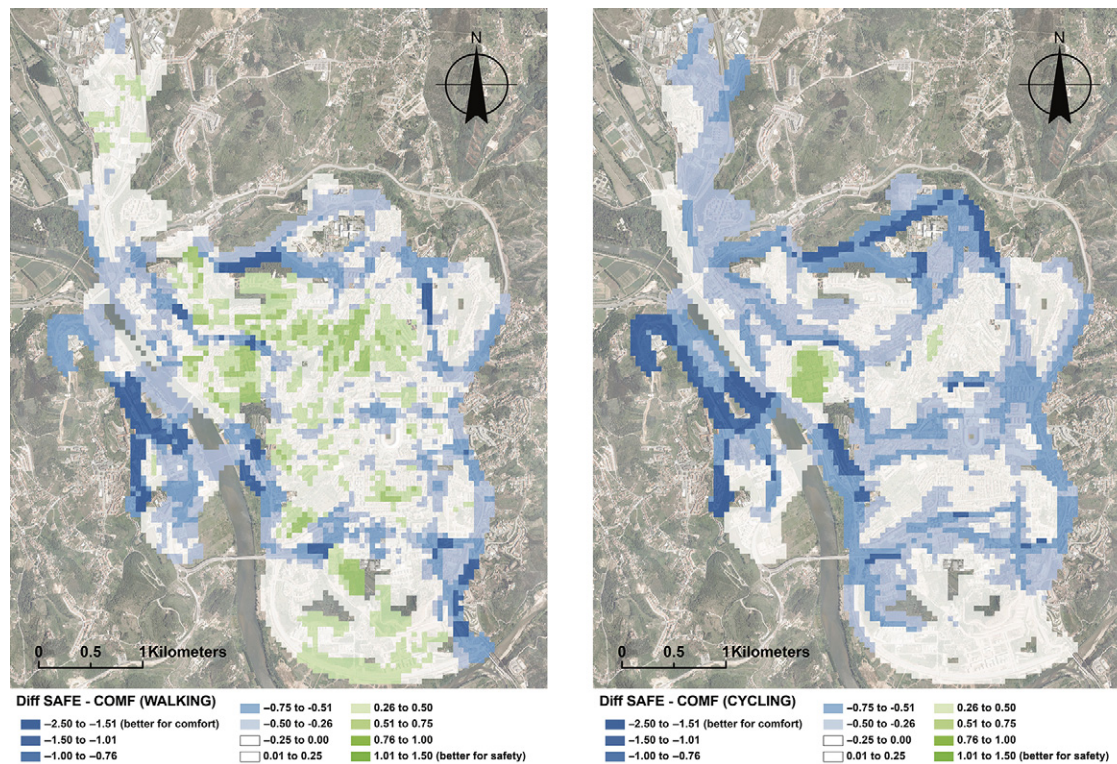


Figure 6. Left: differential BF-WF indicator (focus on safety). Right: differential BF-WF indicator (focus on comfort)



**Figure 7.** Left: differential safety–comfort indicator for walking. Right: differential safety–comfort indicator for cycling

The main point of the safety vs. comfort analysis is the observation that the pattern “high traffic volume roads are better for comfort than for safety” applies to both modes, that is, the similarity between both maps of Figure 7. This suggests the following infrastructure asset management decision: intervene on active infrastructure that runs along high traffic volume roads, creating cycleways and associated buffer zones that adequately separate both active modes from traffic.

Such intervention would, in one stroke, greatly reduce the “red spots” of Figures 4 (left) and 5 (left), making it a strong candidate for consideration in the municipal active mobility development plans because of the potential savings of retrofitting two infrastructural networks at the same time.

A slightly different approach might be necessary if municipal authorities wish to prioritize accessibility to jobs which, like accessibility to urban facilities, also form a considerable fraction of urban trips. However, such approach would require including job locations in the analysis. See (Monteiro *et al.*, 2023) for a possible way to make that inclusion in Equation (1) and in the GIS calculations. For the case study, given the importance of the distributor roads with poor safety scores, it is expectable that extending the analysis to jobs would lead to results in line with those of the present research.

It should be mentioned that the management inferences drawn in the previous sections are based on map results. Optimal use of that information requires judgement by a decision-maker with knowledge of the study area and field experience, for example, someone who knows where, for instance, distributor roads and cobbled roads are located, and this is perhaps the main limitation of this study. But that is so only on theoretical grounds: in practice, while results depend considerably on the datasets, it is precisely that dependence that gives the methodology and its output a tangible value as a decision-aid instrument.

**6. An intervention plan for Coimbra**

Based on the findings of the previous section, an intervention plan is now presented. Network arcs assessed as class 1 in either walk or cycle (focus on safety) that lay along roads with high traffic volume were considered for intervention. The focus on safety was preferred because of the aforementioned large deterrent effect of poor safety on the use of active modes.

Each network arc was analysed and the cheapest intervention action that would improve its ELECTRE TRI class to at least class 2 safe was chosen. The list of actions is presented in Table 4, whose budgeting was estimated by an experienced contractor. In budgeting, the preparatory and consolidation actions necessary to carry out the

T4

**Table 4.** Estimated intervention actions and cost (€) in Portugal

Action	Network	Description	Cost <sup>1</sup>
1	Walking	Build from scratch (sidewalk missing)	€130/m (Portuguese pavement <sup>2</sup> ) €110/m (pavet pavement <sup>2</sup> )
2	Walk	Improve conservation status	€56/m (Portuguese pavement) €26/m (pavet pavement)
3	Walk/Cycle	Build buffer zone with pins (30 cm width)	€120/pin, 2 m pin spacing
4	Walk	Build buffer zone with trees (1 m width)	€200/tree, 2 m tree spacing
5	Walk	Increase sidewalk width	€97/m (Portuguese pavement) €87/m (pavet pavement)
6	Walk	Remove standing obstacles	€150/obstacle
7	Walk	Build access ramps at crossings	€280/ramp
8	Cycle	Build two-way cycleway over bituminous road	€60/m
9	Cycle	Build two-way cycleway over cobblestone road	€120/m
10	Cycle	Build two-way cycleway over sidewalk	€120/m

<sup>1</sup>Costs per linear metre, where applicable.

<sup>2</sup>Depending on street architecture.

interventions were considered, along with the fact the contractor will be working in an urban environment and is likely to face situations on the field that require further, unforeseen actions. The values were valid for Portugal at the time of writing and may climb an additional 50% if the urban environment turns out to cause extra difficulties (e.g. subsoil issues, construction site setup issues, etc.). Values across Europe and the UK may vary. Some interventions require multiple actions, in which case costs were added.

It should be noted that due to street space restrictions building two-way cycleways may require either making the street

one-way for motor traffic or removing parking lanes. A one-way street would imply traffic soothing, further enhancing the safety criterion. However, since high traffic volumes are usually hard to reroute, this intervention proposal assumes parking lane removal instead and maintains traffic volume assessments.

Table 5 presents statistics on the actions proposed and respective costs, as well as the class progressions achieved. Actions are not mutually exclusive, as about half the arcs require more than one action.

T5

**Table 5.** Intervention plan statistics

Type	Network	Nr. actions	Total length	Cost
1	Walk	24	4,212 m	€485,648
2	Walk	20	4,055 m	€188,588
3	Walk	237	38,428 m	€2,335,080
3	Cycle	40	6,726 m	€408,240
4	Walk	35	4,608 m	€467,800
5	Walk	6	789 m	€74,322
6	Walk	8	1,068 m	€31,650
7	Walk	57	11,148 m	€17,360
8	Cycle	131	28,343 m	€1,700,566
9	Cycle	10	558 m	€67,005
10	Cycle	58	15,789 m	€947,369
Total	Walk	387	64,309 m	€3,600,448
	Cycle	239	51,416 m	€4,070,549
Total intervened <sup>1</sup>	Walk	272	43,036 m	<b>Grand total:</b>
	Cycle	199	44,691 m	<b>€7,670,997</b>
	—	—	—	—
<b>Progress</b>	<b>Network</b>	<b>Class 1→2</b>	<b>Class 1→3</b>	<b>Class 1→4</b>
Class SAFE	Walk	237	34	1
	Cycle	26	115	58
	—	<b>Present avg.<sup>2</sup></b>	<b>New avg.</b>	<b>Class progress</b>
	Walk	1	2.13	+1.13
	Cycle	1	3.16	+2.16

<sup>1</sup>Without adding actions/length for multiple interventions on the same arc.

<sup>2</sup>Only Intervened arcs.

Classes progress mostly by 1 for walking and by 2 for cycling infrastructures. This is because for many arcs a progression of at least 1 for cycling could not be achieved without a dedicated cycle lane, which by itself improves safety considerably.

T6,F8-9 Table 6 and Figures 8 and 9 show, respectively, the friendliness index statistical progress and map representation of this progress on the field, for the safety set of weights. Full maps, including similar ones and progression statistics for the comfort set of weights, are presented in the supplemental material.

Figures 8 and 9 paint a similar picture for both modes: the maps colours become much better overall, now exhibiting only few red spots, and very considerable friendliness scores improvements in the neighbouring areas of the intervened roads. The higher friendliness progress for the cycling mode (c.f., Table 5) is reflected in a

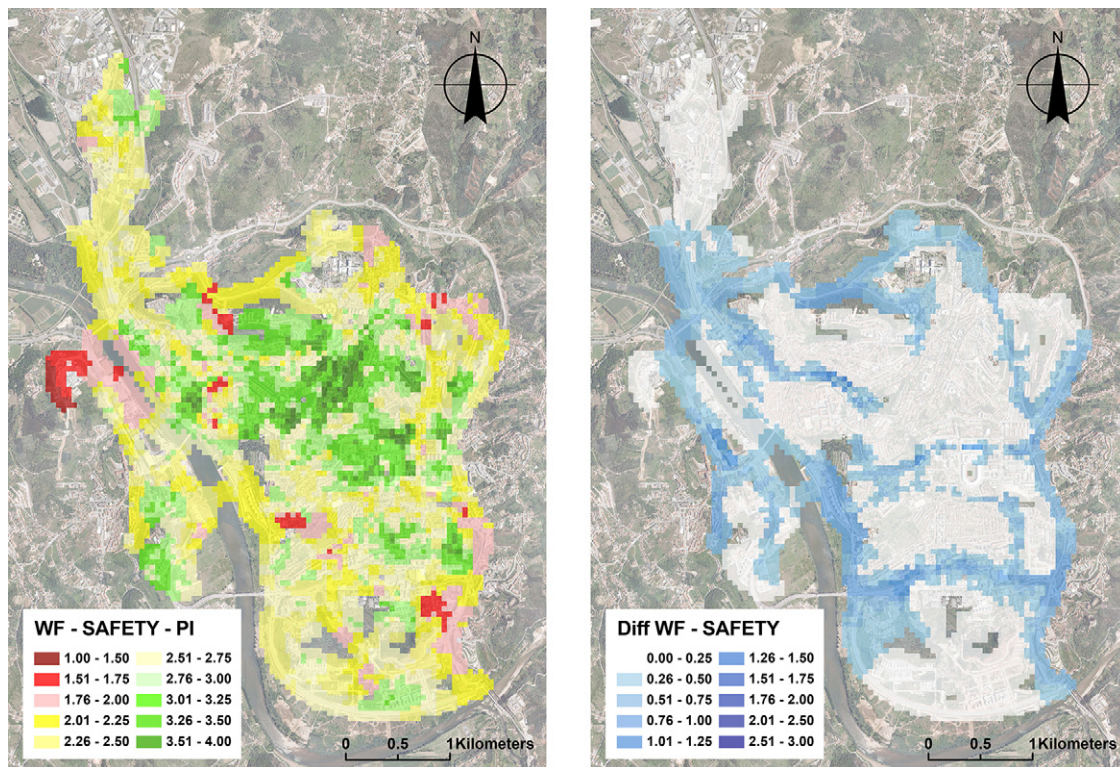
more intense and widespread coloration of the differential map, especially in the western side of the study area.

The cost/benefit columns of Table 6 compare the financial effort with the class progressions thus obtained. The values can be interpreted as cost (in EUR) per linear meter to improve the respective safety-based friendliness indicator by 1 unit, both for the intervened roads and for the city globally. It is then up to the decision maker to judge whether the benefits for the city compensate the costs. To the authors' value judgement, it definitely does, even if a 50% or slightly higher cost increase were to prove necessary due to extra complexity of the works, bringing the total budget to about €11.5 million. Indeed, the municipal budget of Coimbra allocated €19.1 million for transport spending in 2024 (CMCoimbra, 2024), so an extra spending of, say €2–3 million per year (11%–16% increase), should suffice to carry out the

**Table 6.** Modal friendliness progress statistics

Indicator	Current avg.	Post-int. avg.	Global progress	Intervened cost/benefit <sup>1</sup>	Global cost/benefit <sup>2</sup>
WF <sup>safe</sup> ___	2.25	2.52	+0.27	74.04	309.86
BF <sup>safe</sup> ___	1.81	2.42	+0.61	42.17	149.31

<sup>1</sup>EUR/progress on intervened roads.m; <sup>2</sup> EUR/global progress.m.



**Figure 8.** Left: post-intervention WF indicator (focus on safety). Right: differential after–before indicator (focus on safety)

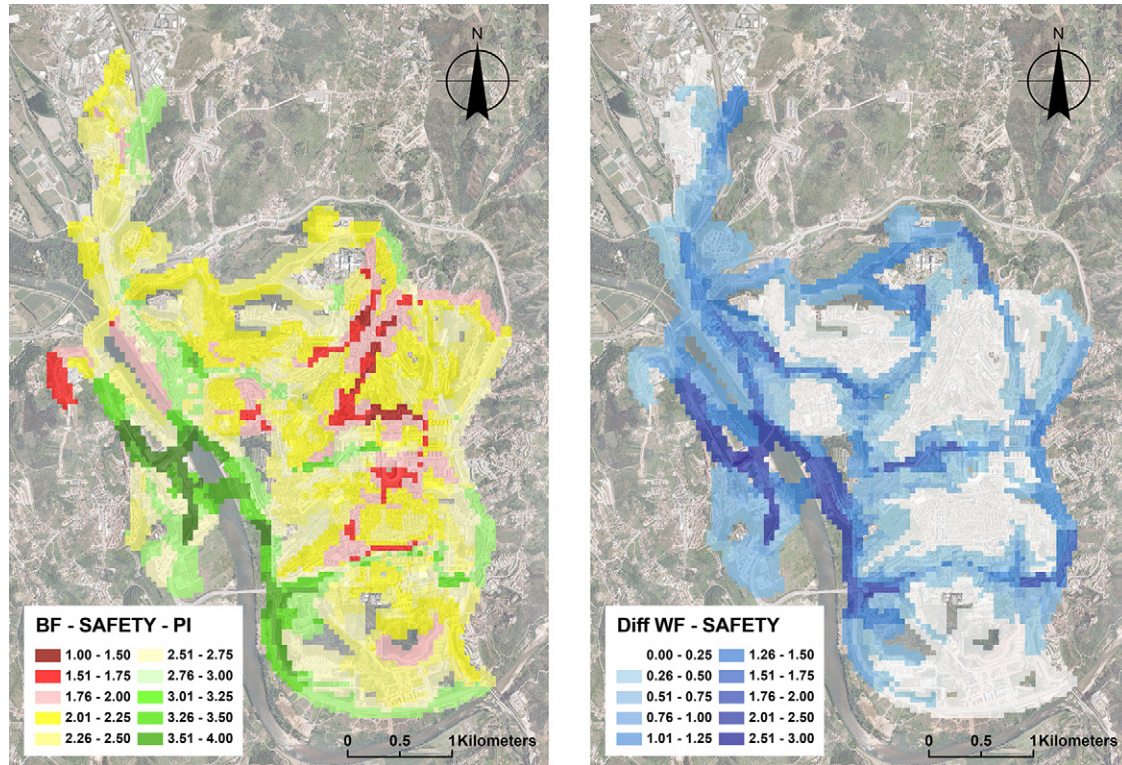


Figure 9. Left: post-intervention BF indicator (focus on safety). Right: differential after–before indicator (focus on safety)

necessary infrastructure improvements over a regular four-year city council mandate.

## 7. Summary and conclusions

This article presented a case study of the impact of active infrastructural condition on accessibility trips to the urban facilities of Coimbra, Portugal, based on a modal friendliness approach. Results showed that Coimbra, a prototypical city which over the years prioritized motorized transport, is not a friendly city for active modes, especially cycling.

A deeper look at the results revealed a common problem of the pedestrian and cycling networks, namely the lack of safety from traffic measures for both active modes along main distributor roads. This in turn suggested the synergistic managerial decision of concentrating financial and constructive effort on creating dedicated infrastructure along those roads, with correctly sized buffer zones insulating active modes from motorized traffic.

The case study is a showcase for the sort of results that can arise when an approach is followed that addresses both active modes simultaneously and goes beyond the mere assessment of the condition of individual components of a transport network, extending it to the impact that condition has on actual trips.

Furthermore, the proposed intervention plan, based on the conclusions drawn from the differential maps of Figure 7, show an interesting cost-benefit trade-off. Its implementation is likely to substantially improve modal shares, at a moderate cost. Different case studies will lead to different managerial decisions and therein lies the richness of the approach, together with the flexibility it provides for exploring the results, as various types of analyses can be made.

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