THE INFLUENCE OF AIR POLLUTION IN THE SELECTION OF HEALTHY ROUTES FOR WALKING AND CYCLING

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ABSTRACT

In this paper, a model for generation of alternative routes for walking and cycling will be presented, taking into account the impact of environmental noise and air pollution in urban areas. The main objective resides in the reduction of the exposure level and risk of development of respiratory and cardiovascular diseases. Depending on the type of optimization criteria, the output of the model could be the least noisy, the least air-polluted or the healthiest route. The formulation of the model to generate healthy routes is initiated with the generation of pollution maps, followed by the contamination of the walking and cycling network and finally outputs the generated different types of healthy routes. An application of the overall model will be presented in a case study example developed for a central area of the city of Braga, in northern Portugal, with special focus on the influence of air pollution in the selection of healthy routes in urban environments.

1 INTRODUCTION

Urban renovation and regeneration of cities should consider the mobility of active modes of transport as a key issue to promote higher and more equitable levels of mobility and accessibility for all citizens.

Mobility has an important impact on the overall functioning of cities, namely due to high motorization rates related with a strong preference for the use of private cars as the main mode of transport that often results in road congestion. Motorized traffic is associated with massive emissions of noise and other types of pollutants, in which greenhouse gases are included, as well as high costs related with time, fuel and the degradation of people's health. To minimize the externalities of the performance of the transportation system it is recognized that the influence of motorized vehicles in urban mobility has to be reduced. This can be accomplished through the promotion of the use of public transports, with the adoption of new solutions of car-sharing, car-pooling or bike-sharing and, lastly, with the promotion of active modes of transportation: walking and cycling.

Walking and cycling are the most suitable modes of transportation for short distances. Thus, the promotion of these modes is related with the city layout, namely with the location of different uses, which can have an important role in the achievement of higher levels of accessibility and mobility. In the past, the promotion of the active modes of transportation was based on building, walking and cycling infrastructures, yet this was not enough mainly for Portuguese cities, where the use of cars, even for short trips, is higher than any other mode of transportation.

Nowadays, in this information age, it is necessary to propose different approaches to promote active mobility, namely by the use of route planners and real-time navigation devices oriented for active modes in order to provide equal or more information than that currently available for drivers. On the other hand, pedestrians and cyclists are more exposed to noise and air pollution than any other road users. The density of motorized traffic, the safety conditions and the level of pollutants in urban environments are a real threat to people's integrity and health.

In this paper, a model for generation of alternative routes for walking and cycling will be presented, taking into account the impact of environmental noise and air pollution in urban areas. The main objective resides in the reduction of the exposure level and risk of development of respiratory and cardiovascular diseases. Depending on the type of optimization criteria, the output of the model could be the least noisy, the least air-polluted or the healthiest route. The formulation of the model to generate healthy routes is initiated with the generation of pollution maps, followed by the contamination of the walking and cycling network and finally outputs the generated different types of healthy routes. In order to validate the model, two environmental indices will be presented to allow for comparisons with the shortest route.

An application of the overall model will be presented in a case study example developed for a central area of the city of Braga, in northern Portugal, with special focus on the definition of the least noisy routes in urban environments. Healthy routes can be applied to attract and promote the use of active modes of transport in a regular basis in urban environments, towards achieving healthier communities and cities.

2 ACTIVE MODES USAGE

In most industrialized countries, people live mainly in urban environments. In Europe, this value represents around 60% of the population. On the other hand, a growing trend of the use of motor vehicles by commuters has been observed, especially in home-work and home-school trips and these are mainly short trips of lengths below 3 km. According to ECC (2001), the most efficient modes of transport for short trips, in terms of time spent per kilometre, are the active or soft modes of transport, especially cycling.

According to the World Health Organization, short trips taken in motorized vehicles should be potentially replaced by walking and cycling, with clear benefits for human health due to the associated physical activity. For a long time, several studies related with public health risk have shown some inertia on the recognition of the global impact in human health of the generalized use of motorized traffic (e.g. accidents, air pollution and noise) for most activities in urban environments. However, this lack of use of soft modes of transport is already a new trend on practices and policies towards the achievement of a more sustainable urban mobility.

Walking and cycling have different rates of use across European countries and, in this context, Portugal occupies almost the last positions, especially when compared with countries such as Denmark or the Netherlands (ECC, 2001; ECC, 2007). Recently, it was observed that a new paradigm was implemented for the establishment of local mobility policies through the adoption of actions oriented to the promotion of soft modes of transport over motorized traffic (APA, 2010).

The proportion of adult population suffering from obesity, overweight or inactivity has grown in accordance with car dependency. Complementarily, there is an agreement and acceptance about the impact of motorized traffic on Earth's global warming, as well as on environmental issues related with air pollution and traffic noise at a local level. Thus, it is necessary to encourage a change of the current patterns of urban mobility through the replacement of the more pollutant and less sustainable modes, such as cars, by alternative environmentally friendly modes of transport, which may contribute to a healthy society as well as the promotion of a greater social equity.

According to FHWA (2006), the introduction of the bicycle was an important innovation for the promotion of social inclusion. Some studies show that when the per capita income increases, the use of private car increases, while walking and cycling decrease. This situation is similar in some small and medium-sized cities of Portugal.

Moreover, FHWA (2006) identified a wide range of benefits ranging from environmental issues to improvements in the functioning of the transport system, related to the use of walking and cycling modes. The implementation of short-term travels on foot or by bicycle can bring socio-economic, environmental and health benefits, which are evidenced mainly in the reduction of air pollutant emissions and in the congestion of urban road networks.

Several studies have shown significant benefits that derive from the regular and daily practice of physical exercise. Walking is the primary option to increase physical activity in sedentary populations (Morris & Hardman, 1997). Even moderate or low levels of physical activity performed regularly can reduce the risk of coronary heart disease, diabetes, stroke and other chronic diseases. Additionally, it reduces the costs related to health care, contributing to greater autonomy and independence of people, especially at advanced ages. On the other hand, walking allows a greater interaction between people, as they socialize during these trips, especially in comparison to private car travel.

3 THE EFECTS OF AIR POLLUTION IN URBAN ENVIRONMENTS

The effects on human beings of air pollutants could vary from a simple eye irritation to death. Most of the principal effects are associated with a worsening of pre-existing diseases or people's health and well-being, with an increase on the susceptibility of individuals to infections and with the development of chronic respiratory diseases. In the following table 1 are shown the main health effects associated with specific pollutants.

In urban areas, some pollutants are more frequently observed than others mainly due to different sources of pollution and for most of them the principal source is the motorized traffic. For this reason, in this work four types of air pollutants were studied and characterized: particulate matter (PM10), benzene, nitric oxides (NOx) and sulphur dioxide (SO2). According to World Health Organization (WHO, 2005) the principal source of these pollutants due to human usage is the motorized traffic except for sulphur dioxide, for which industries are the main responsible for its presence in the atmosphere. In this work, pollutants such as carbon monoxide (CO) were not characterized since it was not possible to model its dispersion due to software restrictions.

According to the European Environment Agency, long term particulate matter (PM) and noise (Fig.1) represent an important sum of years of potential life lost due to premature mortality and the years of productive life lost due to disability – the DALY – that considers in its calculation the mortality, (loss of) mobility, self-care, daily activities, pain/ discomfort, anxiety/ depression and cognitive function (EEA, 2010).

Table 1 Specific air pollutants and associated health effects (Vallero *et al*, 2008)

Pollutant	Effects
CO	Reduction in the ability of the circulatory system to transport O2 Impairment of performance on tasks requiring vigilance Aggravation of cardiovascular disease
NO2	Increased susceptibility to respiratory pathogens
O3	Decrement in pulmonary function Coughing and chest discomfort Increased asthma attacks
Lead	Neurocognitive and neuromotor impairment Heme synthesis and hematologic alterations
SO2/ particulate matter	Eye irritation Increased prevalence of chronic respiratory disease Increased risk of acute respiratory disease

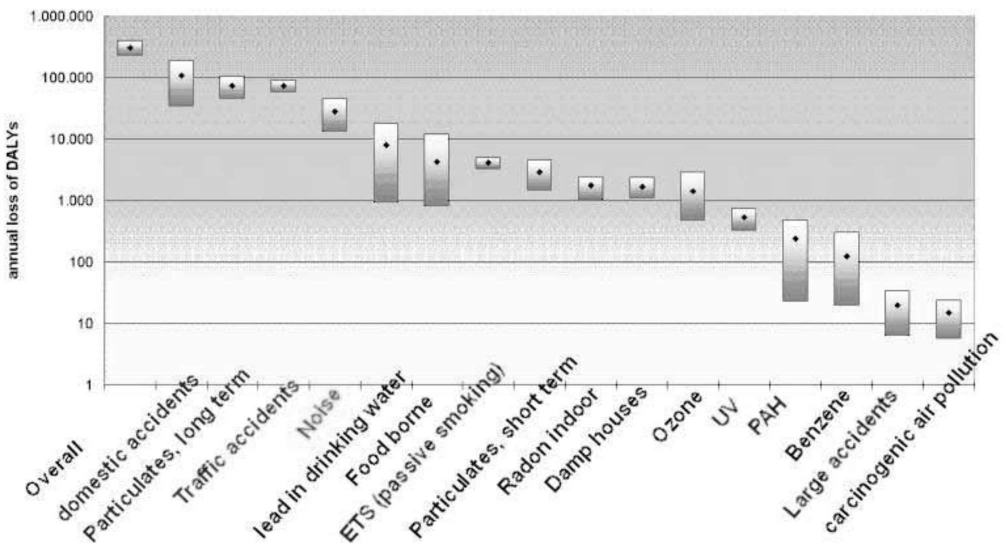

Fig. 1 Estimate of DALY's from different environmental aspects (EEA, 2010)

The evidence on the health effects of particles comes from several major lines of scientific investigation: characterization of inhaled particles; consideration of the deposition and clearance of particles in the respiratory tract and the doses delivered to the upper and lower airway and the alveoli; animal and cellular studies of toxicity; studies involving inhalation of particles by human volunteers; and epidemiological studies carried out in community settings (WHO, 2005).

According to WHO (2004) the most severe effects in terms of the overall health burden include a significant reduction in life expectancy of the average population by a year or more, which is linked to the long-term exposure to high levels of air pollution with PM.
The most recently works on the effects of the principal air pollutants on human health in urban areas enabled to conclude that particulate matter is the pollutant that more often exceeds the legal limit values and represents a potential high hazard to populations

(Ribeiro, 2011). For this reason particulate matter – PM10 – should always be used as an indicator of the air quality of urban areas.

4 HEALTHY ROUTES – THE MODEL

The concept of healthy routes for walking and cycling considers in the definition of a set of impedances of environmental nature and certain aspects associated with health applied in the route calculation, aiming to provide a comparison between different routes towards achieving the healthiest route.

In general terms, the model has three distinct phases, which are: i) the generation of the pollution map; ii) the contamination of distances; iii) the generation of healthy routes (Ribeiro & Mendes, 2010; Ribeiro & Mendes, 2011; Ribeiro, 2011).

The generation of the pollution map implies the estimation of noise levels and concentrations of various pollutants. These will be combined according to the level of impact that those pollutants have on human health, from which a single air pollution time-dependent map will be produced. The maps are carried out with the use of specific software – CadnaA, which is based on the AUSTAL2000 program for the generation of emissions and a dispersion model of pollutants. Geographic Information System software should be used, since it allows operating with networks and traffic data, handling and treating the results of noise mapping and air pollution, in order to get the global pollution map for the selected areas.

The contamination of distances refers to the creation of impedances to be assigned to all segments of the active modes network, taking into account the data extracted from the pollution maps. To obtain a global overview of the variability of the environmental conditions over space and time, the production of hourly maps is recommended, or alternatively of maps in the most representative periods of the day. In this stage of the routing process, it is essential to develop a GIS working platform to integrate the air pollution and noise information with the transport network facilities, and thereby build a base of contaminated network for each pollutant or for a combination of pollutants.

The last phase of the model consists on the route calculation through the use of route optimization algorithms, in order to determine a wide range of routes, including the shortest, noisiest, least air polluted and the healthiest routes. To this end, there is a variety of commercial programs offering this possibility. In this work, the Network Analyst extension of ESRI's ArcInfo was used.

Finally to compare the different types of routes it is necessary to evaluate the weighted average noise level and concentration of PM10. In order to see the influence of the levels of air pollution on the definition of the healthiest route a comparison should be done with the shortest routes (network without contamination).

5 CASE STUDY APPLICATION – LESS AIR POLLUTED ROUTES

In this paper, an example of an application of the model will be presented to generate healthy routes for a central area of the city of Braga located in north of Portugal. This area is a part of the CBD of the city with a lot of public infrastructures such as schools, administrative buildings, as well as commercial and residential areas.

The three types of healthy routes in this paper will address the exemplification on the achievement of the less air pollutant routes, which could be seen as a particular case of the healthiest routes where noise is not considered a key factor for pedestrian and cyclists during their journeys.

5.1 Generation of the pollution map (air pollution)

To generate the air pollution maps, it was necessary to evaluate the air pollution sources and for the area it was possible to conclude that motorised traffic is the principal source of emissions. And for that, daily traffic counts were made in eight street sections that were considered representative of the traffic behaviour for other streets of the city road network and for other streets hourly traffic counts were made to cover the whole city area (Fig. 2).

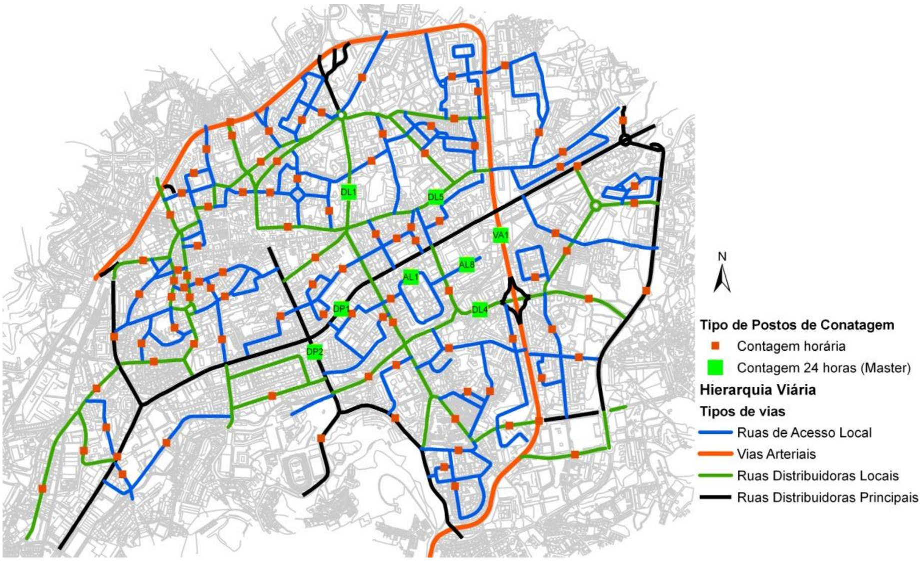

Fig. 2 Functional road hierarchy and location of traffic counts (Ribeiro, 2011)

To estimate the long term concentration of air pollutant, the Air Pollution extension of the CadnaA software was used, which has some limitations in relation to the pollutants that could be considered on these analyses, such as carbon monoxide that is an important element on the evaluation of the walking and cycling environment.

It was necessary to create a geographic database related to urban infrastructures that should integrate the characterization of the existing terrain, buildings and road network. For this, a GIS platform was used where data could be imported and exported to CadnaA.

A calculation of air pollutants distribution with CadnaA-APL implies the specification of several parameters, such as:

- *species of pollutants: particles (PM10), benzene (C6H6), sulphur dioxide (SO2) and nitrogen oxides (NOx).*
- *time interval: year*
- *type of pollutant: average*
- *quality level (specifies the emission rate of particles): qs = 2 (256 million particles)*
- *grid overlap*

- *roughness length z0*
- *anemometer height*
- *anemometer location: (0,0) lower left corner of the calculated area*
- *include digital terrain mode: yes (but considering all region flat*
- *include buildings: yes*

According to Datakustic (2007), the quality level specifies the emission rate of particles (default value –4). An increase by 1 result in doubling the number of particles and in a decrease of the statistical uncertainty (spread). However, the calculation time is doubled as well. The corresponding holds for reducing the quality level. The calculation increases proportionally with the number of particles. Thus, a calculation with qs=4 requires a calculation time which is longer by the factor of 256 than a calculation with qs=-4. Associated with the grid configuration, these parameters are the principal responsible for the quality of the results and for the time spent in calculation. For these reasons, only four periods of time in a day were considered to generate the long term air pollution maps.

Other important aspect to model air pollution dispersion is the calculation of the wind field based on a weather meteo-file information. CadnaA-APL uses a specific software named TALdia. The meteo-file contains data regarding wind direction, wind speed and the stability class according to Klug/Manier (classes 1-6).

In Figure 3 the example of calculated maps for particulate matter – PM10 - is presented. The concentration of benzene and sulphur dioxide was insignificant, while the presence of nitrogen oxides (NOx) and particles (PM10) are considerable in areas closed to the main traffic conduits.

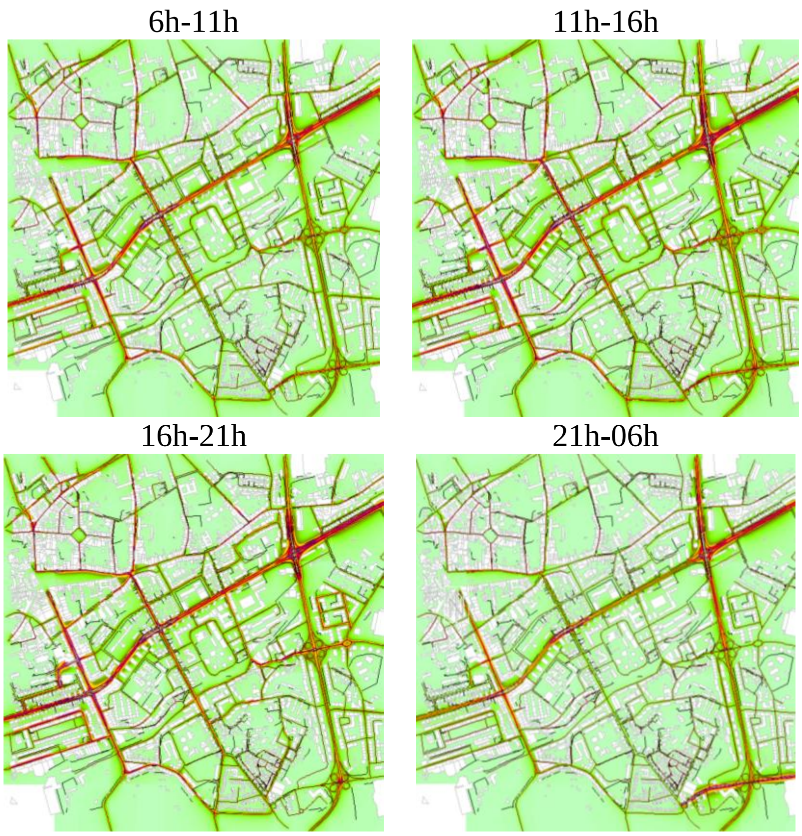

Fig. 3 – Long-term maps of concentration of PM10 (Ribeiro, 2011)

5.2 Distances contamination to achieve the less polluted routes

The contamination of distances consists on the application of a multiplicative factor to the length of a walking or cycling network, which is schematically represented in Fig. 4. The multiplicative factor can be represented through a fuzzy variable that relates the concentration of air pollutant with the factor. For PM10 a linear relation was considered. The anchor values were established by the legal limit concentration of PM10 of 40μg/m^3 and the average lower values registered in less polluted areas of the municipality of Braga of 20μg/m^3.

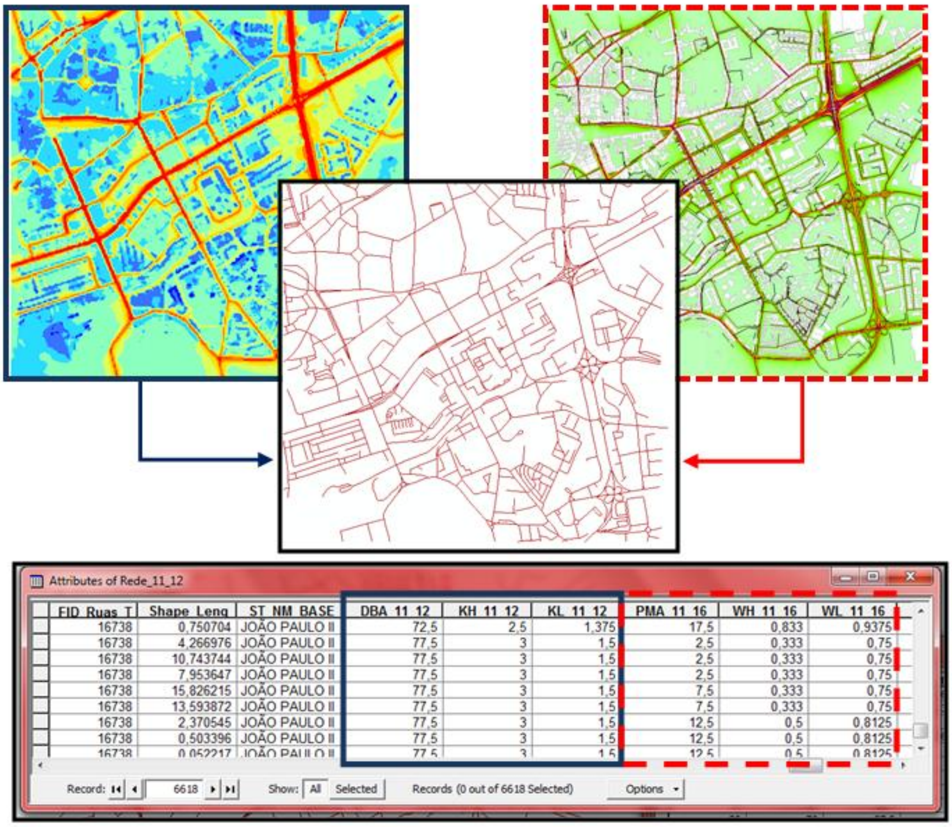

Fig. 4 Schematic of the multiplicative factors applied to the road network

On the other hand, according to the purpose of the walking and cycling journeys, two possibilities of preference in route choices were created that have direct influence on the choice of the multiplicative factor to contaminate distances.

For common journeys, usually related to commuting, users would prefer to walk in less polluted streets but with a small increase in the total trip length, while for sport and leisure purposes it is expected that users would rather travel through less polluted pathways even though they have to walk or cycle more than if they take the shortest route. So for commuting purposes, the contamination of distances should be light, while for leisure purposes the contamination should be heavy.

A light contamination corresponds to a lower variation on the range of the multiplicative factor - WL, i.e between 0,75 and 1,5. On the other hand, a heavy contamination corresponds to WH factors varying from 0,33(3) to 3,0, as it can be seen in Table 2.

Table 2 Multiplicative factors related to PM10 concentrations (Ribeiro, 2011)

PM10 (μg/m^3)		Multiplicative factor	
Range	**Average**	**W Heavy - WH**	**W Light – WL**
<20	<17,5	0,33333	0,75000
20 - 25	22,5	0,66667	0,84375
25 - 30	27,5	1,33333	1,03125
30 - 35	32,5	2,00000	1,21875
35 - 40	37,5	2,66667	1,40625
>40	>42,5	3,00000	1,50000

5.3 Route calculation – Less air polluted routes

This phase consists in making the generation process of routes and healthy itineraries operational. After having "contaminated" the active modes network, a GIS database was produced with all contaminated distances (segments of the network). These are used in route optimization algorithms, in order to determine a wide range of routes, including the shortest and the route with lower concentrations of air pollutants (a form of a healthier route). In this work, the Network Analyst extension of ESRI's ArcInfo was used, which allows the production of several network datasets (Figure 5) essential for the calculation of all types of healthier routes.

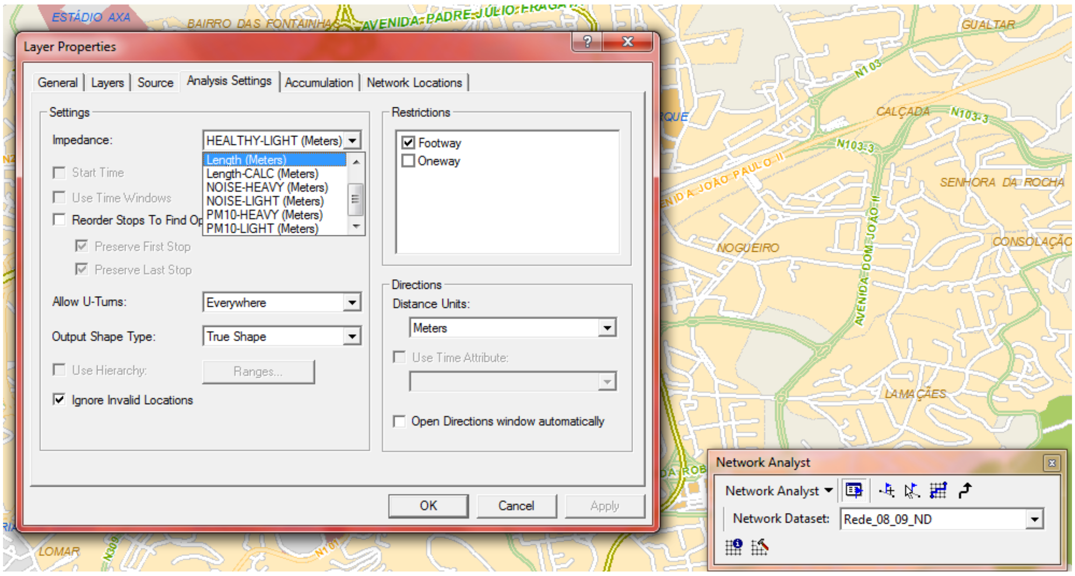

Fig. 5 Example of definition of parameters for the calculation of routes in the Network Analyst

In this work, the determination of the shortest route was used as an optimization criterion through the Network analyst application. The use of those algorithms allows replacing the actual segment length of the network by properly contaminated axes. In this case the contamination takes only in consideration the effect of the concentration of particles – PM10 – in the air.

In Fig. 6 are shown the results of a route calculation for an origin (*bairro residencial do Fujacal – Residential Neighbourhood of Fujacal*) and a destination (Universidade Catolica de Braga) in the centre of Braga, between 8:00 and 9:00. It is important to note that the long term maps of air pollution concentrations of PM10 were calculated for four periods of the day, so in this case any routes calculated between 6:00 and 11:00 would be the same.

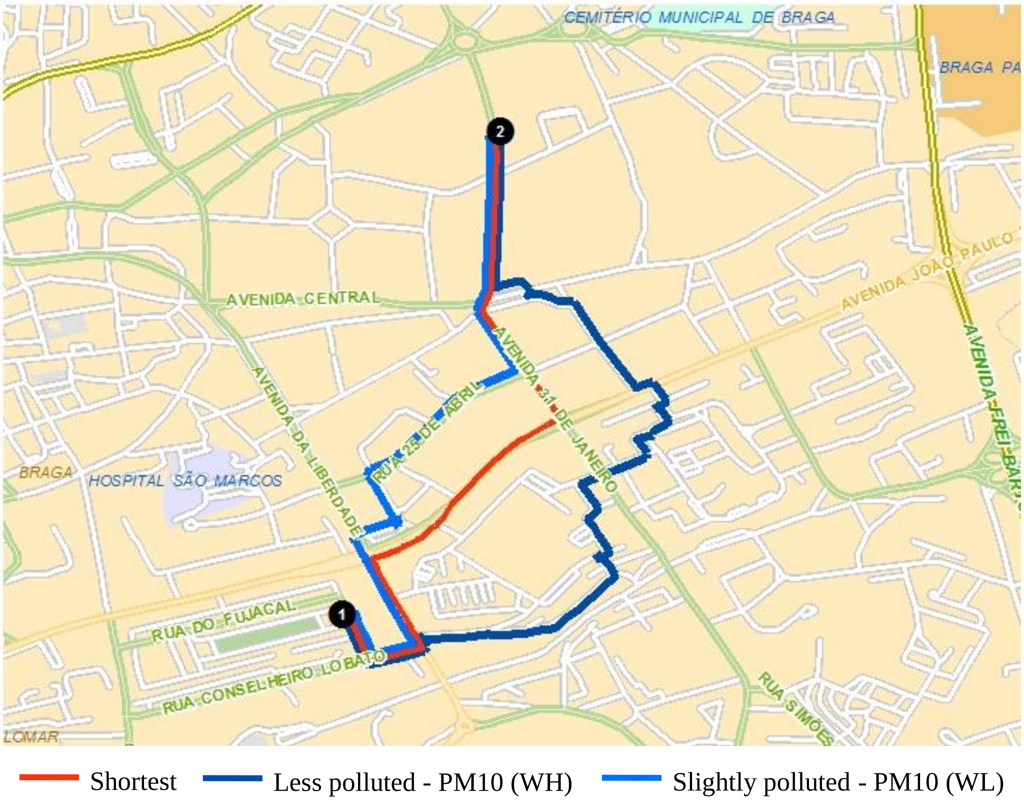

Fig. 6 Example of the calculation of different routes between two points

In order to compare the different routes obtained in Fig. 6 the weighted average values of the concentration of PM10 by the segment length of the routes were calculated. A comparison of the length and the weighted average PM10 of the optimized routes with the shortest, as it can be seen in Table 3.

Table 3 Comparison of the least/ slightly polluted with the shortest route

Routes	Length (m)	Distance contaminated (m)	Weighted average of PM10 (µg/m³)	Difference to the shortest route	
				Length (m)	PM10 (µg/m³)
Shortest	1785,9	1785,9	30,8	-	-
Least polluted - "W Heavy"	2285,7	1981,9	24,0	499,8	-6,8
Slightly polluted - "W Light"	1816,1	1875,0	27,5	30,2	-3,2

From Table 3 it is possible to conclude that, as expected, the shortest route has the higher weighted average of PM10 of the three types of calculated routes, followed by the slightly and the least polluted route, thus validating the proposed model.

In the limit, all routes could converge to a unique solution, the shortest route. However, in this case the three routes are clearly different, as it can be seen in Fig. 6. Furthermore these routes present very different performances. The route performance cannot be seen only in terms of the reduction obtained in the average values of the concentration of PM10, but it should simultaneously integrate those values with the total length of the routes.

The comparison between the slightly polluted with the shortest route shows that taking a route 30 meters longer than the shortest, it is possible to have a reduction of 3,2 $\mu g/m^3$. However to have a reduction of 6,8 $\mu g/m^3$ it is necessary to walk or cycle 500 meters more. In this case it is also possible to observe that higher reductions on pollutants concentrations presumably imply traveling greater distances, which are in line with the travel purposes presented on point 3.4. Thus for a commuter, such as a student, a slightly polluted route is certainly a better choice than the shortest or even the least polluted route because the former involves more pollution and the latter represents a significant increase in the total travel distance.

6 CONCLUSIONS

One of the main fields of application of this methodology of generation of healthy routes, herein presented, consists on the development of a decision-making tool and a route planning and navigation system exclusively for active modes of transportation, namely through a website or a navigation device such as a smartphone, in which it would be possible to get a set of spatial, functional and performance information for each displayed route. Thus, the pedestrians and cyclists can plan in advance the best route to suits their needs.

For this purpose, it is necessary to obtain relative values as a means to evaluate the impact of different pollutants in human health and its physical activity, which was done through the definition of a relation between the concentration of a certain type of pollutant and the effects on health. Moreover, it should be noted that there is a combined effect of different pollutants, even if its performance is studied separately. Thus, the validation and definition of thresholds and limit values for the various pollutants can be difficult, if not impossible to make. This complexity is even more significant when trying to account for how different individuals assimilate and react under various types of pollutants.

Recent research has shown that particles (PM10) have a relevant impact on health of urban citizens, mainly when the main source of pollution is the motorized traffic. However, it is important to enhance that a combination of other pollutants could be important, namely the combined concentration of carbon monoxide and benzene.

In this paper, a specific type of healthy routes for active modes of transport was presented, the least polluted and the slightly polluted routes, which result from a calculation of the shortest distance between two or more points assuming that the distance does not correspond to the actual length of a segment of the active modes transport network but to a contaminated distance. Actually, the calculation of the contamination of the distances assumes a very important role in the definition of healthy routes, in this case those with lower values of concentration of PM10 in the air. The example presented in the case study enhances the benefits that can be achieved with the circulation on less polluted routes instead of travelling through the shortest route to a given destination. Another issue that is important to highlight is the freedom that pedestrians or cyclists have on the choice of the route that best suits their travel purposes.

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