SSD

SCIENCE FOR A SUSTAINABLE DEVELOPMENT

Systematic Analysis of Health Risks and Physical Activity Associated with Cycling Policies

"SHAPES"

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Health & Envionment

FINAL REPORT PHASE 1

SYSTEMATIC ANALYSIS OF HEALTH RISKS AND PHYSICAL ACTIVITY ASSOCIATED WITH CYCLING

"SHAPES"

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1 SUMMARY

This report is the summary of the results of phase 1 of the SHAPES project. A scientific research project within the SDD programme of the federal science policy.
SHAPES was conceived as a 4 year project with specific objectives for the first two year (i.e. validation the instruments (software and hardware) and designing the methodologies needed for the experiments and policy oriented work in phase 2).
All of the major objectives of phase 1 (2007-2008) were accomplished and the results are discussed in this report. More data was collected than anticipated and some preliminary analysis was undertaken earlier than planned. Not all of this extra information is reported here because the final analysis is part of the second phase which will be finished by 2010
The information contained in this report will be reviewed further by the authors before being submitted to peer-reviewed scientific journals which will have priority over the information contained in this report.

2 INTRODUCTION

The SHAPES project is implemented by the research teams of three institutions that had not previously collaborated. Each institute's pre-existing expertise is distinct with no overlap to the other partners. However, in the framework of SHAPES it was anticipated that the existing expertise was fully complementary.

During the first phase of SHAPES it has been clearly demonstrated that this approach has worked very well and has thus enabled the researchers of each team to explore scientific subjects that were out of their research field before the cooperation in SHAPES was started. This is made possible through a unique symbiosis of individual scientists that match together on a personal level. This positive attitude now ensures the proper completion of the individual tasks as well as the common experimental work. In addition there is a lot of exchange of ideas, positive feedback on subjects that fall mainly within the domain of one partner.

Although there is no formal network agreement between the partners, some basic agreements e.g. on co-authorship of papers and presentations are well respected (e.g. Annex A p.59).

VITO plays a key role as coordinator and proves to be an efficient interface between the partners. In particular, it correctly ensures the administrative coordination of the project as well as it favors the collaboration and synergies within the network. The multidisciplinary framework is especially visible through the implementation of the on-line injury registration system: a close collaboration was established between the different partners and conducted to an inquiry integrating different scientific topics (e.g. health, emissions of cars and air pollution aspects) are all integrated in the registration system). Since the launch of the on-line registration system, a continuous collaboration is driven through dissemination and promotional events (e.g. conferences, Dring Dring, Velocity, …) and in the national press.

Field tests conducted by VITO and VUB and aiming at measuring the concentrations of air pollutants and tidal volume also involved all three partners. These field tests are really fruitful and interesting experiences since they allow sharing and integrating different scientific knowledge; it was a real team building activity. Finally, the expertise acquired by the Department of Geography (UCL) in GIS was useful to VITO for modelling emission values on sloping trajectories (paragraph 6.1) and attributing them to the cycling trajectories used for field tests.

3 RESEARCH CONTEXT

In this paragraph we focus on the international context mainly from a policy perspective. Reference to the scientific international context is given in the relevant paragraphs in section 4.

The promotion of public transports and/or non-motorized modes – such as walking or cycling – is nowadays expected to address environmental and mobility problems (when compared to the general perception at the start of this project). In particular, bicycling is a "green" alternative to commuting by car. Also it is a space- and energy-efficient mode and is affordable for a large majority of households (see e.g. Pucher et al., 1999; Rietveld, 2001; Gatersleben and Appleton, 2007). Thus a substantial shift from car to bicycle could reduce urban congestion as well as the environmental harm caused by air and noise pollution. Moreover, according to the British Medical Association, cycling to work can provide health benefits (only if regularly performed) and consequently cope with the growing concerns related with physical inactivity, which is the second major cause of premature death in industrial countries after tobacco (Pucher et al., 1999). Commuter cycling conveniently combines both the level of activity and the frequency necessary to improve fitness. Finally commuter cycling is quickly becoming a favourable low-energy mode in times of soaring fuel prices.

In Belgium, while approximately 21% of the commuters are located within cycling distances (i.e. less than 5 km) from their job and 39% make trips less than 10 km, only 6% of all trips are carried out with a bicycle as main transport mode and these statistics highly vary within Belgium (Verhetsel et al., 2007). For distances up to 5 km, the percentage of active people that cycle is relatively low (19%) while a large majority of active people (more than 53%) use their car for work trips and, for several reasons, do not opt for more environmentally friendly modes such as cycling or public transports. Hence, there is a great potential for a shift from car to bicycle when commuting. Nevertheless, there are still several social, economic and environmental factors that dissuade from cycling (such as the lack of cycling infrastructure, topography, weather, road accidents, the need to carry bulk goods and/or to be well-groomed, households-related constraints or bad physical health) and that need to be clearly identified in order to help policy makers to mitigate (or to get rid of) them and to promote the bicycle use in Belgium. Such findings could then partly support the implementation of adequate policies in favour of a modal shift from car to bicycle commuting.

Another major shift in the public opinion has occurred with respect to exposure to PM emissions from transport. While this effect was recognized by scientists 10-15 years ago, and taken up by (local) policy makers during the last decade, public opinion has only recently turned against public works on the basis of fear of exposure to PM. Much more attention is now given to smaller PM fractions (PM2.5 and UFP). In this respect SHAPES often finds itself in the middle of attention e.g. when exposure of cyclists to PM emissions from scooters suddenly becomes a topic in the media.
Not only the public opinion, but also the European commission is now paying much more attention to finer fractions of PM and to exposure. This is shown by recent (final) approval of a directive setting both new standards for PM2.5 and implying a decrease in exposure of people to PM2.5.

Since the start of the SHAPES project in Belgium, international interest in commuter cycling is also growing. Recently contacts were made with the collaborators of the WHO HEAT for Cycling project. Oral agreement was made on refining the WHO cost-benefit analysis of the HEAT for Cycling project with the data that will be gathered during the SHAPES project.

A proposal for a symposium was made for the 3rd International Congress on Physical Activity and Public Health (Toronto, Canada) in the spring of 2010. SHAPES will also be present on the Vélocity conference in Brussels in 2009 and will actively prepare an international symposium within BELSPO PM²TEN* where high level international speakers are invited. Part of the SHAPES questionnaire data will already be presented at the International Society of Behavioral Nutrition and Physical Activity (ISBNPA) Conference, Lisbon 2009 (17 to 20 april, Symposium title: Transport Cycling: What Makes It To Be A Health-Enhancing Physical Activity?)

The results from the SHAPES project will also be disseminated to the wider scientific community by means of peer-reviewed papers. After studying the likely outcome of the data that was already collected or will shortly become available, 10 opportunities to write such a peer reviewed paper were identified (see Annex A).

* PM²-TEN: Particles, Mobility, Physical activity, Morbidity and The Environment Network http://www.belspo.be/belspo/ssd/science/projects/PM2TEN_en.pdf

4 OBJECTIVES

The main objective of SHAPES is to collect data, design and perform experimental measurements that will enable an unbiased scientific study of the major health risks and benefits associated with cycling as a mode of transport for commuting. Results should enable policy makers to make clear and science-based choices regarding commuter cycling and transport mode shift in cities.

We summarize some the partial objectives of SHAPES from the proposal:
- evaluate the exposure to air pollution for cyclists compared to car users;
- evaluate the physical condition of cyclists compared to car users;
- implement an on-line injury registration system to monitor minor injuries (accident related and others) in commuter cyclists;
- perform a spatial analysis for accident risks;
- integrate these risk factors into a common framework, to evaluate costs and benefits;
- perform a spatial analysis for trajectory choice and methodology for infrastructure development in the three Belgian regions;
- propose policy options that will contribute to safer and healthier cycling conditions and to lower emissions and social security costs in the long term.

The main outcome of SHAPES will be an integrated framework to evaluate the costs and benefits of commuter cycling. A distinct set of policy options will be drafted that can be used to promote a modal shift to cycling and substantially improve public health in a cost-efficient manner while taking into account the physical capabilities of different groups and spatial constraints in different regions with special attention for a correct geographical differentiation.

The expected outcome of Phase 1 includes:
- a statistical and geographical analysis of accident data to identify the causes of accidents with cyclists and the correlated spatial attributes; (see paragraph 0)
- a statistical and geographical analysis of bicycle commuting data to identify the major spatial drivers of bicycle choice; (see paragraph 4.1.1)
- a model predicting the emission levels from transport while taking into account the slopes along the trajectory; (see paragraph 4.2.1)
- a detailed planning for the integrated measurement campaigns on all of the selected case studies including a pilot test to demonstrate feasibility; (planning not detailed in this report, see paragraphs 6.1 and 7.2 for the results of the pilot tests)
- a dedicated website to inform the user committee and the wider public about the SHAPES project (see www.shapes-ssd.be)

5 METHODOLOGY

5.1 Spatial analysis of commuter traffic, injuries and accidents in Belgium at high resolution

Part of the results of this research has already been accepted for publication in Transport Policy (see Annex A, N°1). Other results will likely result in 3-4 other peer reviewed papers (Annex A, N° 2-5, 8).

5.1.1 Identify spatial constraints to commuter cycling

We here aimed at understanding commuting by bicycle and its spatial variations. More particularly, we: (1) evaluating the link between urban hierarchy and bicycle use for commuting, (2) examining who is choosing the bicycle as transport mode for commuting, and (3) examining the constraints to cycling.

- *Urban cycling (e.g. topography, etc.) and identification of "bikeable" environments*

These analyses are based on the 2001 socio-economic census data (NIS, 2001) and are conducted at a meso-scale (i.e. the 589 Belgian communes). The role of distance to workplace was particularly studied as well as its influence on the bicycle share, and this separately for each hierarchical rank of the cities. Among a large number of factors influencing the modal choice, we hence focus on municipality features (e.g. urban design, lay-out of transport networks, accessibility to facilities, diversity of land-use, or cycling policies) and trip-related factors (e.g. distance to the workplace, travel time, speed, or travel complexity).

The use of non-motorized modes is generally influenced by the way land is developed and used. Environmental variables such as proximity (characterized by the density and the diversity of land-use) and connectivity (characterized by the lay-out of the transport network) correlates with walking and cycling (see e.g. Saelens et al., 2003). Indeed, it will be more convenient to achieve a specific activity schedule (e.g. work, recreational activities) in a compact and mixed-use environment than in a low-density area such as a small rural town, since trip distances tend to be shorter and more bikeable (Saelens et al., 2003; Pucher and Buehler, 2006). Thus, it may be expected that cities with high population densities are the most favourable environments for non-motorized modes such as walking and cycling. In a very global way, it holds true for Belgium but it is worthy of note that the largest and densest cities (noted here H_1) do not present the most favourable environment for cyclists. In contrast, it does for H_2. Figure 1 supports this assertion, illustrating the proportion of commuters who cycled (*Y*-axis) as a function of the distance they travelled to work (*X*-axis) and the type of commune in which their workplace was situated. It confirms that, for most people, 10 kilometres is the limit for cycling to work, whatever the environment of the workplace. Below that limit, bicycle use is more frequent in urban environments.

However, the rank of the city also plays an important role: for distances below 5 km, cycling appears to be most popular in communes of rank H_2 (regional cities), while large cities (H_1) are characterised by the lowest proportion of cycling commuter (only approximately half the rate in H_2). This can be explained by the fact that in large cities (H_1), walking is frequent due to the close proximity of different places/activities. Public transport is also well-developed (dense network, high frequency, comfort, etc.) and hence is highly competitive to cycling (Figure 2). It encourages intermodal journeys including walking as feeder mode (for both access and egress trips). In large cities such as Brussels, the distance between the place of residence (or work) and the closest public transport stop/station is generally short: approximately 96% of the inhabitants (and jobs) are located less than 500m from the closest public transport stop (Vandenbulcke et al., 2007). In H_1 cities, traffic is also much denser than elsewhere, and an adequate cycling infrastructure is often lacking. All these reasons may dissuade people from cycling to work in large cities.

In smaller cities (H_2), road traffic is less dense and public transport is often limited to buses (no tram or metro). This may explain the popularity of the bicycle for commuting. Moreover, many of these regional cities (Bruges, Leuven, etc.) are located in Flanders where cycling is traditionally more common and where the city networks are tighter. In Wallonia, the city networks are looser, leading to longer (and hence unbikeable) commuting distances (see Verhetsel et al., 2007).

Figures 2 and 3 confirm that the proportion of commuters who walk to work is very high (60%) for trips of less than 1 kilometre, but decreases sharply with increasing distances. By contrast, the proportion travelling by car increases steadily with distance: it is more than 40% for trips of 2 kilometres and rises to over 60% for distances of 5 kilometres or more. Comparing Figures 2 (H_1) and 3 (H_2) confirms the importance of the size/rank of the destination town on mode of transport: bicycle use is greater in H_2 than in H_1, after which it slightly decreases for smaller towns. Fewer commuters use public transport to reach low-ranked communes (e.g. H_8), probably because of the poorer quality of public transport (which also explains the high figures for car use in such areas).

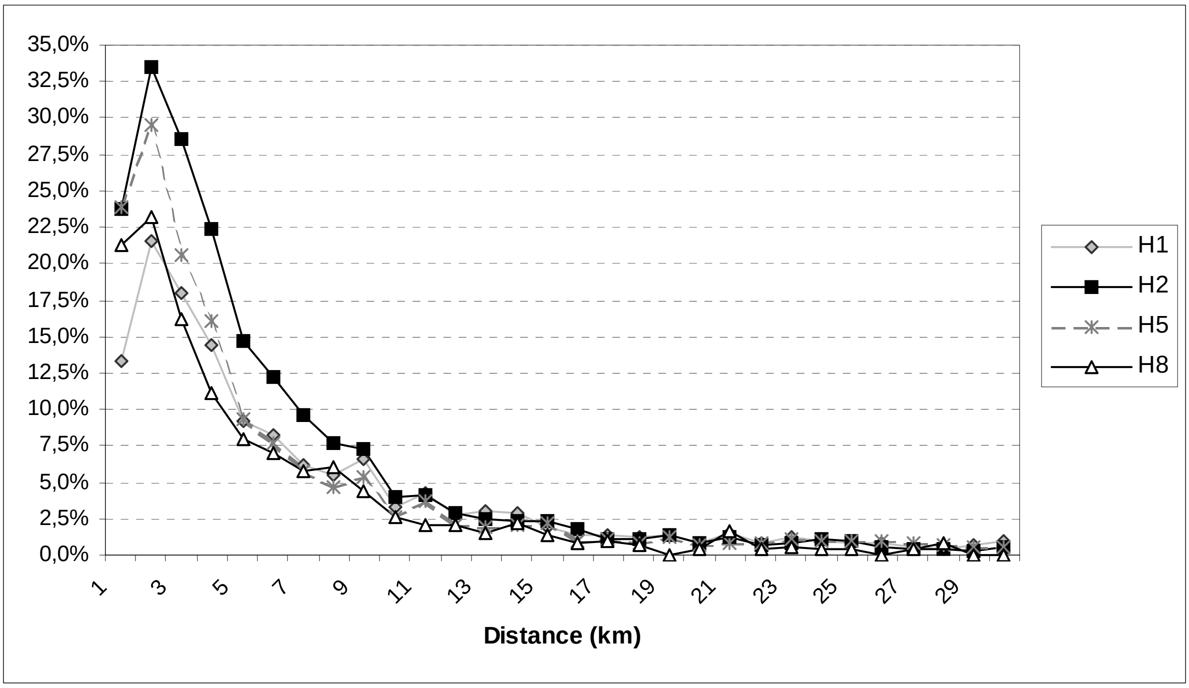

Figure 1: Proportion of commuters that cycle in function of the urban hierarchy (H_j) of the workplace and commuting distances (2001)

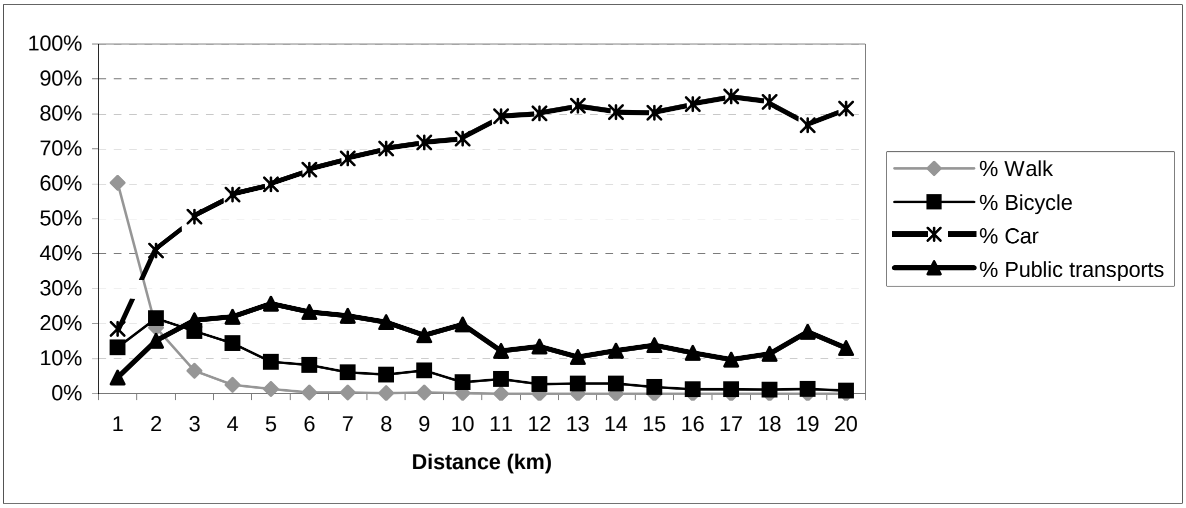

Figure 2: The proportion of commuters using different modes of transport for destinations in H_1 cities (2001)

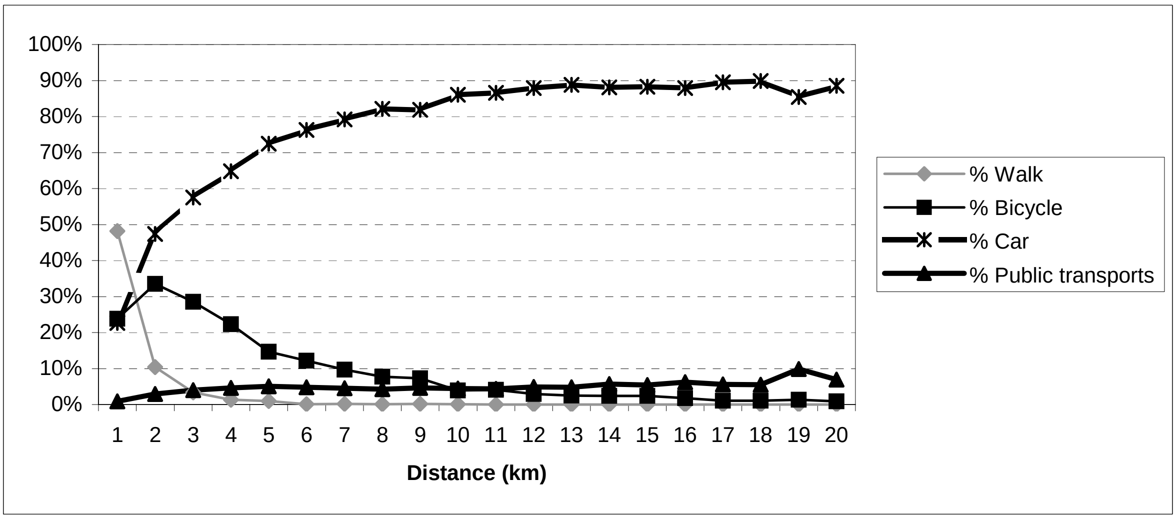

Figure 3: The proportion of commuters using different modes of transport for destinations in H2 cities (2001)

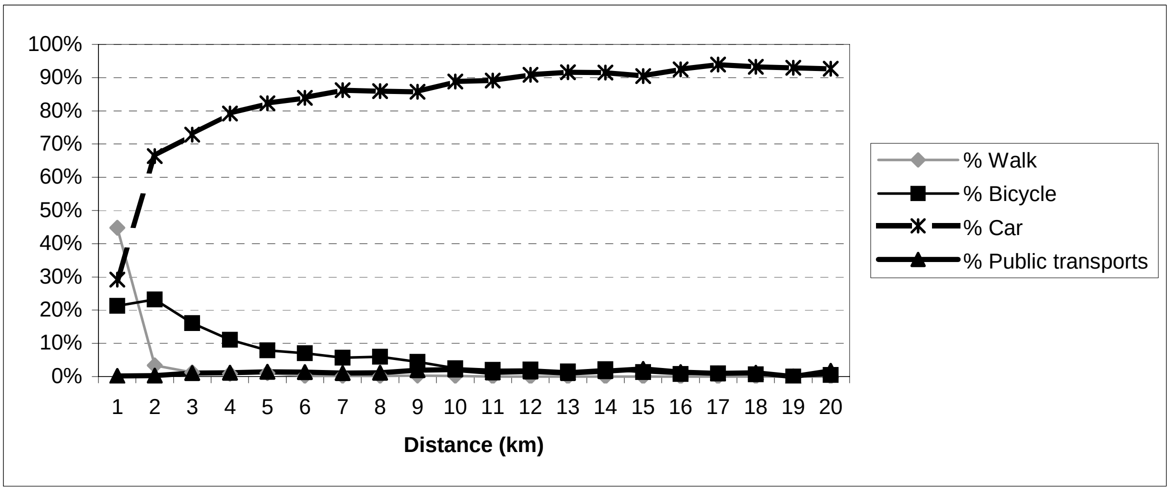

Figure 4: The proportion of commuters using different modes of transport for destinations in H8 cities (2001)

- *Modelling meso-scale spatial variations of bicycle use*

This second part aims at examining which are the factors that influence bicycle use for commuting in Belgium. It differs from previous work in several points. First, we aim at explaining the *spatial* variation of bicycle use performing multivariate analyses (i.e. linear regression, principal components analysis, …) at the scale of all 589 Belgian communes. Second, a larger set of "explanatory" variables is included in the analysis, with a specific attention on environmental variables as well as demographic components. Finally, special attention is put on spatial autocorrelation (correlation of a variable with itself through space), endogeneity (correlation between the independent variable and the error term in a regression model) and multicollinearity problems (correlation between two or more variables in a multiple regression).

a. Literature: identifying the main determinants of bicycle use

A large range of factors have an impact on the use of bicycle in commuting trips: individual, social, cultural, but also environmental and policy-related variables act as deterrents or encourage cycling. **Individual factors** are e.g. age, income, gender, education, professional category and status, and family commitments (e.g. having young children). **Social and cultural factors** also influence bicycle use (see e.g. Pucher et al., 1999; Rietveld, 2001; Dickinson et al., 2003; Rietveld and Daniel, 2004; Witlox and Tindemans, 2004; Plaut, 2005; Pucher and Buehler, 2006). In particular, differences between countries, regions or – even – ethnicities are probably explained by *traditions* and lifestyles. Among **environmental variables**, the main determinants that have an impact on bicycle use are the relief, the weather – and eventually climatic – conditions, the urban spatial structure and the infrastructure. Lastly, **policy-related variables** play a key role in encouraging more and safer cycling (Pucher et al., 1999) through the implementation of a large range of measures, e.g. the provision of safe and secure infrastructures (e.g. cycleways or guarded cycle parking facilities), the creation of financial incentives, the use of adequate land-use and transport planning, the regulation of the private car, the policies adopted by companies, or the promotion of cycling (Rietveld, 2001; Dickinson et al., 2003).

For further information, please see Vandenbulcke et al. (2008).

b. Data collection at the municipal level

Explanatory variables fall into 4 main categories: (1) socio-economic variables, (2) accessibility variables, (3) land-use data, and (4) environmental variables.

<u>*Socio-economic characteristics*</u>

This first group of variables comes to a large part from two databases: the 2001 socio-economic Census and the National Institute for Statistics (NIS). Note that the first database is preferred to other surveys (e.g. MOBEL, 1998-1999) since it is applied to the entire Belgian population and it is the most recent source of socio-economic data in Belgium. In particular, the median incomes, the percentage of active people that are men, and the percentage of households that do not own any car are extracted from the website of the National Institute for Statistics (2001). Additionally to these data, the 2001 socio-economic Census was of great help to compute the percentages of active people belonging to various life phases (i.e. being less than 25 years or between 45 and 54 years of age, for instance) or having specific education levels (e.g. percentage of active people having a university degree as highest qualification). It is shown that a large majority of commuter cyclists have got a secondary

(60%) or primary (7%) education as highest degree in Belgium. It is also interesting to note that the highest share of commuter cyclists (9.1%) is observed within the population of commuters having a primary degree, while it only reaches 6.4% when commuters have an university degree. Such observations go in the opposite direction of results obtained by Plaut (2005), who shows that a higher education encourages cycling (in U.S.). Another variable extracted from the 2001 Census is related with the subjective health of people, and consequently with the (physical and/or mental) ability to cycle. This variable is the percentage of inhabitants in a commune declaring not to be in good health (NIS, 2001).

The 2001 socio-economic census finally allows us to get a measure of family commitments: the percentage of active households (i.e. with one or more active parents) having one or more young children (i.e. aged between 0 and 5 years). Some exploratory analyses show that having young children has a deterrent impact on bicycle use and that differences exist with gender. Although the difference is not very large (which explains that we do not focus exclusively on women when constructing the variable related with the family commitments), less women cycle to work when they have one or more young children (Figure 5). This impact is the highest when women have 2 young children, while it is the lowest when they have 3 children or more. Nevertheless, having one or more children has not always a deterrent impact: indeed, the share of women that cycle to work increases when the children have between 12 and 17 years (whatever the number of children); the share of active women cycling and having 3 or more children aged between 12 and 17 years raises to 10.6% while it is only 6.2% without children (still aged between 12 and 17 years). Also the share of women driving to their workplace is lower when the children are aged between 12 and 17 years (compared with women taking care of younger children). This observation justifies the fact that we limit ourselves to children aged less than 5 years.

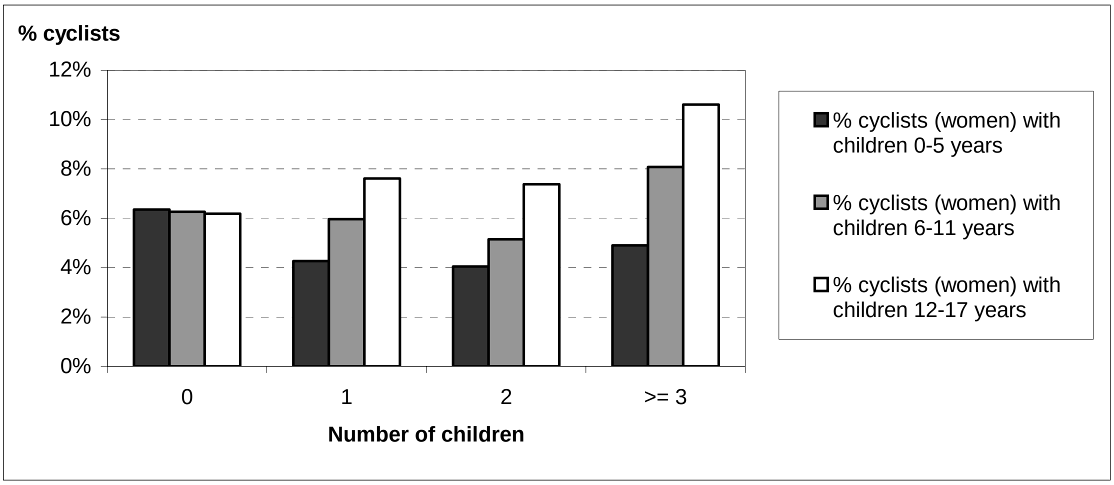

Figure 5: Share of commuter cyclists (women) having children being between 0 and 5 years of age. Source: NIS, 2001.

<u>*Accessibility (commuting distances)*</u>

Accessibility is a key factor in transport geography; its exact measurement is not straightforward (see e.g. Geurs and van Eck, 2001). However, in our case, we simply considered the commuting distance, which highly constrains transport mode choice (Kingham et al., 2001; Dickinson et al., 2003; Saelens et al., 2003). It is here expressed as the observed average distance between residence and workplace, by commune of residence (Source: NIS, 2001). Originally, two other variables were included in this group (i.e. the minimum network distance to the closest town and the percentage of commuters that live no further than 10 km from their workplace) but they were removed due to a lack of significance in the multivariate analyses.

Land-use characteristics

Land-use characteristics are highly constrained by the availability of the data. The National Institute for Statistics provides population and jobs densities, as well as the percentages of urban, forest, agricultural, public and recreational land surfaces in each commune. It is here expected that the presence of public areas in a commune stimulate bicycle use. Exploratory analyses conducted in the framework of this study show that most of cyclists generally work in public fields (e.g. administration, education and health). According to Wendel-Vos et al. (2004), we also assume that high percentages of forest or recreational areas encourage cycling. Lastly, the urban hierarchy was also considered (Van Hecke, 1998). It is divided into 8 types of communes. The variable is coded in such a way that the largest towns have low values (Brussels is coded 1), and inversely for the smallest towns (codes 6, 7 or 8).

Spatially speaking, high population densities are observed in the main Belgian cities. It is here assumed that commuters are the most likely to cycle when they live in environments with moderate densities. Communes with low densities are characterised by large commuting distances and so they are not attractive environments for cycling, whereas communes with high densities do not necessarily lead to high bicycle shares because of the presence of public transports. Also walking trips are favoured in such environments (this is due to the fact that distances are small between the activities).

Environmental variables

This last subset includes variables that characterize the neighbourhood of the communes where the commuters live; in other terms, it gathers variables that define how attractive the nearby environment is for cycling. Firstly, the National Geographic Institute (NGI) provides a Digital Elevation Model (DEM) for which height values are attributed to pixels (90 x 90m). Slopes were then estimated by integrating the DEM in a Geographic Information System (GIS): more particularly, the function 'Slope' (Spatial Analyst) was used in ArcGIS 9.2. and allowed to calculate the maximum rate of change from each cell (or pixel) to its closest neighbours. The final step consists in estimating the mean slope along the municipal road network (except motorways and express roads since they are forbidden to cyclists). The presence of slopes is expected to have a deterrent effect on bicycle use.

Secondly, concerning the cycle ways, we extracted a proxy variable from the 2001 Census since there is no database about this in Belgium. For the first time, the last census has a question about how happy the households feel about several elements of their living environment, among which cycle ways. The proxy is then defined as the percentage of households estimating that cycling facilities located in the neighbourhood are of poor-quality.

Thirdly, the risk for a cyclist being involved in a road accident was also roughly estimated using the 2001 Census and NIS data. This risk[1] is defined as follows:

[1] Note that the risk of accidents calculated in the Equation (1) is probably under-estimated (for all communes) since most of studies using or evaluating the NIS data show that only a small part (15-30% depending on the estimations) of the bicycling accidents are reported (see e.g. De Mol and Lammar, 2006; IBSR-BIVV, 2006; Hubert and Toint, 2002).

$$R_i = N_i / T_i \qquad (1)$$

where N_i is the average annual number of injuries to cyclists aged between 18 and 65 years, between 2002 and 2005 and occurring on weekdays in commune i. T_i is the total time (return trip) spent travelling by commuter cyclists living in commune i per year (assuming 232 working days). It is considered as the exposure time to potential injury from commuter cycling. Note that in communes with less than 10 regular cycle commuters, the total commuting time T_i was interpolated from the average times in neighbouring communes.

Fourthly, we expect that cycling is discouraged where bicycle thefts are frequent. Data from the Federal Police were used for the period 2000-2002. In Belgium, criminality statistics show that there are approximately 32,000 bicycle thefts but, in reality, only 45% victims lodge a complaint and the rate of report varies spatially. Note that calculating the ratio between the number of thefts and the number of cyclists in the commune did not lead to relevant results in the multivariate analyses, which explains we only accounted for the number of bicycle thefts by year and by commune.

Fifthly, traffic data (vehicles.km by commune) were obtained from the FPS Mobility and Transports by using results from countings, surveys and estimations (these latter are based on the size of the automobile park and on the volume of traffic transiting on the neighbouring road sections). These data were used to compute a proxy variable for the volume of road traffic transiting in a commune. Such a proxy is defined as the number of vehicles by kilometre of municipal or regional road (motorways are excluded since they are not 'bikeable') and is expected to have a deterrent impact on bicycle use when the volume of traffic is high.

Finally, the ambient air quality was also used, as we expect that high concentrations of pollutants discourage cycling. Particulate matter concentrations (PM10) were obtained from the Belgian Interregional Cell for the Environment (IRCEL-CELINE) for the years 2000-2005. Measurements are made in telemetric stations and interpolated to a grid data formed by pixels of 4 x 4 km. Using the grid data and performing zoned statistics, we were able to estimate the mean concentration of particulate matter (PM10) by commune.

c. Results

In this section, bivariate and multivariate analyses are performed for (1) estimating the relationships between each of the explanatory variables and the dependent variable (i.e. the share of commuter cyclists). This allows us to identify which are the variables that most influence bicycle use. We also (2) examine the relative importance of variables explaining the spatial variations of bicycle use at the scale of communes. This requires the development of a model using multiple regressions. Such an analysis allows us to quantify which impact (potential) variations of variables have on cycling levels.

Also note that attention is put on multicollinearity when performing regression analyses. Spatial autocorrelation and endogeneity will be approached in a forthcoming version of the paper (not presented here).

Basic statistics and bivariate correlations

Table 1 presents some basic statistics as well as Pearson correlation coefficients between each of the explanatory variables and the share of commuter cyclists. A Spearman Rank correlation was also performed for the variable related to the city size because this latter is expressed on an ordinal scale. For the calculation of the bivariate correlations only, several variables (noted in italic form) were transformed using a logarithmic function (*ln(x+1)*) in order to satisfy the assumption of normality. This latter is essential to test the Pearson correlation coefficient (Ebdon, 1985).

Most explanatory variables are significantly correlated with the dependent variable and have the expected signs. The highest correlations are observed for variables related to the (un)satisfaction of cycle paths (-0.82), the slopes (-0.77) and the (bad) health of inhabitants (-0.58). Such variables seem to discourage strongly the use of the bicycle in commuting trips (negative sign). It is also noteworthy that the positive correlation between the share of commuter cyclists and the number of bicycle thefts (0.75) does not highlight the deterrent effect that might be caused by the thefts on cycling; it just seems indicating that a high number of bicycle thefts is to be found where bicycle share is high (expectable). As a consequence, bicycle thefts will further be excluded from our analysis.

Other variables show strong relationships with bicycle use. In particular, commuting distances (-0.54), the proportion of active households having young children (-0.39), the proportion of active people being between 45 and 54 years of age (-0.39), the proportion of forest area (-0.33) and the accident risk (-0.32) are all negatively correlated to the share of commuter cyclists. At the opposite, the proportion of active people being less than 25 years of age (0.54), the density of jobs (0.38), the proportion of urban area (0.34) and the traffic volume on regional roads (0.31) show positive correlations with bicycle use in commuting trips. On average, these relationships confirm hypotheses about mode choice processes in transport geography.

Table 1: Basic statistics and bivariate correlations with the share of commuter cyclists at the scale of the communes (n = 589)

Variable	Mean	Standard Dev.	Min	Max	Correlations
Share of commuter cyclists (dependent)	4,6	4,6	0,0	21,7	1,00***
Incomes	19430,8	2005,3	13379,0	25120,0	0,25***
Active men	57,6	2,0	50,7	64,6	0,00
Population density	675,6	1735,7	21,4	19128,6	0,28***
Jobs density	203,6	725,9	1,3	8342,1	0,38***
Age 1 (< 25 years)	10,0	1,9	5,2	17,5	0,54***
Age 2 (45-54 years)	23,5	2,4	15,7	42,4	-0,39***
Age 3 (> 54 years)	6,9	1,5	3,9	15,3	-0,30***
Education 1 (primary degree)	6,0	1,9	2,0	15,3	0,05
Education 2 (secondary degree)	57,5	7,3	25,8	70,3	0,21***
Education 3 (university degree)	36,6	8,4	15,3	71,8	-0,20***
Young children	20,7	2,7	10,5	30,6	-0,39***
Car availability	18,1	6,9	8,1	57,1	-0,25***
Cycle path satisfaction	65,1	18,4	24,6	95,8	-0,82***
Commuting distance	22,6	5,7	10,2	42,7	-0,54***
Bicycle thefts	56,4	166,8	0,0	2451,7	0,75***
Accident risk	0,3	0,5	0,0	7,0	-0,32***

Urbanisation	28,4	19,5	4,7	99,5	0,34***
Forests	14,3	16,2	0,0	74,0	-0,33***
Agriculture	57,3	21,2	0,5	93,6	0,09**
Public services	1,0	1,7	0,0	22,9	0,17***
Recreational areas	2,0	2,4	0,1	15,9	0,12***
Air quality	29,3	4,2	20,6	40,8	0,23***
Slopes	2,8	2,0	0,7	10,8	-0,77***
City size	6,3	1,5	1,0	8,0	-0,23***
Traffic volume 1 (regional network)	3,1	1,9	0,0	14,0	0,31***
Traffic volume 2 (municipal network)	0,2	0,2	0,0	1,4	0,12***
Health	24,1	5,0	15,1	39,4	-0,58***

**Significant at the 95% level
***Significant at the 99% level
Italic: variables logarithmically transformed.

Regression analyses

A stepwise regression is performed here. The analysis of condition indices, tolerance and VIF values (Variance Inflation Factors) further reveals that there are still strong relationships between several of the explanatory variables. So we formulated the following conditions in order to assume that the multicollinearity problems are not significant in the model: (1) tolerance > 0.30, (2) VIF < 3.50, and (3) condition index (without intercept) < 10. These conditions lead us to remove other explanatory variables (additionally to these removed by the stepwise regression) and conducts to the final regression model. Results are reported in Table 2 and indicate that the goodness of fit of the regression model is quite good (R^2 = 0.8804). All parameters are at least significant at a 10% level of probability and the VIF values are rather low. Also, the validity of the regression model was appreciated by testing the four major assumptions of the regression. Performing several statistical tests (e.g. Kolmogorov-Smirnov test, White test, …) indicated that assumptions of linearity, homoscedasticity and normality were all satisfied. However, the calculation of the Moran's coefficient (I) showed that the independence of residuals was not satisfied and that spatial autocorrelation exists among the residuals. Indeed, the value of Moran's coefficient in this case is 0.28 and the significance test indicates that the distribution of residuals is not significantly different from random (z = 14,4). A cartography of the local Moran's I index of spatial autocorrelation (not shown here) confirms this result. It shows strong spatial autocorrelation for Brussels and several Flemish communes. Note here that such a problem will be approached in a further part of this paper. Analyses were performed with a software (GeoDa 0.9.5-i) that allowed us to address the spatial autocorrelation problem.

Table 2: Regression model (stepwise) aiming at explaining the share of commuter cyclists at the scale of the 589 Belgian communes

Variable	Parameter Estimate	Standard Error	t-value	Pr > t	Variance Inflation
Intercept	1,79454**	0,76366	2,35	0,0191	0,00
Active men	0,04766***	0,00844	5,65	<.0001	2,03
Age 2 (45-54 years)	-0,04468***	0,00697	-6,41	<.0001	2,02
Education 1 (primary degree)	0,01836**	0,00860	2,14	0,0332	1,89
Young children	-0,05783***	0,00635	-9,10	<.0001	2,10
Cycle path satisfaction	-0,01325***	0,00116	-11,39	<.0001	3,19
Commuting distance	-0,01141***	0,00340	-3,35	0,0009	2,66
Air quality	0,01433***	0,00389	3,69	0,0002	1,88
City size	-0,09111***	0,01046	-8,71	<.0001	1,76
Health	-0,05304***	0,00359	-14,76	<.0001	2,23
Accident risk	-0,17262***	0,05337	-3,23	0,0013	1,22
Traffic volume 2 (municipal network)	-0,89308***	0,16294	-5,48	<.0001	2,70
Age 3 (> 54 years)	-0,16772*	0,08944	-1,88	0,0613	1,90
Education 2 (secondary degree)	0,65382***	0,14286	4,58	<.0001	2,84
Slopes	-0,46949***	0,04748	-9,89	<.0001	3,21
R-squared	0,8804				
Ajusted R-squared	0,8775				
F-value	301,95***				
Root MSE	0,2899				
N	589				

*Significant at the 90% level
**Significant at the 95% level
***Significant at the 99% level
Italic: variables logarithmically transformed.

Table 2 shows that all parameters of the explanatory variables are significant and have the expected signs. It also indicates that most of the explanatory variables have a deterrent impact on the modal share of commuter cyclists and are related with socio-economic and environmental features of the communes. Varying a single explanatory variable and holding all others constant at their means is one practical way to determine this relative importance between the variables (see e.g. Rodríguez and Joo, 2004). Additionally to this, it also predicts the share of commuter cyclists for different values of one specific variable. As illustration, Figures 6 and 7 show the results for several explanatory variables (the fact that different units of measurements are used in the model prohibits us from making the comparison on a same figure). At first glance, variables such as the proportion of active households with young children or the proportion of commuters being between 45 and 54 years of age seem to act as strong deterrents for cycling. For instance, when a commune increases its share of active households with young children from 10 to 20% (all other variables being held constant at their means), the share of commuter cyclists is reduced by 50% (it decreases from 20% to 10%). Approximately the same effect (but slightly lower) is observed concerning the proportion of commuters being between 45 and 54 years of age. It is noteworthy that the share of commuter cyclists increases when the percentage of active households with young children is higher than 64%. Probably the higher share of young children in the population forces the road users to be more careful (since young children are more present and visible), thus making the environment more bikeable.

Figure 6 reveals the deterrent impact on bicycle use associated with the percentage of households estimating they have bad bicycle paths in the neighbourhood. This variable shows a quite linear function, which suggests that a 10% increase of the percentage of unsatisfied households would reduce the bicycle share by more than 13%. Variables such as the percentage of inhabitants feeling they have a bad health or the share of commuters being more than 54 years of age also act as deterrents, but their impact is rather small. Nevertheless, we observe that it is not especially true when communes have low shares for the second variable (which is almost still the case). Indeed, an increase from 5 to 10% of commuters being more than 54 years of age would lead to a 10.6% decrease of the bicycle share, which is quite high. Surprisingly, the comparison between both variables related with the age however shows that the percentage of commuters being between 45 and 54 years of age has a stronger deterrent impact on bicycle use. The need older commuters have to maintain or improve their fitness is probably one of the main reason explaining such differences. Figure 6 finally indicates that some explanatory variables stimulate cycling, especially these related with the education and the gender of commuters. More particularly, the percentage of commuters having a primary degree as highest qualification and the percentage of active people that are men have an outstandingly stimulating effect on bicycle use when their shares are higher than 20%. It is noteworthy that this effect is reduced for increasing percentages of commuters having a secondary degree.

Figure 7 refers to environmental variables and commuting distances. As expected, increasing values of the mean slope, the traffic volume on the municipal network, the accident risks, and the commuting distances decrease the propensity to cycle. Interestingly, the slope variations for relatively flat terrains have a more pronounced effect on cycling: an increase from 0 to 1° of the slope on the road network (e.g. due to works or deviations on the road network) could reduce the share of commuter cyclists by more than 29%. Conversely, it also suggests that reducing the slopes along the road network significantly increases the bicycle share, especially for communes where the mean slopes goes up to 5 degrees (or 8.7%). Above this "limit", the impact is lower and leads to small increases in the share of bicycle use (approximately 6% per degree). Concerning the traffic volume on the municipal network, the results show that even small reductions of traffic lead to high increases of bicycle use in commuting trips. Indeed, a decrease of 100,000 vehicles (by kilometer and by year) could increase the bicycle share by 9%. Risks cyclists have to be involved in accidents also strongly discourage bicycle use: an increase of this risk from 0.5 to 1 (which corresponds to 2 more victims by year and per 100,000 bicycle-minutes) results in a 5.3% reduction of the share of commuter cyclists. Longer commuting distances also have deterrent effects and do not stimulate commuters to cycle. For instance, an increase from 5 to 10 km leads to a 6% decrease of bicycle use.

Other variables such as the city size or the air quality were not illustrated in the previous figures but they however show interesting results. In particular, the analysis of the effect of the city size on bicycle use reveals that rural communes have low or modest shares of commuter cyclists (i.e. less than 10% on average) while the largest towns are associated to high shares of bicycle use (i.e. more than 15% on average). Air quality also seems to matter: surprisingly, the results show that increasing concentrations of PM10 lead to higher bicycle shares. The spatial analysis of this explanatory variable (not illustrated in this paper) shows that congested urban areas are the most concerned about high concentrations of particulate matter. Hence this suggests that more road congestion probably stimulates more commuters to cycle in order to avoid the losses of time caused by the traffic jams.

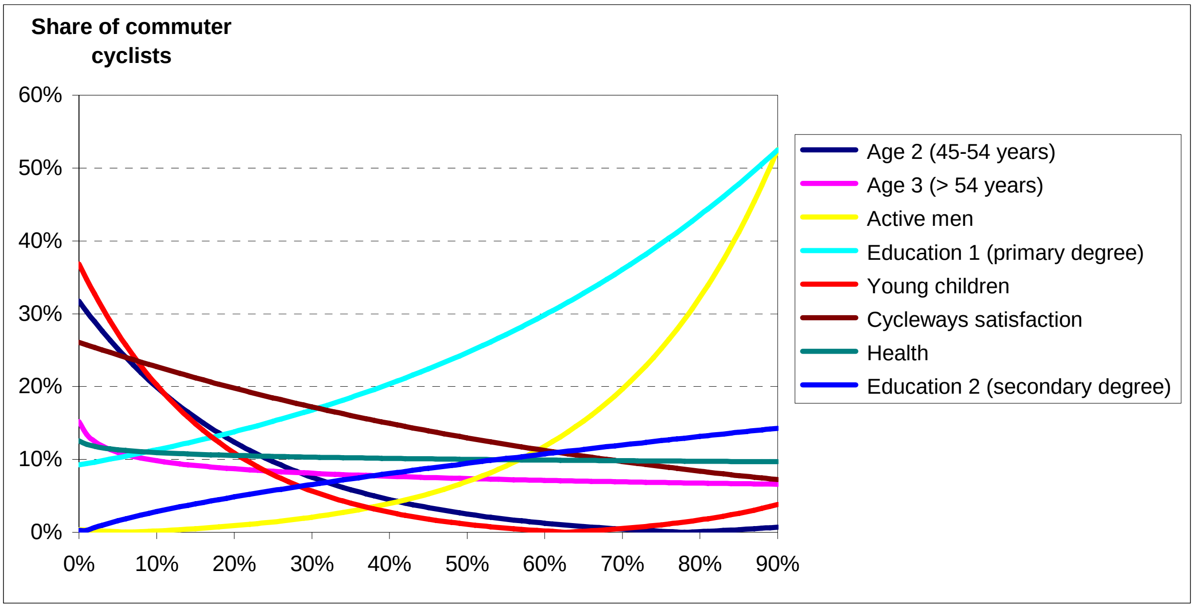

Figure 6: Variation of the dependant variable (i.e. share of commuter cyclists) as several explanatory variables change while holding all others constant at their means

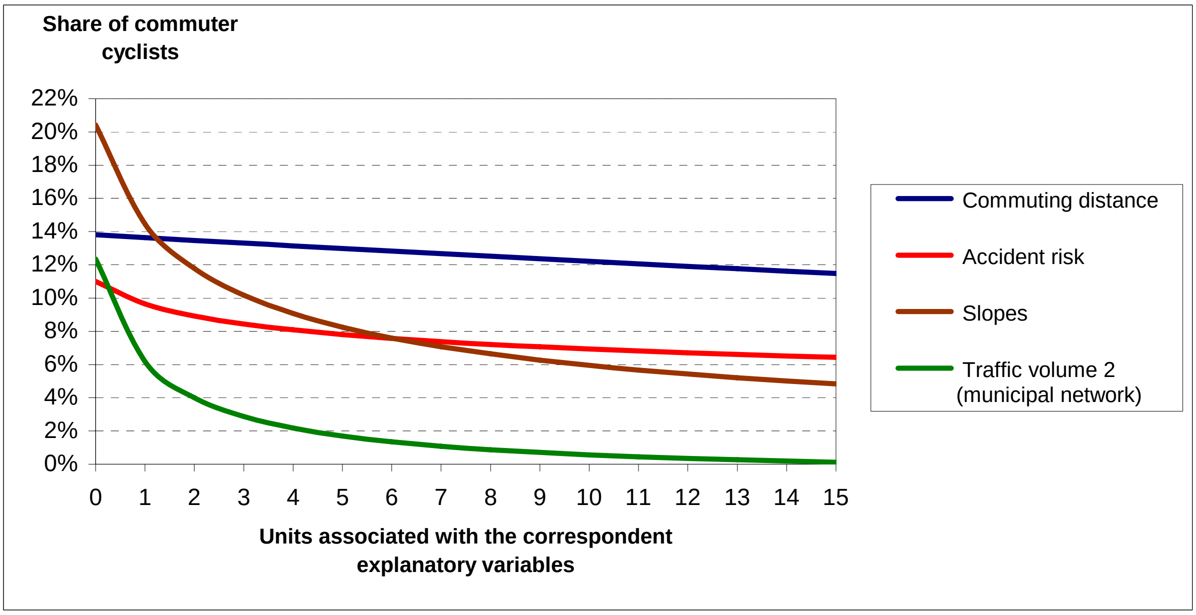

Figure 7: Variation of the dependant variable (i.e. share of commuter cyclists) as several explanatory variables change while holding all others constant at their means

d. Spatial regression model

The calculation of the Moran's coefficient (*I*) and Lagrange Multiplier (*LM*) tests in the GeoDa software revealed the presence of spatial dependency (spatial autocorrelation) when modelling bicycle use. They also suggested to use a spatial lag model to deal with this issue, thus indicating that the value of the dependent variable in one commune (or municipality) is affected by neighbouring values of the dependent or independent variables.

In general, the results obtained by means of the spatial lag model were quite similar to those obtained with OLS techniques (see Table 3). They still show that inter-municipality variation in bicycle use is mainly related to physical aspects such as relief, city size and distance travelled, as well as population features. Interestingly, they also reveal (through the introduction of a spatially lagged coefficient in the regression) that high bicycle shares stimulate cycling in neighbouring communes and hence that a mass effect can be initiated, i.e. more cyclists travelling to work encourage even more commuters to cycle. Such findings support policy measures aiming at developing bicycle use in urban areas by means of the implementation of bicycle sharing systems.

Note that this part of the research is still on-going.

Table 3: Regression model (stepwise) aiming at explaining the share of commuter cyclists at the scale of the 589 Belgian communes

Variable	Coefficient	Standard error	z-value	Probability
Spatially lagged coefficient (ρ)	0,59819	0,03204	18,67203	0,00000
Intercept (α)	1,45228	0,71572	2,02910	0,04245
Median income	0,00001	0,00001	1,16803	0,24279
Active men	0,01587	0,00687	2,31045	0,02086
Age 2 (45-54 years)	-0,02634	0,00563	-4,67832	0,00000
Education 1 (primary degree)	0,00458	0,00664	0,68908	0,49077
Young children	-0,02644	0,00513	-5,14906	0,00000
Cycleways satisfaction	-0,00486	0,00100	-4,87793	0,00000
Commuting distance	-0,00721	0,00265	-2,71762	0,00658
Air quality	0,00343	0,00301	1,13883	0,25478
City size	-0,08536	0,00808	-10,56589	0,00000
Health	-0,01861	0,00365	-5,09388	0,00000
Accident risk	-0,14043	0,04097	-3,42764	0,00061
Traffic volume 2 (municipal network)	-0,55257	0,12561	-4,39921	0,00001
Age 3 (> 54 years)	-0,15428	0,07023	-2,19668	0,02804
Education 2 (secondary degree)	0,29025	0,11277	2,57375	0,01006
Slopes	-0,17927	0,04010	-4,47022	0,00001

Italic: variables logarithmically transformed.

5.1.2 Identify 3 case study commuting trajectories

There is a need for selecting representative commuting trajectories in order to help the other teams to conduct physical tests. We suspect that the place of the test is of prime importance. Hence, several spatial analyses were performed in order to show and measure spatial differences within Belgium. One of these analyses held our attention: it is based on the well-known assumption that higher bicycle shares are generally correlated with lower cycling fatality rates (Jacobsen, 2003; Pucher and Buehler, 2006).

Our aim is hence to classify the 589 communes by means of two criteria: exposure of cyclists in traffic (i.e. time spent cycling) and accidents rates. We here used official databases and combine accident statistics for the years 2002, 2003, 2004 and 2005 (INS) with trip-related data (i.e. travel time for commuter cyclists) extracted from ESE2001 (population census, INS). For each commune the share of cycling commuters is obtained (census) as well as an accident risk[2]. Those two variables lead to a classification of the communes, underscoring some specific clusters that are easily associated with specific social and cultural features, physical conditions, as well as transport and land-use policies. Results show that high shares of cyclists in commuters' flows are generally correlated with low risks to be seriously injured or dead in traffic crashes.

- *Bicycle use and risk of road casualties*

a. Formulating a risk of road casualties for cyclists

Road accident statistics are compiled annually by the National Institute for Statistics (NIS). They indicate that about 7,200 cyclists were injured or killed in 2002 and almost 8,000 in 2005. However, the number of deaths decreased from 108 in 2002 to 71 in 2005. The data used here are limited to a period of 4 years (2002-2005) and allow the risk of an accident to be computed for each commune. It is well-known that these statistics strongly underestimate the total number of cycling accidents, particularly when the cyclist is the only person involved and/or when no hospitalisation is involved. In Belgium, several authors have estimated that only 15 to 30% of cycling accidents are officially reported (see e.g. Doom and Derweduwen, 2005; De Mol and Lammar, 2006; IBSR/BIVV, 2006). As no correction exists for the entire country, we decided to include only accidents involving casualties that require hospital treatment (since these are systematically registered). An index of risk (R_i) was computed and used as a proxy for cyclists exposure to casualties:

$$R_i = N_i / T_i \qquad (2)$$

where N_i is the average annual number of injuries to cyclists aged between 18 and 65 years, between 2002 and 2005 and occurring on weekdays in commune i. T_i is the total time (return trip) spent travelling by commuter cyclists living in commune i per year (assuming 232 working days). It is considered as the exposure time to potential injury from commuter cycling. Note that in communes with less than 10 regular cycle commuters, the total commuting time T_i was interpolated from the average times in neighbouring communes.

Figure 8 indicates that in Flanders, the risk of a cyclist being seriously injured or killed in an accident was spatially homogeneous and lower than the average for the whole of Belgium ($\overline{R}_i = 0.069$, i.e. nearly 7 casualties occur when 10 000 000 bicycle-minutes are achieved). Only a few Flemish communes on the coast, near the linguistic border, in Limburg (Flemish provincy, in the north-east) or in the periphery of Brussels had casualty risks higher than the mean. In Wallonia, the casualty risks were much more varied: there was a very low casualty risk (equal or close to zero) in the majority of communes (due to the fact that very few if any cyclists were seriously injured or killed). On the other hand, nearly 38% of communes had quite a high casualty risk.

Interestingly, a low casualty risk was observed in most of the large cities, which seems to suggest that an urban environment is safer than a rural one for commuter cyclists. This may be partly explained by the large number of hurdles (traffic lights, pedestrian crossings,

[2] Accident risk is here defined as the ratio between the average number of cycling casualties, by year and by commune, and the travel time during which a commuter cycles between an origin i (residence) and a destination j (workplace). It is considered as a proxy used in order to estimate (for each commune i) the risk a commuter cyclist has to be seriously injured or dead in a traffic crash.

congestion, etc.) that reduce the speed of traffic in towns. However this is not true for all cities: moderate or high casualty risks are observed in some regional cities (25 000 to 120 000 inhabitants).

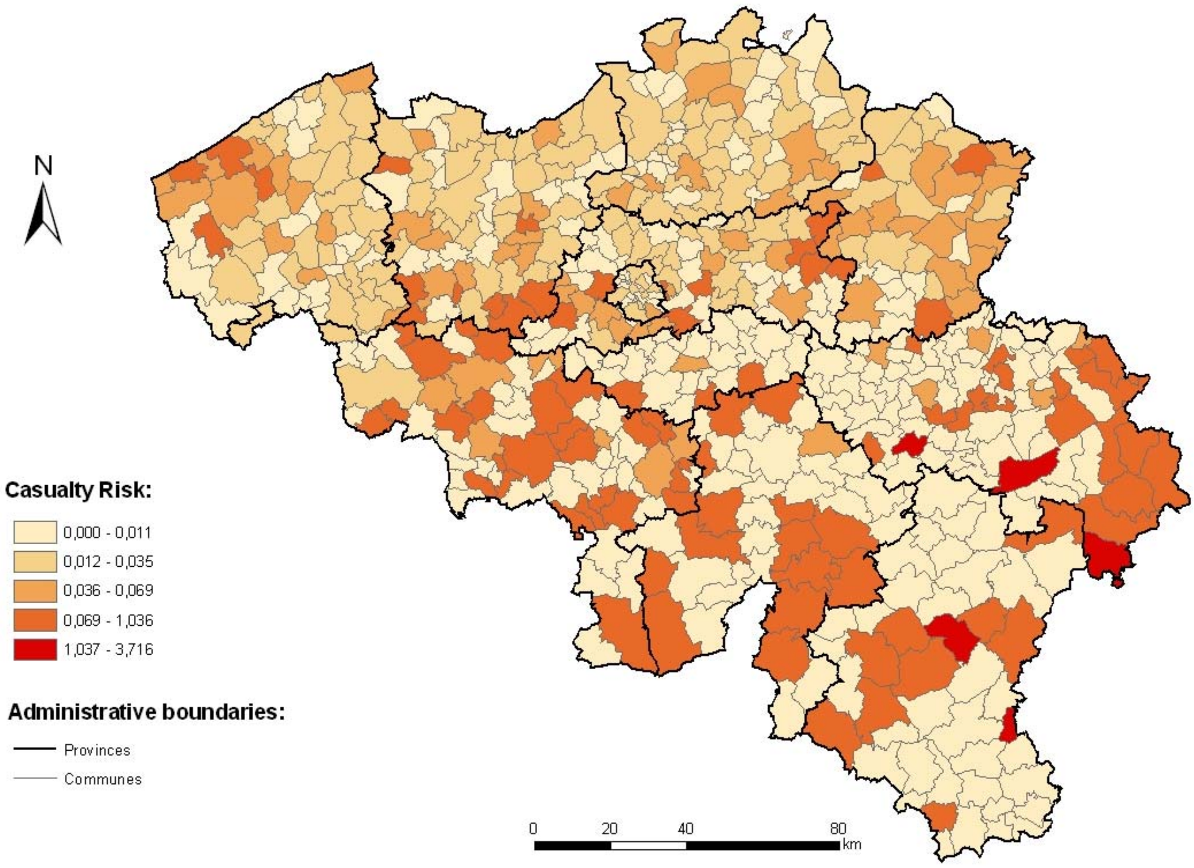

Figure 8: Casualty risk, defined as the average number of casualties

per 100 000 bicycle-minutes, by commune

b. Clustering communes

We clustered the 589 Belgian communes according to the exposure of cyclists commuting to these destinations to the risk of becoming casualties (approximated by T_i, the total journey time per year) and the proportion of commuting which was by bicycle, using Ward's ascending hierarchical method (Ward, 1963). At each step, this method minimises the sum of squares of any pair of clusters to be merged, so that the two closest clusters are joined to form a new cluster. In order to determine the optimum number of clusters, the *CCC* (cubic clustering criterion), the pseudo-*F* statistic (*PSF*), the pseudo-t^2 (*PST2*), the semi-partial *R*-squared (*SPRSQ*) and the *R*-squared (*RSQ*) were helpful (see e.g. Fernandez, 2002; Tufféry, 2005 for further information). These statistics suggest the use of eight clusters for the classification. The results help us to understand the geography of road accidents for cyclists, and suggest clues for local policy.

Figure 9 shows interesting spatial patterns, and emphasises the regional differences. Communes in clusters A, B and C provide the most "bikeable" environments (i.e. high and safe bicycle use) while those in clusters F, G and H are regarded as the least bikeable (i.e. low and unsafe bicycle use). **Clusters A**, **B** and **C** all have a low or moderate risk of casualties to cyclists, combined with moderate or high proportions of commuter cyclists (a few communes located on the coast or in Limburg have moderate accident risks, but the high use of bicycles offsets these risks). Such communes – mainly located in Flanders – are characterised by a safe and attractive environment for cyclists, encouraging cycling and leading to a virtuous circle (since more cyclists on roads reduce the risk of cyclists having accidents). In such communes, the availability of an adequate cycling infrastructure (e.g. cycleways, traffic lights for cyclists at junctions), the flat terrain, the lifestyle, and the presence of pro-cycling policies are some of the factors that stimulate cycling (Rietveld, 2001; Rietveld and Daniel, 2004; Witlox and Tindemans, 2004) and – as a consequence – make it safer. Also, many of the car drivers living in the Flemish Region are themselves cyclists (when commuting trips or for other reasons) and are perhaps more respectful towards commuter cyclists than drivers elsewhere.

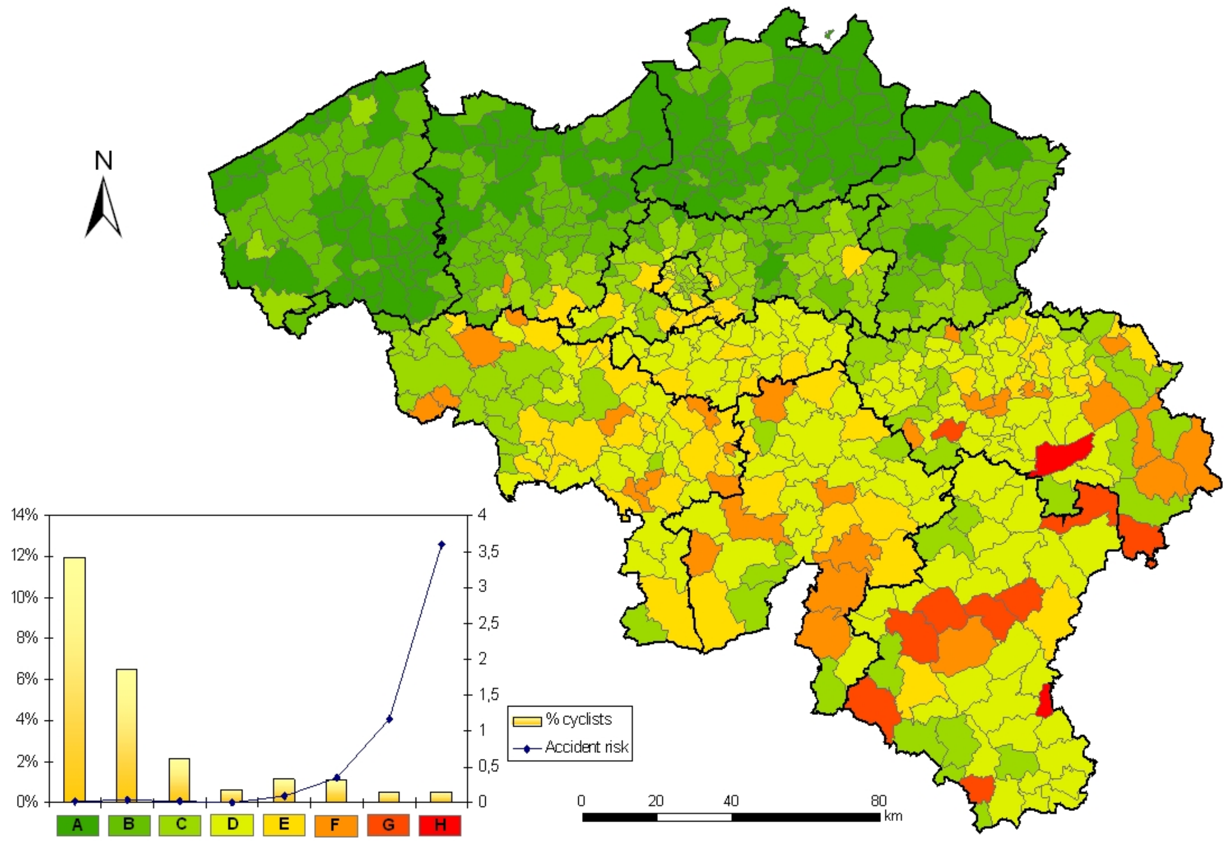

Figure 9: Classification of communes based on the two variables of bicycle use and the risk of cyclists becoming casualties

Cluster D covers communes that have both a small proportion of cycling commuters and a very low risk of cyclists becoming casualties (equal or close to zero). They are mainly located in Wallonia and consist of both urbanised and rural communes. In most of these communes, there were no cyclist casualties occurred for cyclists during the period studied (2002-2005) (in other words, the casualty risk was zero). However, in three communes (Uccle, Namur and Liège), the casualty risk was not zero, although it was still low. These communes are all highly urbanised, suggesting that the numerous impediments, such as crossroads and pedestrian crossings, slow down the faster traffic and so decrease the danger for cyclists.

Moderate bicycle use together with moderate or high casualty risks are found in **clusters E** and **F**. Most of the communes included in these clusters are in Wallonia, athough a few are in areas of Flanders close to Brussels. Every day, a large amount of traffic converges on Brussels, having passed through neighbouring communes, which may well increase the risk to cyclists in these latter. Road accident statistics (NIS) seem to confirm this assumption, in that they show that the proportion of accidents involving motorised vehicles is high in these communes.
One of the main factors triggering accidents is the driving behaviour of motorists: car drivers often make bad manoeuvres or lose control of their vehicle (*ibid.*). Moreover, they frequently do not respect the right-of-way (*ibid.*), which illustrates both the fact that cyclists are not an integral part of the "street scene" and that motorists do not always respect cyclists (especially in Wallonia). Cyclists constitute only a low proportion of the road traffic (i.e. they have low visibility) and most road users have never themselves experienced cycling as a way of commuting, which suggests that they cannot really put themselves in the cyclist's place. Of course, some accidents are caused by the cyclists themselves, when they do not follow the traffic signals (right-of-way) or are not in the correct place. Many accidents also happen when cyclists lose control of their bike or simply fall. Surprisingly, few of these accidents are caused by bad weather (e.g. rain or snow) and/or bad road conditions (e.g. wet or dirty roads), which suggests that other reasons are at the root of the accident: e.g. driving a poorly maintained bicycle or performing the wrong manoeuvre. The prevalence of such accidents suggest that improving cycling infrastructure and traffic education in some parts of the country (especially in Wallonia and Brussels) might help to reduce the risk of casualties among cyclists.

Finally, **clusters G** and **H** consist of hilly communes, characterised by high casualty rates and low proportions of cycling commuters. The commuting distances in these communes are generally large. They consistute unsafe and, consequently, unattractive environments for (potential) cycling commuter. All the communes in these clusters are located in Wallonia. According to the road accident statistics (*ibid.*), most of the cycling casualties there are due to the fact that riders fall off their bike, which may suggest that the steep gradients play a role (winding roads, and hence less visibility). Some accidents also happen when the motorised vehicles overtake the cyclist or do not respect his or her right-of-way (*ibid.*). The driving of motorists and the fact that cyclists are unusual on Walloon roads probably explain such occurrences. The lack of a high-quality infrastructures may also play a role: the 2001 census indicates that more than 80% of households in these communes are not satisfied with the state of the cycle paths there (NIS, 2001; Verhetsel et al., 2007), which suggests that the accidents are not inevitable.

c. Discussion: policy recommendations

Based on the results underscored in the previous subsection, we here aim at establishing some suggestions as to how to compensate for some of the main deterrents from cycling and, hence, how to promote it and make it safer. Let us summarise and discuss them, by focusing on four of the 5Es[3]. First, **engineering** can be very effective in increasing bicycle use and making it safer through better development, design and maintenance of cycling infrastructures. Providing safe and well-designed cycleways (i.e. continuous, equipped with traffic lights, etc.) could prevent cyclists from falling or colliding with faster means of transport (such as cars, trucks and buses). Accidents due to bad manoeuvres by both motorists and cyclists (caused by hesitations and/or infractions of the traffic code) could hence be avoided (or at

[3] The 5 Es are engineering, education, encouragement, enforcement and evaluation.

least their consequences could be mitigated). Other engineering measures can improve the safety and convenience of cycling by planning urban centres and new housing estates in such a way that obstacles and cycling dangers are removed. Providing traffic-calming areas or safe crossings for cyclists, as well as implementing routes that reduce exposure to pollutants, are some examples of such measures (Pucher and Dijkstra, 2003; Hertel et al., 2008; Int Panis et al., in preparation; Thai et al., 2008). Finally, developing secure cycle parking facilities at transport stops (e.g. cycle lockers or guarded parking at stations) could stimulate bike-and-ride and so could be effective in increasing bicycle use, particularly in large cities (such as Brussels) where vandalism and theft may deter cycling.

Second, the results suggest (through the analysis of the road accident statistics) that motorists tend not to respect cyclists in Wallonia and Brussels, which often leads to collisions (e.g. non-respect of the right-of-way, etc.). Hence, special attention should be paid to traffic **education**. Examples of such measures are: disseminating information (e.g. through safety campaigns), improving driver training for motorists, and teaching safe walking and cycling practices to schoolchildren (Pucher and Dijkstra, 2003).

Encouragement could also be useful to promote and increase cycling in Wallonia and Brussels. Campaigns and mass events organised by public authorities and advocacy groups could underscore the health benefits as well as the improvements in the quality of life associated with bicycle use (reduction of noise and air pollution in the cities).

Last but not least, **enforcement** strategies are useful in encouraging all road users to adopt a more responsible driving style and to respect the rules of the road. Combined with traffic education, enforcement could make motorists more aware of and respectful towards cyclists, especially in Wallonia and Brussels. Collisions caused by drivers not respecting the right-of-way of cyclists (or triggered by the cyclists themselves) could be reduced by greater enforcement. As part of this strategy, the police presence should be made more visible, and the punishment for violations of the traffic regulations should be far more severe, so that the perceived risk of being punished (following an illegal/dangerous manoeuvres) is increased.

d. Selection of the 3 case study commuting trajectories

Results illustrated by the classification support that eight study commuting trajectories should be chosen. For technical reasons, we however focus on three areas, characterized by different accident risks and bicycle shares, i.e.:

- high cycling rate/low accident risk (e.g. Mol)
- low cycling rate/low accident risk (e.g. Brussels)
- low cycling rate/high accident risk (e.g. Ottignies-Louvain-la-Neuve)

The analysis of the descriptive statistics (i.e. mean, …) shows that these 3 areas are representative of the different clusters that were underscored by the classification. Analysing the ranking of the most "bikeable" communes (Table 4), Mol was showed to be ranked 67th (among 589 communes) while Brussels and Ottignies-Louvain-la-Neuve were ranked 337th and 501st respectively. Interestingly, the first ten communes are located in Flanders, while the last ones belong to the Walloon Region.

Table 4: Ranking of communes, based on the cluster analysis and the two variables

(bicycle use and the risk of cyclists becoming casualties)

Commune	Rankin g	Commune	Ranking
Vosselaar	1	Marchin	577
Waarschoot	2	Farciennes	578
Baarle-Hertog	3	Bertogne	579
Meulebeke	4	Libin	580
Hove	5	Bouillon	581
Lendelede	6	Vielsalm	582
Hooglede	7	Meix-devant-Virton	583
Lichtervelde	8	Tinlot	584
Hemiksem	9	Burg-Reuland	585
Niel	10	Saint-Hubert	586
Mol	**67**	Sainte-Ode	587
Brussels	**337**	Martelange	588
Ottignies-LLN	**501**	Stoumont	589

Two trajectories were chosen in the town of Mol. The first one is 5 km long and takes 20 minutes to cycle. Start and finish are at the VITO campus and the trajectory loops through a variety of local and busy streets. Sections along the Campine canal are closed to motorized traffic. By choosing this route we include two important slopes (the bridges across the canal) in the Flemish case study which we will be able to compare with results from sloping trajectories in Brussels and Louvain-la-Neuve. The second trajectory is along the busy N18 national road between the bridge and the town centre. It is in the immediate vicinity of the first trajectory and both can also be cycled in one continuous trial. This section was added to allow repeated tests of the instruments under high exposure conditions thought to be similar to the condition expected in Brussels.

Two trajectories were chosen in Brussels. The first one is 2.38 km long and takes about 15 minutes to cycle. The trajectory starts at the crossroad of the Kroonlaan and the General Jacques laan. The Kroonlaan will be followed towards the centre of the city until the crossing with Mouterijstraat. Then the first street on the right will be taken (Nieuwelaan) until reaching the Boulevard General Jacques. The Kroonlaan is a very busy street with lost of cars and busses going in and out of the city centre. The first 400 m of the trajectory are descending, the next 550 m are almost flat (a little bit descending). The Mouterijstraat is only 100 m long and flat. The first 480 m of the Nieuwelaan are slightly ascending. The next 300 m are strongly ascending. The last part of the trajectory is 250 m and flat. The Nieuwelaan is a smaller street with only local cars driving and with no busses.

The second trajectory in Brussels is located in the centre of the city and follows bicycle lanes over the whole trajectory. The second trip will start at the cross point of the Wetstraat and the Willem de Zwijgerstraat. The total trip is 1.5 km long and will take about 10 min. First, the Wetstraat will be followed in the direction of the city centre and is ascending over a distance of 768 m. The Wetstraat is one of the major car and bus roads of Brussels. Then we go right on the Kunstlaan which is about 100 m and has a flat course. The Josef II is the next first street on the right and descends over a distance of 623 m.

- *Statistical analysis of accident risks and injuries*

a. Analysis of spatial explanatory variable for accidents

We further aim here at understanding the locations of road accidents involving cyclists at different scales of spatial aggregation (hectometre at local level, but also at more aggregated levels such as communes in order to weight/measure the problem in the different parts of the country and at different levels of urbanization). Modelling the risk of being involved in a road accident for different type of road users (gender, age, …) and spatial environments will be the result.

For this research task, road accident census data of 2002, 2003, 2004 and 2005 (NIS) will be used. If they are globally available, there is still a problem associated to the most important information: location. Due to encoding and location errors, corrected data had to be collected for each Region (except for Brussels where the data are not corrected). Nonetheless, accident data are only available for the Walloon (since 2007) and Flemish Regions (since February 2008).

We are aware that accidents census data underestimate the accidents occurrences, especially for cyclists, but this database is the only one available at the level of the country at a yearly basis and gives very interesting information about the accident, its circumstances and its environment. We hence assume that the underestimation is almost the same all over the country (strong assumption).

- *Injury registration system*

The web-based injury registration system was officially launched on the 10th of march 2008, together with the website, since these two are integrated in each other.
The injury registration system is based on existing national official registration systems for traffic accidents (e.g. Belgisch Instituut voor Verkeersveiligheid), recent literature and the BLITS registration system for sports injuries®. Both the retrospective and prospective questionnaires were adapted to the needs for registration of minor injuries and accidents occurring in traffic during cycling to work.
The questionnaire is implemented in an online questionnaire system (SurveyEngine). This system is a web application programmed in PHP, which is an open source scripting language. The data are saved in a MySQL database. The whole system is supported by an Apache web server.

During an intensive preparation period the online web-based questionnaires were tested for its contents. The whole system is available in Dutch and French. In a second phase, an internal and external quality control was done with a paper and pencil version that was made available for all the members of the SHAPES team.
The final draft version of the questionnaire was made available on-line to the members of the follow-up committee on 15/12/2007 and was tested for 1 month.

When people register on the website they receive an automatically generated e-mail which gives them the possibility to fill in a General Questionnaire. In this questionnaire general traffic related aspects are questioned. Together with this mail they receive the first weekly diary, which will be sent to all the participants every week for 1 year. The last question of the weekly diary asks about accidents that eventually occurred during the past week (7 days). If an accident occurred, the participant gets access to the Prospective Questionnaire. One week after registration, a large Retrospective Questionnaire is sent to all registered users. Questions about accidents and injuries that occurred during the past 12 months are asked. Both the Retrospective and the Prospective Questionnaire will give detailed information about the circumstances of the accident and the health and financial consequences. Special attention was given to make a clear distinction between the cause of the accident and the cause of the injury.

A link to the SHAPES website was put on the website of organisations that promote cycling for transport as ProVélo, GRACQ, Fietsersbond, Interenvironement Wallonie, … A lot of attention was generated for the SHAPES project during TV, Radio and newspaper interviews and specific events which all served to promote participation in the on-line questionnaire.

5.2 Air quality

This Work package is situated entirely in Phase 1 so the results described here can be regarded as final results of the SHAPES projects. We have developed the tools needed for the scenario analysis in Phase 2 when these tools will be recalibrated with data from the field campaign. VITO leads this WP.

Most of the Air quality work done in Phase 1 is discussed under 5 & 6 (experimental) work. This is more logical and highlights the fact that SHAPES has truly achieved an integration of disciplines. The final results will be published in the final report of the LIMOBEL[*] project.. Improvements of existing models to study the air quality at selected hot spots is discussed in paragraph 6.2.1 and paragraph 7.1.

5.3 Health impact assessment

The researchers have the intention of using the results of this workpackage to prepare a peer-reviewed paper on the subject of health impact assessment (Annex A, N°6).

5.3.1 Health impact assessment methodology

In this WP we bring together the experimental results, the geographical analysis, the statistical data to balance the potential risks against the potential benefits.

The concept of a risk-benefit model of commuter cycling is compared with commuting by car which will be the baseline assumption. The risks and benefits associated with cycling will be assessed and then a comparison will be made between car drivers and cyclists. To enable a clear evaluation a monetary approach is preferred. In this monetary evaluation risk and benefits are translated into costs (both positive and negative), or incremental costs compared to car use. Monetary values however do not exist for every potential impact due to cycling (or car use). In this case other indicators or qualitative descriptors of risks and benefits need to be used.
In SHAPES 3 main impact categories are taken into account: accident or injury risk of cycling in comparison to car use, benefits of cycling through health improvement form physical activity, exposure to air pollutants compared to car users. Other impact may exist like the life cycle impacts of car production versus bicycle production (e.g. resource depletion) etc, but they are out of scope in SHAPES.

[*] LIMOBEL : Long-run impacts of policy packages on mobility in Belgium
http://www.belspo.be/belspo/ssd/science/projects/LIMOBEL_en.pdf

Summarizing the approach for each of the 3 impact categories:

1. The retrospective and prospective survey on commuter cycling injuries will complement existing accident data to develop indicators and costs of cycling accident and injury risks. Accidents while commuting by car are available from statistics and previous research. Together we can evaluate the incremental accident or injury risk of commuting by car or by bicycle.

2. Air pollution exposure to PM10, PM2.5, PM1 and ultra fine particles (UFP) is measured simultaneously in car and on bicycle at several locations and on a number of days. Also simultaneously spirometric data are gathered, to enable a comparison of inhaled dose next to the comparison of external concentrations. The SHAPES project is not an epidemiological study, and thus impact function from literature are used (e.g. on potential cardiovascular effect of exposure and inhalation). When quantitative dose-effect relationships are not available we will use the dose as an indicator of the potential risk. If the impact is quantified it is also possible to translate this impact into monetary costs and add to the monetary costs of accidents and injuries

3. Finally we use existing data and knowledge on the benefits of physical activity.

We are aware of the system boundaries and limitations of our approach. It is conceivable that car users do more sport activities than cyclists after work, and are hence compensating for their sedentary lifestyle. Exposure to air pollution does not stop after commuting, and it may well be possible that the average daily exposure is different than that during cycling/driving to work. However within our scope and goal, i.e. to develop scientific based advice to policy makers to promote the use of bicycles to commute, we do not need to consider these limitations comprehensively. As a general advice people should be aware of their physical (in-)activity, and exposure should be as low as possible everywhere and every moment of the day.

Our literature overview on particulate matter air pollution and health starts from the review made in the framework of the NEEDS project (Torfs, Hurley and Rabl, 2007), which in turn is based on and consistent with the analyses in CAFE (Hurley et al., 2005) and by the WHO (2006). It focuses on the derivation of established concentration-response functions for ambient particulate matter. Both cardiovascular and respiratory effects are addressed. Chronic exposure to PM2.5 is associated with an increase in cardiovascular mortality, acute exposure to PM10 with an increase in cardiovascular hospital admissions in the population. From the chronic effect studies in the US it is evidenced that the total mortality endpoint is almost entirely due to cardiovascular deaths (Pope et al., 2004; Pope and Dockery 2006). Short-term particulate exposures seem to contribute to acute coronary events, especially among patients with underlying coronary artery disease or those who survived a myocardial infarction. Only a few studies report the onset of cardiovascular events in relation to exposure to traffic just before the incident, both with PM and UFP. These findings especially will be useful in our evaluation of exposure during commuting.

In a review by Brugge et al (2007) of the epidemiologic evidence of the health risks related to near-traffic pollution gradients most evidence is derived indirectly through PM2.5, and UFP is considered to be a likely candidate to contribute to cardiovascular health effects, due to its characteristics, and its potential to induce inflammation. UFP is part of the diesel exhaust, that is labelled likely carcinogenic by the US-EPA. An interesting study in Copenhagen backs this hypothesis, where it is shown that cyclists in traffic have more oxidative DNA damage (Vinzents et al., 2005). But Brugge et al. conclude that “while the evidence is considerable, it is not overwhelming and weak in some areas”. Delfino et al. (2005) also start from the time series and cohort studies on PM10 and PM2.5 to derive an indirect assessment of the potential role of traffic-related UFP in these epidemiological associations between particulate matter and cardiovascular and respiratory health endpoints. Although direct epidemiological evidence is limited (e.g. Wichmann et al. 2000) there is some direct evidence of the effect of UFP on clinical or sub clinical effects like ECG ST depression, and heart rate variability decrease, both linked to cardiovascular illness. Pathophysiological mechanisms that connect UFP exposure and deposition in the lungs with cardiovascular responses are available. There is unconvincing evidence of the association between UFP and blood pressure. According to Delfino et al. UFP exposure assessment and misclassification is one of the reasons that UFP effects are still not well defined.

There is incontrovertible evidence from observational and randomized trials that regular physical activity contributes to the primary and secondary prevention of cardiovascular disease and several other chronic conditions (diabetes mellitus, some cancers, obesity, hypertension, depression, …) and that it is associated with a reduced risk of premature death (Surgeon’s General Report, 2006; Warburton et al, 2006). Because of its dual role in health promotion and disease prevention and its influence on morbidity and mortality, physical activity is a particular important health behaviour (Speck and Harrell, 2003).
To promote and maintain health, all healthy adults need moderate-intensity aerobic (endurance) physical activity for a minimum of 30 min on five days each week or vigorous-intensity for a minimum of 20 min on three days each week (Haskell et al. 2007). Moderate-intensity aerobic activity, like commuter cycling (de Geus et al. 2007) that noticeably accelerates the heart rate, can be accumulated toward the 30-min minimum from bouts lasting 10 or more minutes.

While evidence points into the direction of respiratory and cardiovascular effects of UFP, some of the evidence is still circumstantial and there is need for more targeted and convincing research to link UFP from traffic to health endpoints.

5.3.2 Cost assessment of commuter cycling

During the 2nd International Congress on Physical Activity and Public Health (Amsterdam, 14-16 April 2008), contacts were made with S. Kahlmeier, N. Cavill and H. Rutter. They worked out the Health Economic Assessment Tool for Cycling (HEAT for cycling) for the World Health Organisation. During this discussion it was stated that our data will be useful to refine the WHO HEAT cost-benefit analysis and work out a more advanced form.
Different scientific and policy based cost-benefit analysis were collected and analyzed in order to have all the needed resources for the cost-benefit analysis, planned at the end of the project. VITO is in the process of hiring an expert in transport economy to ensure proper execution of this specific task. The same expert will also analyses the cost data associated with the questionnaire.

6 MODELS & MATERIALS USED

6.1 Laboratory and Field measurements

The results of this work package will contribute to the completion of papers N°5, N°6 and N°9.

6.1.1 Experimental Work

Although the most important experimental work and measurements are planned in phase 2, the design of the experiment is started in phase 1. Furthermore, a "proof-of concept" pilot test was performed. VUB leads this WP.

The field campaign measured the exposure of cyclists and car drivers on equivalent trajectories taking into account differences in concentrations, exposure, and tidal volume.

6.1.2 Laboratory and Field measurements

- *Task 4.1.1 VO_2 max measurements*

Subjects that will be tested in the Field study will undertake a maximal exercise test in the laboratory under standardized atmospheric conditions, in order to measure their maximal aerobic (VO2max) and anaerobic capacity. The VO_2max values will serve as an objective parameter of the endurance capacity of the subject. Additionally, the results of the maximal exercise test will be used to calculate at what percentage of the maximal values the subjects' cycle during the field tests. This is important since the higher the cycling intensity, the higher the tidal volume and inhaled air and the higher the potential inhalation of ultra fine particles (UFP).

Maximal physical performance was determined by a maximal incremental exercise test (MT) on an electrically braked cycle ergometer (Excalibur Lode, Groningen, the Netherlands). The saddle and handlebars were repositioned to suit each subject.
After resting measurements were collected, the maximal exercise test began with an initial workload of 80 Watt (W) at a pedalling rate of 70-80 rates per minute. A ramp protocol was chosen with a workload increase of 30 W. The subjects were encouraged to exert themselves until volitional exhaustion. The decision to stop was based on signals of extreme fatigue and was confirmed by a heart rate that approximated the theoretical maximal heart rate (220-age) and/or a respiratory exchange ratio above 1.10. After reaching exhaustion, the subjects had to continue cycling at 50 W until the heart rate reached a rate below 120 beats per min. The maximal external power (Wmax) was defined as the highest power output that could be reached during the MT.

Oxygen uptake (VO_2) and carbon dioxide production (CO_2) were measured throughout the test using a portable cardiopulmonary indirect breath-by-breath calorimetry system (MetaMax® 3B, Cortex Biophysik, Leipzig, Germany). The validity of the MetaMax 3B was tested in an independent study (Wüpper et al., 2003). A flexible facemask (Cortex Adult Face Mask, Cortex Biophysik, Leipzig, Germany) covered the subject's mouth and nose. Before each test, gas and volume calibration took place with a 3-L syringe, according to the manufacture's guidelines. The oxygen analyzer was calibrated with known gas mixtures of

15% O_2 and 5% CO_2. The room air calibration was automatically run before each test to update the CO_2 analyzer baseline and the O_2 analyzer gain so that they coincided with atmospheric values. VO_2peak was defined as the highest VO_2 attained during MT over a time interval of 30 sec (de Geus et al., 2007). Respiratory exchange ratio (RER) was calculated by dividing the measured CO_2 by the measured O_2. Heart rate was recorded through the MetaMax® via a Polar® X-Trainer Plus (Polar Electro OY, Kempele, Finland) measurement system. Maximal heart rate (HRmax) was defined as the highest heart rate during the test. In order to measure the lactate concentration blood samples (20µl) were drawn from an arterialised ear lobe, before the start of the maximal exercise test and at the point of exhaustion. Lactate concentrations were determined enzymatically (EKF, BIOSEN 5030, Magdeburg, Germany). Subjects were also requested to state their rate of perceived exertion (RPE) according to Borg scale (Borg, 1962) of 6-20 before and at the end of the test.

- *Task 4.1.2 Design of field study*

The field study was designed in such a way that routes with a different slope can be compared. This will be combined with routes in areas with a different pollution rate. Routes in the city and in a more rural area are chosen. Also the moment of the day (morning traffic jams vs fluid less dens traffic) plays an important role.
Since the fine particle devices are quite sensitive to air humidity and rain only measurements in dry weather condition were performed. Although most cycling trips are performed in dry weather, special attention needs to be paid to those persons commuting by bicycle in rainy conditions.

During the field tests (FT), tidal volume and oxygen uptake were measured using a portable cardiopulmonary indirect breath-by-breath calorimetry system (MetaMax 3B, Cortex Biophysik, Leipzig, Germany). The MetaMax was fixed into a chest harness worn by the participant. A flexible facemask (Cortex Face Mask, Cortex Biophysik, Leipzig, Germany) covered the participant's mouth and nose. Before each test, gas and volume calibration took place with a 3-litre syringe, according to the manufacturer's guidelines. The oxygen analyzer was calibrated with known gas mixtures of 15% O_2 and 5% CO_2. Before each individual test, ambient air was measured according to the manufacturer's instructions. Heart rate was recorded through the MetaMax via a Polar X-Trainer Plus (Polar Electro OY, Kempele, Finland) measurement system. Blood samples (20 µL) were drawn from the ear lobe, before and at the end of the trip, and stored in a cooled box until analysis. Lactate concentrations were determined enzymatically (EKF, BIOSEN 5030, Magdeburg, Germany). During the FT, subjects were asked to cycle, using the same intensity as during their daily trips to and from work.

- *Task 4.1.3 Selection of experimental population*

The final experimental population in phase 2 will consist of men and women of a different physical capacity. This is important since the better the physical capacity and the higher the cycling intensity, the higher tidal volume and inhaled air and the higher the potential inhalation of UFP.
Subjects will be part of the participants that took part in the injury registration study and will be regular commuter cyclists (> 2/week to work during the past 6 months). This will enable us to compare the cycling intensity during the field test with the intensity of cycling (cycling speed) as reported in the weekly diaries. Furthermore, this will enable us to obtain the social-demographic

and personal transportation data, as well as the registration of the cars owned or used by commuter cyclists. For the pilot testing we used people from the SHAPES research team.

- *Task 4.1.4 Pilot and trial campaign*

This section contains a summary of the methodology and the results of some of the validation testing. In the first few paragraphs we discuss the methodology to measure different PM fractions while cycling. In the last paragraphs we discuss exposure through inhalation. Furthermore we discuss the exposure to PM and compare measurements of both concentration and inhalation in cars and on bicycles for the pilot test.

6.1.3 Introduction on measurement methodology and strategy

In the SHAPES project we collect data on the exposure of cyclists to particulate air pollution. In this paragraph we present a methodology to estimate the exposure of cyclists to ultra fine particulate matter (UFP number concentration) and fine particulate matter (FP mass concentrations) and show the results of measurements performed while cycling in real traffic. A novel measuring strategy was developed using small battery driven optical sensors which allows us to collect data on levels of Particulate Matter (PM) while cycling in real traffic. Initial work focused on simultaneous measurements of PM10, PM2.5, PM1 and Ultra Fine Particulate matter (UFP). A combination of both weight based PM measurements and particle numbers proves to be very useful because both are related to distinct sources which we can identify from simultaneous video recordings. In this paragraph we also report UFP levels measured while cycling on a cycling track and the effect of the distance of the cycling track to the road on the exposure of cyclists.

6.2 Air quality models

6.2.1 EnviMet

The ENVIMET model, is a CFD model that enables us to study the effect of obstacles such as houses and vegetation … on the dispersion and deposition of pollutants in the air. This model was used to try to repoduce the measurements on the Turnhoutsebaan in Mol.

The results of any model will of course depend on the quality of the input data such as meteo (esp. Wind direction and wind speed, stbility class, solar irradiation, humidity and temperature…) background concentrations, 3D configuration of the area and emissions (see paragraph 4.2.1) depending on the number and type of vehicles). Most of these data were not available for the other locations.

No calculations were therefore performed for the other test trajectories.

6.2.2 Streetcanyons

No street canyon calculations were performed.

7 RESEARCH RESULTS

7.1 Concentrations

When comparing modelled and measured values, the model seems to predict the observed decrease in concentrations with acceptable accuracy (despite the severe lack of input data (see before). At least a the downwind side of the road the results were acceptable, model results for the upwind side of the road are not realistic. From the measurements and the modelled concentrations it seems clear that at very short distance from the road (in this case the cycling path) traffic induced turbulence is the major factor deptermining dispersion and concentrations. This effect can, at this time, not be covered by the model.

From our model, wind speed (aerodynamic effect) is one of the major parameters. Any decrease in windspeed at the same hight as the emission sources (traffic on the Turnhoutse baan) causes a clear increase in air concetrations. Wind our noise shield and hedges therefore have a negative effect on local air quality at short distances.

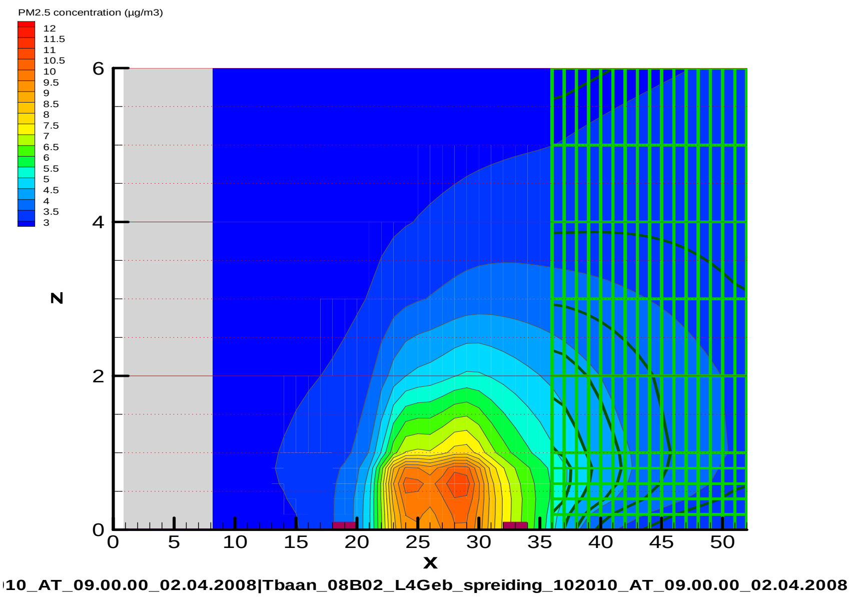

Figure 10: Modelled concentrations along a road with buildings on the left and wind blowing from the left. The location of the bicycle paths is indicated in red.

7.2 Exposure

The results of this scientific stream within SHAPES will be used to prepare a number of scientific papers (Annex A, N°5 & N°6) and contribute to several others. In addition we plan to write a joint paper with the researchers from the PARTHEALTH project within the framework of the PM²TEN experiment (Annex A, N°10).

7.2.1 Experimental – Method - Validation

A SHAPES bicycle equipped with a number of different instruments was used to measure aerosol concentrations in the ambient environment and to evaluate personal exposure of cyclists. It consists of 4 different instruments: a GRIMM 1.108 Dust monitor, a TSI P-TRAK, a commercial GPS and a video camera. The GRIMM 1.108 spectrometer is a portable environment dust monitor which can simultaneously measure PM1.0, PM2.5, PM10 and TSP. For the pilot tests, the results from the Grimm monitor (a non-reference sampler) were calibrated by comparing them to a TEOM-FDMS located at VITO. For the field testing in phase 2 a co-located Harverd impactor at the different test sites will be used to calibrate the PM mass concentration.

Ultra fine particle counts at 1-second resolution were made using P-TRAK Ultra fine Particle Counters (TSI Model 8525), for particles in the size range 0.02–1 µm. The P-TRAK is a hand-held, field instrument based on the condensation particle counting technique using isopropyl alcohol. It has a relatively robust performance while in motion, rapid warm-up, battery-powered, and it has an operation time which is longer than more sophisticated instruments. This makes the GRIMM & PTRAK instruments readily deployable in the field, and useful for mobile measurements in the SHAPES project. Initial pilot tests revealed that the P-TRAK was rather sensitive to shocks leading to temporary gaps in the data collected. This was circumvented by designing a shock absorbing suspension and by manually by-passing the electronic shock detection mechanism. This final set-up was used for all later measurements.

All measurements discussed in this paragraph were executed while cycling in real traffic in and around the city of Mol, Belgium. A test trajectory was chosen that includes a cycling track parallel to a major regional road. The cycling lane is between 1.8 and 2 meters wide and is mostly separated from the road to the left by a 1.8 meter wide parking lane except at a signalized intersection. A first set of validation tests was conducted to test the reliability of the P-TRAK instruments as well as the set-up on the bicycle. Two P-TRAK instruments were carried in a pannier and supplied with sampled air through two tubes of variable length fitted to an extendible post so that any sampling height and direction could be chosen (see figure below). It was first tested whether the two available P-TRAK instruments provide identical results when sampling tubes are placed at the same location (case A in figure). Subsequently the effect of sampling height (case B) and sampling direction (case C) were tested.

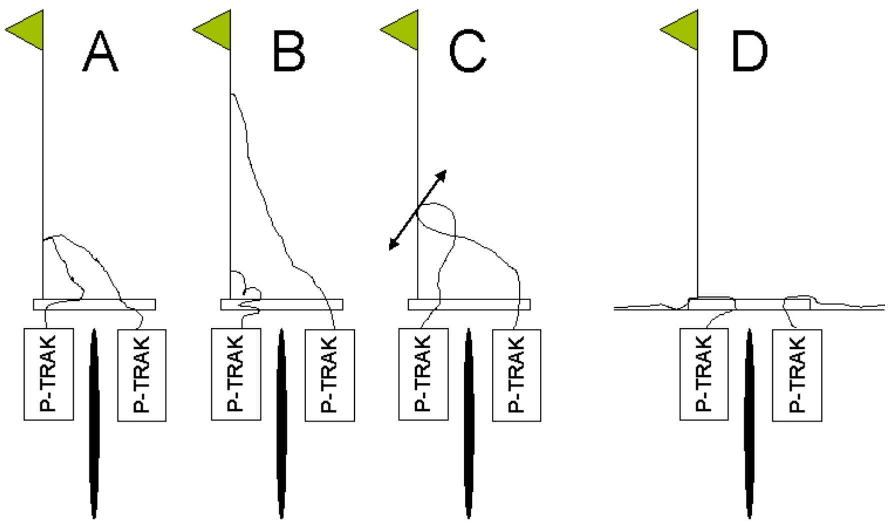

Figure 11: Experimental set-up for validation of the methodology.

A: sampling at 1m above the ground for both instruments.
B: sampling at 0.8m and 1.6m above the ground.
C: sampling in different directions at the same height.

D: set-up to determine the effect of distance on UFP exposure on the cycling track. The horizontal distance between both sampling tubes was 2 m in the pilot test and 1 m during the final test.

Subsequently the bicycle was set-up to measure UFP concentrations on a cycling track. Simultaneous measurements were taken at a horizontal distance of 2 meters while cycling (case D). After analysis of the initial results it was decided to reduce the horizontal distance between sampling points to just 1 meter to improve manoeuvrability and safety while measuring. A new set of 10 trips in both directions were made in April 2008. The total trajectory is exactly 4 km long and was cycled in about 12 minutes with an average speed of 19.6 km/h

The ratio and 95% CI between measurements taken during the pilot test by both instruments were 1.00 (0.94-1.05) for case A, 0.98 (0.86-1.09) for case B and 1.01 (0.94-1.09) for case C respectively. We concluded that the set-up was reliable and reproducible although a small correction was sometimes needed to off-set systematic differences between instruments. There is no effect of either sampling height or sampling direction on the results. The results of the measurements will there-fore adequately reflect the concentration in the breathing zone of the cyclist and his/her external exposure to UFP.

7.2.2 Comparison of UFP with PM10 and PM2.5 measurements

Results from one of the preliminary tests clearly indicate that peaks of PM10 and UFP often occur at different sites on a test trajectory. Analysis of the video footage revealed that PM10 peaks were often related to construction activities while UFP was most closely related to traffic

7.2.3 Exposure of cyclists to UFP on a cycling track

The pilot test revealed an unexpected but important difference over a horizontal distance of 2 meters. Measurements taken at the side of the road were on average 10% higher than those taken simultaneously at the other side of the bicycle (Ratio 1.096; Stdev 0.044 p=0.05). Average particle numbers during the 3 days of the pilot test were around 30000 cm-3. The preliminary results were confirmed in the second test although average particle numbers (~20000 Pt/cm3) were significantly lower than during the pilot test (T-test p<0.001). Some results are shown in the figure below. The measurements are characterized by an important number of high peaks coinciding with motorized traffic on the road and alternating with much lower values. Values around 10000 particles per cm^3 are most common while frequent peaks over 100000 particles per cm^3 have been recorded. The highest values are in excess of the P-TRAK range (500000 Pt/cm^3). P1 (closest to the road) frequently records higher values than P2 (only 1 meter further away from the road). Although occasionally P2 values are marginally higher than P1, values of P1 are often 3 to 5 times as high during peak UFP events (right axis in the figure).

On average, 1150 (stdev: 722) more particles per cm3 were measured closer to the road. Although there is a lot of variation and data is obviously not distributed normally, non-parametric tests reveal that the average P1 values for each trajectory are significantly higher. The average P1/P2 ratio is 1.06 (stdev 0.04).

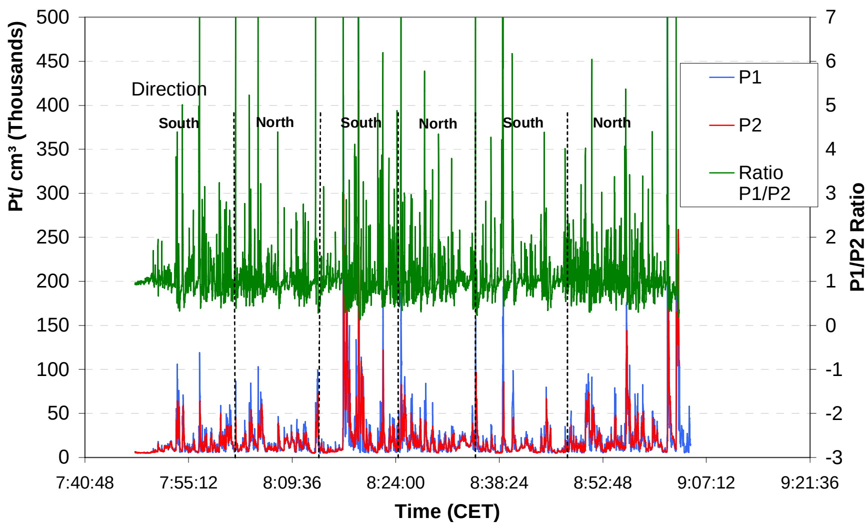

Figure 12: Number of particles on the cycling track (P1 closest to the road, P2 1 meter further away from the road). 6 trips on April 2nd 2008.

7.2.4 Discussion

These limited sets of measurements resulted in two surprising conclusions. Firstly, our validation measurements revealed that UFP concentrations at the cycling track are independent of height. The exposure of children should therefore not be higher than that of adults although the opposite is often claimed. Future studies should however confirm if heavier particles such as TSP (Total Suspended particles) or PM10 (e.g. from re-suspension) and exhaust UFP behave differently.

Our results also highlight the surprising fact that concentrations of UFP may decrease significantly over a small distance from the emission source even though this distance is of the same order of magnitude as e.g. the width of the cycling track or the variation in the exact position of the exhaust pipes relative to the cycling track.

Further studies are required to corroborate the tentative conclusions of this experiment. In this paper we have focused on mobile measurements in real traffic because these are most relevant for exposure of cyclists and to policy makers. In the future we will seek to confirm the results for different wind speeds and directions and determine the rate of decrease at different distances. This decay function will then be used to construct a CFD model in ENVI-met that will allow us to make more general predictions as well as study scenarios that may modify exposure to UFP on the cycling track. This work will be performed during phase 2. Future research should confirm these results for other particles sizes (PM10) at different locations and under different meteorological conditions and elucidate the mechanism explaining our observations.

7.2.5 Exposure and inhalation of particles

In chapter 6.3 we discuss the amount of UFP and PM10 that is actually inhaled by cyclists and compared it to the exposure of car drivers. The geographical analysis shows that areas with high concentrations of PM10 also have high bicycle shares in the modal choice of commuters. It is therefore important to measure the exposure of cyclists to air pollutants since lots of them commute in environments having a poor air quality.

We present new data on the exposure of cyclists (while cycling!) to particulate air pollution using the PM measuring strategy described above. In addition we present a comparison of the

exposure of cyclists and car drivers. Equivalent measurements in a car where performed by putting the equipment in the front seat next to the driver.
True exposure is defined by a combination of concentrations and inhalation. Therefore we take simultaneous measurements of tidal volume (volume of air per breath). These combined measurements allow us to determine the exact quantity of particulate matter that is inhaled. It is important to determine this quantity accurately, because in the end it determines whether cyclists are exposed to a higher internal dose with respect to car drivers. No other project has ever designed such simultaneous measurements. Other studies have used a simple definition of exposure that only takes into account the difference in time needed to complete a trip which may be slower or faster by bicycle depending on assumptions.

As an example of a typical field measurement result, the pilot test performed in Mol is presented in a step by step way:
- fine and ultra fine dust concentrations measured on the bicycle
- comparison of the concentrations measured on the bicycle versus the car
- inhaled quantity of fine and ultra fine dust for the cyclist and car driver, taking into account breathing rate.

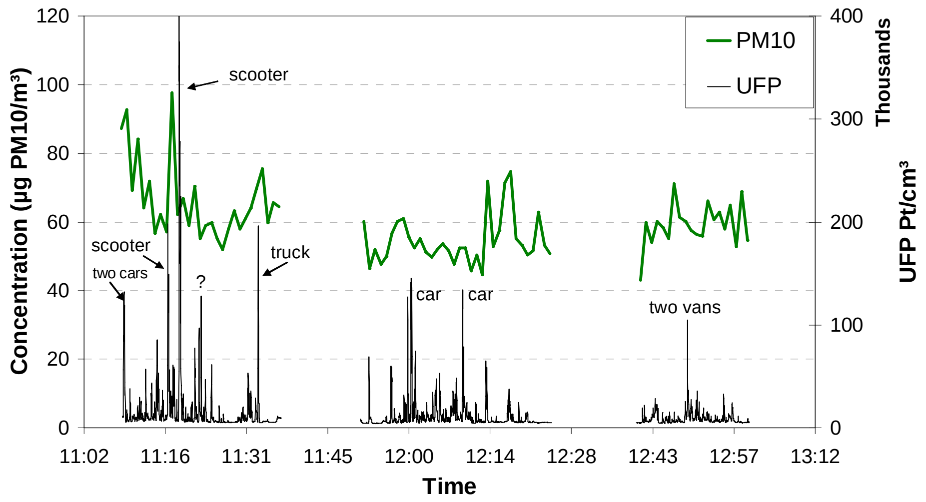

Figure 13: UFP numbers (right axis) and concentrations of PM10 (left axis) for three of the cyclists. Sources of UFP peaks > 100000 pt/cm³ were identified from video footage.

As an example we show the second by second measurements of UFP for three cyclists in figure above. PM10 concentrations are shown with a time resolution of 1 minute (i.e. minimum time resolution of the FP instrument). Peaks of PM10 and UFP do not always coincide. Individual UFP peaks over 100000 particles/cm³ were identified from simultaneously recorded video footage. The highest peaks were recorded when cyclists were overtaken by scooters on the cycling track. Other peaks coincide with being overtaken by trucks and vans. Some cars can be associated with specific high peaks, but most cars do not cause a distinct peak in measured UFP concentrations.

Average UFP numbers over the entire trajectory are 11233 particles/cm³ (SD=1350 N=4) in the car and 13302 Pt/cm³ (SD= 3364; N=6) on the bicycle. The slightly higher average on the bicycle is not statistically significant and is caused by a higher number of UFP peaks measured while cycling (hence the higher SD). The fact that the difference is small may be due to overall low traffic levels during this experiment in Mol (see figure below). Average PM concentrations are approximately 50% higher in the car than on the bicycle. These differences are statistically significant for all PM fractions.

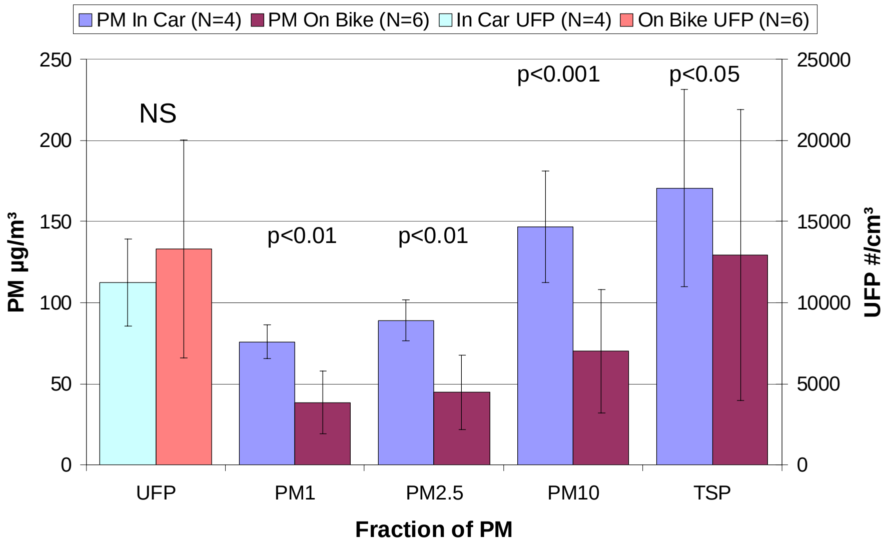

*Figure 14: UFP numbers (right axis) and concentrations of PM fractions (left axis) for cyclists and car drivers respectively. Average concentrations (2*Standard deviation, paired t-test). PM concentrations are higher in the car than on the bicycle. UFP numbers are not significantly different.*

Tidal volumes for all of the car trips were very similar and yielded an average of 15.7 litres/minute. The average tidal volume for cyclists in this study was 3.3 times higher than for car drivers. The Figure below shows the exposure results for 5 cyclists when explicitly taking differences in tidal volume into account. The inhalation of all PM fractions and UFP is higher while cycling although the concentrations are higher inside the car. The difference in exposure between car drivers and cyclists is statistically significant (paired t-test $p<0.05$).

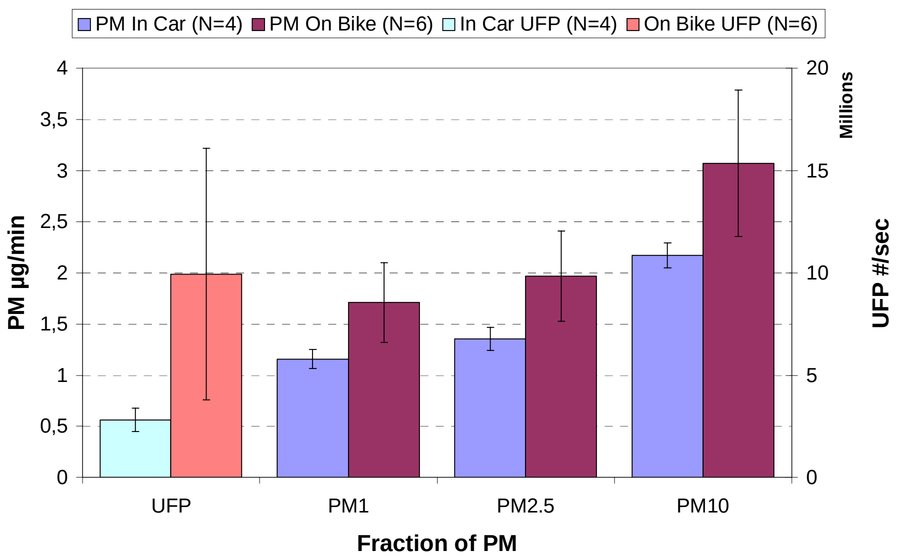

*Figure 15: Amount of PM (µg/minute; left axis) and UFP (particles per second; right axis) actually inhaled while driving or cycling the trajectory. (Averages and 2*standard deviation, paired t-test). Quantities inhaled by cyclists are higher for UFP and all PM fractions.*

7.3 Health impacts

7.3.1 Air quality

There are very few published data on levels of PM and UFP while cycling or driving. Bogaard and Hoek (2008) found higher UFP concentrations in cars compared to cyclists while unpublished results from Int Panis et. al, (in prep.) suggests that cyclists are exposed to higher UFP concentrations in Brussels, Belgium. The difference could be caused by the fact that cars and bikes followed different trajectories in the Dutch study. Bogaard and Hoek (2008) list but do not discuss results for PM2.5 because they could not validate their measurement methodology. Hertel et al. (2007) report modelled levels of PM2.5 (10.1 - 13.5 µg/m3) and PM10 (15.9 - 22.6 µg/m3) for 50 cycling routes in and around Copenhagen. Modelled concentrations for equivalent bus routes from that study are only 2-5% higher suggesting that their model does not adequately reflect the dispersion of PM fractions to different road users. Significant variation in UFP concentrations at very small scales has been reported by Int Panis et al. (2008).

The difference between the results based on concentration measurements only (Figure 4) and those including tidal volume (Figure 5) clearly demonstrates how important it is to take the physical effort that cyclists make into account. Nevertheless, to our knowledge no other project has ever designed such simultaneous measurements. Most authors have either used rough estimates to account for the higher tidal volume of cyclists (den Breejen, 2006) or ignored differences in tidal volume (Hertel et al , 2007; Bogaard and Hoek, 2008). den Breejen (2006) used a common value of 2.3 for all cyclists (based on Rank et.al, 2001). Our initial assessment suggests that this is a serious underestimation even for non-sloping trajectories cycled at low wind speeds. We expect that tidal volume will be even higher for sloping trajectories in other Belgian cities (e.g. Brussels). On the other hand all of our test subjects are adult males and tidal volumes are probably smaller for women and children. Given the ultimate goal of the SHAPES project, to provide conclusions and recommendations for all Belgian regions, it is important to take the effects of slopes on tidal volume into account.

Increased tidal volumes cause an additional exposure of cyclists to PM compared to what the exposure would have been when breathing normally (e.g. at the annual average concentrations in the town were they live). In the next phase of the SHAPES project we will compare this extra exposure of cyclists and its likely health impacts with the well-known benefits of cycling for health. We hypothesise that the extra exposure does not offset the health benefits.

Health impacts for exposure to PM that can be found in literature are usually expressed as an effect of increasing the annual average levels of PM10 by 10µg/m³. There is now a consensus that this leads to a 6% increased mortality rate in the general population (Künzli et al., 2000). If we want to convert our observations using existing epidemiological literature, we need to assume that peak exposure (during cycling) and chronic exposure (over a whole year) are equivalent. In that case a cyclist that covers this trajectory twice a day for 200 (working) days would have inhaled an extra 12 mg of PM10. This is an increase of only about 3% when compared to breathing average ambient concentrations (40µg/m³ in Belgium). The same extra dose could be obtained by raising ambient levels of PM10 by only 1.3 µg/m³ over the entire year which would lead to a 0.8% rise in population average mortality. Andersen et al. (2000) concluded that cycling to work decreased mortality risks by 40%. At first glance we would conclude that, in this small town, risks to cyclists from air pollution exposure are much lower than the health benefits. Nevertheless there are several issues that need to be cleared before we can positively make this conclusion.

Vandenbulcke et al. (2008) demonstrate that commuters are more likely to be cycling in areas with higher concentrations of PM10. The town of Mol is therefore only representative for rural conditions, but not for more common urban and industrial areas.

Beelen et al. (2008) have shown that proximity to traffic is associated with a higher risk. This suggests that PM emissions from traffic (and hence also UFP) may be more toxic than the general urban mixture of PM (see also Brugge et al. 2007). In addition there is data both from modelling (Martonen et al. 2003) and measurements (Jaques et al. 2000, Daigle et al., 2003) suggesting that more (ultra) fine particles (typical of traffic sources) deposit inside the lungs and airways. To complicate things even more, deposition rates depend both on the ventilation volume and expiration rates, both of which are increased while cycling.

Experiments in chambers suggest that peak exposures may be more important than an increase in annual average concentrations (Wyzga, pers. comm.) and we therefore have to be very careful in deriving health impacts from the current set of measurements.

7.3.2 Accidents

The data presented in this report are the results of the data collected from the start of the project in March 2008 until the end of 2008.
About 1700 participants registered on the website. Participants who are included in the data analysis are between 18 - 65 years, have a paid job outside their home, and cycle to work more 2 times per week. From the 1700 participants who left their e-mail address on the SHAPES website, 1166 participants (656 Dutch speaking, 510 French speaking) filled out the General Questionnaire. The General Questionnaire gives us an idea of general traffic related aspects.

The participants predominantly use the bicycle as a mode of transport, with 65,4% of the participants using their bike to travel to work 3 to 5 times per week. 74,5% use the bicycle as major mode of transport and another 11,3% use the bicycle in combination with public transport or the train. Another item to illustrate that the participants are regular bicyclers is that 81% use the bicycle the whole year through to cycle to work. When choosing their route to work nearly half (47%) of them take the shortest way. Twenty five percent take a longer route because of safety reasons and 21% take a longer route because this longer route is more pleasant to cycle then the shortest route. The environment plays an important role in the choice to whether or not you will use the bicycle as a transport mode. In the sample of the population, 38% indicate that they have bicycle paths near their home, on the way to work and in the direct surrounding of their workplace. About 60% indicate that there is a bicycle path near their home or on the way to work or in the direct surrounding of their workplace. The probability to have a bicycle path (near home) is 7,35 x higher in Flanders in comparison with Wallonia (LCI = 5,03; UCI = 10,75). Preventive measurements like wearing a helmet, a flashy vest or lights are one of the first measurements to avoid accidents (Thornley, 2008). Twenty-one percent always wear a helmet and a flash vest and nearly 20% never wear any protective measurements. Significantly more participants living in Flanders wear protective measurements in comparison with participants living in Wallonia.

From the 800 participants who filled out the Retrospective Questionnaire, 27 participants were excluded from the data analysis. From the remaining 773 participants, 64 had an accident that fulfilled the following in- and exclusion criteria: accident with corporal damage in the past 12 months before the start of the study; on the route to work (not during recreational cycling); acute injury.
In the past 12 months before filling in the questionnaire, 64 accidents occurred, from which 47 accidents involved men and 17 women. The risk of being injured while cycling to work is 8,88% for men and 6,97% for women. The most common risk for having an accident is slipping (27%), followed by 'direct contact with a car' (14%) and 'refuse to give priority (13%). It was also asked the participants what the cause of the injury was. The most common cause for an injury was a fall (24%), slipping (21%) and 'direct contact with a car' (19%). Accidents while cycling to or from work meanly occur during periods of dry weather (68,8%), when it is light outside (65,6%) and on a dry road (57,8%). Bicycle accidents occurred most often on the road with motorised transport (32,8%), a bicycle path (23,4%), and on a cross road (20,3%). Eighteen of the 64 accidents occurred on a bicycle path, separated from the regular street.
In 47% of the accidents, more then 1 body part is injured, with graze or bruise (30%) occurring the most often. Fourteen participants (11%) had a fracture. Three percent lost consciousness and 4% of the participants had a concussion. The body part mostly injured is the knee (17,4%), the wrist (13,2%), hand (11,8%) and the shoulder (9,0%). In 64,1% of the cases, more than 1 body part was injured. Unfortunately, permanent corporal damage occurs in 7,8% of the cases and 23,4% is not yet defined if the corporal damage will be permanent. Participants were asked to estimate the medical and the material cost of the accident. The total cost for all accidents together was between € 56450 and € 103000. Materials costs (€ 36200 - € 65700) were more important than the medical costs (€ 20250 - € 37300). The insurance reimbursed a total of € 11700, the employer € 7810 and 'others' € 1452, which makes a total of € 20962. Fifty five percent of the participants where not able to perform their job after the accident for a mean duration of 1,16 month and a total of 53,3 months (sum of all participants). Thirty percent of the participants were not able to perform their hobbies, which resulted in a total loss of 25,6 months of hobbies, with a mean duration of 1,84 month.

During the first 10 months that the Prospective Questionnaire was online more than 17000 week diaries were filled out. A total of 239 participants indicated that an accident occurred. After applying the selection criteria, 62 accidents were maintained for data analysis. To be registered as an accident for this prospective study, the accident had to be acute, in the preceding week on the route to work (not during recreational cycling), and with corporal damage.
The main defined cause of the accident is 'slipping' in 26% of the cases and 'direct contact with the car' (11%). Eight percent of the accidents are caused by inattentiveness of the bicyclers themselves and in another 8% of the cases hindrance on the road like road constructions were the cause of the accident. Twenty seven percent of the accidents did not fit the existing categories. When looking at the cause of the injury we see that slipping (32%) is the most often reason, followed by 'others' (29%). Direct contact with the car (15%) is also an important cause of the injury. Most of the accidents occur during dry weather (72,6%) on a dry road surface (64,5%), and at daylight (72,6%). Crossroads seem to be the place of predisposition for traffic accidents with bicyclers. Cycling on a bicycle path (20%) is the second most important place where accidents occur, followed by a continuing street where cyclists and motorised vehicles share the same road space (18%). Thirty four percent of the participants rode on a bicycle path when they had the accident, which was separated from the main road in 71,4% of the cases.

The body part that is most often injured is the knee (19,9%), the hand and fingers (13,7%), the shoulder (9,6%), and the elbow (9,6%). In 66,1% of the accidents, more than 1 body part was injured. The most frequent type of injury is graze (43,2%), bruise (22,5%), and muscle torn (10,8%). One participant lost consciousness, 1 had a concussion and 1 was in shock. In 59,3% of the accidents, more than 1 type of injury occurred. Material damage occurred on the bicycle (29,2%) and clothes (22,2%).
In order to be able to compare the results from this prospective study with existing literature, it is important to examine if the accidents registered during this study will be mentioned in police, hospital or insurance statistics. In almost 92% of the cases the police did not come to the place of the accident and in 75,8% of the accidents, the insurance was not involved. Medical assistance was needed in 79,0% of the accidents. Participants were taken to the hospital in only 8,1% of the cases.
Security on the road is for a large part the individual responsibility. In 32,2% of the accidents, participants indicated that they could have avoided the accident. 'Imprudence' (16,1%) and 'distracted' (16,1%) are the most often mentioned reasons. Primary protection measurements, as wearing a bicycle helmet, flashy cloths, and lights and reflectors, are also important and can be take by everyone in order to increase the personal security. Only 30,6% of the participants indicate the use the three above mentioned protection measurements. About half of the participants wear a helmet or flashy clothes.

7.3.3 Physical activity

The increasing sedentary lifestyle in large sectors of the population in many developed countries, and the consequent decline in levels of physical activity have become a cause of concern (Warburton, 2006). Two developments in modern life have raised interest in this area. First, chronic degenerative diseases, which are closely related to reduced levels of physical activity, have replaced many infectious and contagious diseases as cause of death and disability. Second, advances in technology have altered most of our occupations and modes of transportation so that we expend less energy in daily activities (Montoye, 2000). There has been a growing recognition that reduced levels of physical activity can partly be explained by the dominance of the car as a mode of transport in the urban society, especially in the way in which it inhibits walking and cycling (Lumsdon, 1999). Since 1970 passenger traffic in the European Union has more than doubled, while that traffic is mainly based on private car use with the related use of fossil fuels and environmental impact (Pocklington, 2000). The car culture of the 70s that promised freedom and wide open space has led in the last decade to dependence and gridlock (Williams, 1996).

Large scale epidemiological studies showed that physical activity is associated with a marked decrease in cardiovascular and all-cause mortality in both men and women and all age groups, even after adjusting for other relevant risk factors (Nocon et al., 2008).
Considerable knowledge has accumulated in recent decades concerning the significance of physical activity in the treatment of a number of diseases, including diseases that do not primarily manifest as disorders of the locomotive apparatus. In their review Pedersen & Saltin (2006) present the evidence for prescribing exercise therapy in the treatment of metabolic syndromerelated disorders (insulin resistance, type 2 diabetes, dyslipidemia, hypertension, obesity), heart and pulmonary diseases (chronic obstructive pulmonary disease, coronary heart disease, chronic heart failure, intermittent claudication), muscle, bone and joint diseases (osteoarthritis, rheumatoid arthritis, osteoporosis, fibromyalgia, chronic fatigue syndrome) and cancer, depression, asthma and type 1 diabetes.

Physical activity has been recommended to reduce coronary heart disease (CHD) risk factors. Primary prevention of CHD aimed at improving lipid and lipoprotein levels (Leon & Sanchez, 2001), and blood pressure (Fagard, 2001; Whelton et al., 2002) begins with a multifaceted lifestyle approach that included physical activity.
Supervised intervention studies (10 – 16 wk) found that physical activity provides mental health benefits to persons who are without serious psychological problems. These benefits included increases in general well-being (Cramer et al., 1991) and reductions in tension, confusion (Moses et al., 1989), and perceived stress and anxiety (King et al., 1993).

Physical activity at moderate intensity may be easier to begin with, and will be more likely to be continued regularly (Andersen et al., 1999; Dunn et al., 1999). Therefore, health experts are broadening their conceptualisation of physical activity from leisure-time activity to 'a lifestyle or way of life that integrates physical activity into the daily routine'. One way of being physically active on a daily basis that can be integrated in the day life routine is cycling to work (Oja et al., 1998).

Those who use the bicycle as transportation to work experienced a lower all-cause mortality (Matthews, 2007) and myocardial infarction rate, even after adjustment for leisure time physical activity, and sports participation discriminated mortality rates even among the more physically active subjects (Andersen et al., 2000). Cycling to work may also have a favorable effect on body fat markers and body mass gain (Wagner, 2001). In a recent meta-analysis, Hamer et al. (2008) stated that active commuting that incorporated cycling was associated with an overall 11% reduction in cardiovascular risk and that this was more robust for among women.
de Geus et al. (2009), Hendriksen et al. (2000) and Oja et al. (1991) showed in their unsupervised intervention studies that cycling to work improves physical performance in previously untrained middle-aged men and women. Both the maximal oxygen uptake capacity (VO_{2max}) and the maximal external power (Wmax) increased significantly in the intervention groups in comparison with the control groups. This increase in VO_{2max} and Wmax was achieved by cycling on a regular basis (~3.0/wk) at an intensity of more than 75% of their maximal aerobic capacity (Hendriksen et al., 2000; de Geus et al., 2007). In addition to the physical performance, it was shown that cycling to work has a positive influence on the quality of life (de Geus et al., 2009) and CHD risk factors (Oja et al., 1991).

8 POLICY RECOMMANDATIONS

On average, we note that the diversity of policies, environments (topography), socio-economic characteristics as well as the availability of infrastructures and facilities mainly explain the spatial variation between the communes. Most of the cycling measures should focus on the 5E's (engineering, education, encouragement, enforcement and evaluation) in order to initiate a modal shift from car to bicycle.

Among the socio-economic variables retained in the regression model, the education, the age and the gender have the greatest impact on bicycle use. In particular, communes with a high proportion of commuters that are women and / or are more than 45 years of age show lower shares of commuter cyclists. Indeed, in Belgium, less women cycle to work compared to men, which is probably explained by the higher concerns they have about their personal security but also by the numerous family commitments they are faced with. From this first analysis based on the most relevant socio-economic factors, it turns out that efficient measures could be promotional and educational campaigns focusing on cycling and conducted in private companies and public services (e.g. administrations, hospitals, schools, …). Such campaigns could increase the share of commuter cyclists, especially if they focus on women and commuters being between 45 and 54 years of age. Within the framework of these campaigns, underlining the health benefits – not only for the commuter cyclists themselves, but also for the population as a whole – and the improvement of the quality of life associated with bicycle use could lead to encouraging results, particularly in Wallonia where the bicycle is still under-promoted and insufficiently used in commuting trips.

Concerning the environmental variables, cycling infrastructure, accident risks, mean slopes and traffic volume explain to a large part the differences of bicycle use between the communes. The main findings showed that flat terrains, high-quality cycle paths, as well as low accident risks and traffic volumes encourage cycling. Particularly in Brussels and Wallonia, the provision of an extensive and high-quality cycling network could certainly cope with the numerous fears and safety concerns inhabitants have about cycling: indeed, it could reduce the accident risks and mitigate the (impact of) the traffic volume, as well as it could improve the global perception (e.g. in terms of cycling dangers or social status) commuters have about cycling. Within this context, the planning of the cycling network plays a key role: it should be planned in an optimal way so that it reduces the impact of deterrent variables. For instance, alternative paths should be chosen so that accident risks, traffic volume (and the associated air pollution) and slopes are minimized. Indeed, the statistical analyses performed in Section 5.2. have shown that decreasing the number of vehicles by 100000 (by kilometre and by year) or the slopes by 1° significantly increases bicycle use. In the same time, avoiding congested roads by taking alternative paths reduces the exposure of cyclists to high concentrations of air pollutants (e.g. PM10) and accidents. From a technical point of view, planners and engineers should conceive paths separated from the road traffic – but still allowing a visual contact between the cyclists and the motorists – so that inexperienced and older commuter cyclists (i.e. having a more feckless behaviour due to the age) feel secure. The results of the regression concerning the mean slopes also suggest that the new cycle paths should be constructed as flat as possible so that they make the bicycle trips easier. Nevertheless, this is not always feasible, especially for several Walloon communes where the mean slopes (along the road network) exceed 5 degrees. For such hilly terrains, the promotion of electric bicycles could probably face with such a barrier. Among others measures, stricter parking policies and cycling facilities at transport stations (and stops) matter for increasing bicycle use in Wallonia.

Land-use and accessibility variables also matter for planners and policy makers, especially through the city size and the commuting distances. Our findings show that the share of commuter cyclists is higher in the largest cities, while it is generally lower in the rural communes. Large urban areas indeed provide high-quality public transports and benefit from a good proximity and connectivity between the different activities, allowing shorter and thus more bikeable (or even walkable) commuting distances. More competitive alternatives to the car are then available, which leads to lower proportions of households owning a car in urban communes. As a consequence, implementing measures aiming at favouring dense and mixed-use developments in cities (e.g. through re-developments in urban areas or financial measures stimulating inhabitants to live in cities) could result in commuting distances that are low and encourage cycling and walking. In the long-run, such measures could not only increase the share of the non-motorized modes and public transports, but it could also mitigate the negative impacts generated by the car traffic (e.g. air pollution, congestion, noise, accidents, health problems, road damages, …) and improve the quality of life in urban areas.

Last but not least, the results obtained in the spatial lag model reveal (through the introduction of a spatially lagged coefficient in the regression) that high bicycle shares stimulate cycling in neighbouring communes and hence that a mass effect can be initiated, i.e. more cyclists travelling to work encourage even more commuters to cycle. Such a finding is quite encouraging for policy measures aiming at developing bicycle use in urban areas, e.g. by means of the implementation of bicycle sharing systems.

The measures recommended above aim at encouraging cycling but they are however not efficient when implemented on their own. Indeed, planners and policy makers should be aware that only a combination of these measures (e.g. promotional campaigns, improvement of cycling facilities, policies based on compactness and mixed-use developments, …) would really lead to an increase of bicycle use by satisfying the potential demand. This increase in turn could allow to address environmental, mobility and health problems with which the society is faced nowadays.

A robust methodology was developed and demonstrated for simultaneously measuring UFP, PM10, PM2.5, PM1 as well as tidal volume, oxygen consumption and work.

- A P-TRAK device can conveniently be used for making UFP measurements while cycling.
- UFP measurements prove to be a very useful supplement to PM10 and PM2.5 measurements as they are more closely related to emissions of motorized traffic.
- UFP tend to fall rapidly with increasing distances from the emission source, revealing important new possibilities to decrease the exposure of people to PM
- Only 8.3% (43 cases) of the participants who filled in the retrospective questionnaire had an accident. This amount is not enough to drawn policy relevant conclusions.
- In the first 10 weeks of the online injury registration (prospective study) 14 accidents occurred. If we succeed in keeping the 500 participants for one year, enough data will be gathered to calculate the incidence of traffic related cycle accidents.
- A permanently renewing feedback system will have to be developed to keep our participants motivated.

- The south part of the country needs extra attention since the participation rate is much lower than in Brussels capital region and Flanders.
- Tidal volume is clearly influenced by the slope of the route.
- The relative intensity at which subjects' cycle influences the tidal volume and by this means influences the potential inhalation of UFP.

In this intermediary report we have also presented preliminary data that indicates that levels of PM10 are higher in the car compared to cyclists. Nevertheless, because cyclists have a higher tidal volume, the amount of inhaled fine particles is higher.
Concentrations of UFP are not significantly different between cars and cyclists. This may be due to overall low traffic levels during this experiment in Mol and should not be extrapolated to other cities or traffic conditions. Data collected in Brussels and Louvain-la-Neuve will be analyzed and compared.
The concentration differences between cyclists and cars for other PM fractions are barely statistically significant and there is an obvious need to collect more data to support this tentative conclusion. The measurements from the pilot study described here will therefore be repeated later in 2008 in two other Belgian cities; Brussels and Louvain-la-Neuve. More replicate measurements (*N*=10) will be done in each city both for cyclists and for car drivers to ensure that we can demonstrate a statistical difference between car drivers and cyclists at the UFP levels found in this study.
The inhaled quantities of UFP and other PM fractions are significantly higher for cyclists than for car drivers because their average ventilation rates are 3.3 times higher when cycling.
The results of this study are likely to have interesting implications on the planning of cycling infrastructure. The fact that small scale distances have a significant impact on exposure implies that changes to the relative lay-out of cycling lanes, driving lanes, parking lanes and other road infrastructure can be used to reduce exposure of cyclists to air pollution. Any measure that causes an increased distance between cyclists and tail-pipes, especially where emissions are high (e.g. at intersections and on slopes), will help to reduce exposure.

9 PERSPECTIVE ON PHASE 2

9.1 Introduction

9.2 Policy scenario analysis

UCL leads this WP. It is planned almost entirely in Phase 2 with the exception of Task 5.1.1 which could started earlier (because part of the data on spatial modelling of commuter traffic is available).

9.2.1 Selecting a policy scenario

In this task we will define a policy scenario, combining policy measures and infrastructure changes that will induce non-marginal effects on health, air pollution and energy use. This scenario then will serve as the starting point to extrapolate the findings on air pollution exposure and activity for typical commuting trajectories to the entire country taking into account a non-marginal change in infrastructure, and modelling the risk of being involved in a road accident for different type of individuals (gender, age, …), and different types of spatial environments.

9.2.2 Assessing the impact of the policy scenario

The result of the policy scenario is calculated. Here we take into account previously collected data and knowledge:

- The spatial model on commuter traffic, to calculate the effect on accident risks under a changed infrastructure;
- The substitution potential taking into account plausible substitution rates between car & bicycle trips, where the possibilities and spatial constraints are analyzed for establishing alternative (equivalent) cycling trajectories that minimize exposure to air pollutions and optimize both substitution rate (e.g. by avoiding slopes) and benefits of physical activity;
- The distribution in time and space of health impacts across the targeted groups in the population (cyclists, car users and residential population), taking into account ageing populations.
- The associated change in health costs thanks to the policy scenario;
- More specific: the improvement in air pollution (for particulate matter) and CO_2 emissions;
- Also more specific: the costs savings in the Belgian social security, and compared to the overall external cost savings.

Task 5.3 Policy advise
The findings will be concerted into advise for both federal, regional and local authorities taking into account their respective competences.

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- Federaal wetenschapsbeleid (http://www.belspo.be/SSD/)

FOLLOW-UP COMMITTEE

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Remko Reuter - ProVélo
Philippe Degand - Coordinateur Mobilité - UCL - SPER
Rudi Torfs - VITO (Vlaams Instelling voor Techonologisch onderzoek)

ANNEX A SHAPES PUBLICATION PLAN

This annex contains a detailed list of the way that the scientific results will be disseminated in the scientific community. Only tentative peer-reviewed papers are included, conference papers were omitted from this list.

Table 5: SHAPES publication plan

N°	Lead author	Aid	Outline	Draft	Final	Submitted
1	Gregory	Isabelle			15/12/2008	15/1
2	Gregory	Isabelle		Fall 2009	?	?
3	Gregory	Isabelle	28/2/2010	31/3/2010	Fall 2010	?
4	Gregory	Claire		31/12/2008	15/1	31/1
5	Bart	Bas	16/1	15/6	31/8	30/9
6	Bart	Bas	31/12/2008	31/1	28/2	9/3
7	Bas	Luc/Bart	15/2	31/3	30/4	15/5
8	Bas	Gregory/Luc	31/3/2009	31/5/2009	15/6/2009	15/8
9	Bart	Bas/Luc	31/3	31/5	15/6	31/8
10	Luc/Tim	Bas/Bart	31/5	31/8	31/10	30/11

N°: 1

Title

Mapping bicycle use and accident risk for commuters in Belgium

Journal

Transport Policy (IF=0.883)

Outline	finished
Draft	finished (Submitted for language revision on Dec 5th 2008)
Final	15/12/2008
Submitted	15/1/2009

Authors

Grégory Vandenbulcke, **Isabelle Thomas**, Bas de Geus, Bart Degraeuwe, Rudi Torfs, Romain Meeusen, Luc Int Panis

Aim:

Exploring and understanding spatial patterns of bicycle use and road accidents when commuting in Belgium.

Main results: Commuters are more inclined to cycle in regional cities (25,000 to 120,000 inhabitants). High shares of commuter cyclists are correlated with low risks of casualties.

Abstract

This paper aims at exploring and understanding the spatial patterns of bicycle use for commuting and the risk cyclists run being injured in a road accident when commuting to work in Belgium. Exploratory data analyses suggest that the observed differences in the use of the bicycle to get to work are strongly linked to the urban hierarchy: commuters are more inclined to cycle in cities and specifically in regional towns (with 25,000 to 120,000 inhabitants). In large cities (more than 200,000 inhabitants), less commuting by bicycle takes place. The relationship between bicycle use and the risk of being seriously injured or killed in a road accident is also studied. A cluster analysis confirms that high proportions of commuter cyclists are correlated with low risks of becoming a casualty. It also shows that there are strong spatial differences (regional and between different types of towns) in bicycle use and the risk of an accident. This suggests that cycling policies should be spatially differentiated.

Comments

- **Presentation (colloquiums, seminars, ...):**

CVS (Colloquium Vervoersplanologisch Speurwerk), 34th Edition, Belgium November 22-23, 2007, Antwerpen, Cultureel Congresscentrum Elzenveld.

N°: 2

Title
Where and why is it more risky to commute by bicycle ?

Journal
Journal in transport and/or geography (IF = ?)
LANDSCAPE AND URBAN PLANNING, Geographical analysis, Environment and planning

Outline	finished
Draft	Fall 2009
Final	?
Submitted	?

Authors
Gregory Vandenbulcke, Isabelle Thomas, ….

Aim:
Understanding the spatial variation of road accidents involving commuter cyclists at the scale of the 589 Belgian communes. Regression techniques are used.

Expected results:
The risk of being involved in an accident will be modelled at the scale of the communes (same kind of paper as preceding one).

Abstract
- accident risks of cyclists are poorly known
- a new database was established based on the SHAPES questionnaire
- 47 + xx accidents were registered retrospective and prospective, including those with only minor injuries

Comments
All data is available

Future presentations:
? ECTQG, September 4-8, 2009, Maynooth (Ireland)

N°: 3

Title
Explaining the intraurban location of road accidents. A geo-statistical approach

Journal
Journal in transport and/or geography (IF = ?)
LANDSCAPE AND URBAN PLANNING, Geographical analysis, Environment and planning

Outline	28/2/2010
Draft	31/3/2010
Final	Fall 2010
Submitted	?

Authors
Gregory Vandenbulcke, Isabelle Thomas, ….

Aim:
Understanding the location of road accidents at a local level, i.e. within different urban regions. Physical variables (urbanized-rural, topography, etc.), morphological variables, accessibility variables and individual variables (e.g. age) will be used.

Expected results:
(Auto-)Logit models will be used to model the probability of road accident for cyclists in specific locations. Development of morphometric indices.

Abstract
Fractal analysis of buildings and structures in the urban region of Charleroi aimed at explaining spatial patterns in the distribution of accidents with commuter cyclists.

Comments
Gridded (4x4meters) KADVEC data will made available to UCL by VITO.
Survey data will be made available by VUB immediately after the end of the formal survey on March 9th 2009.

N°: 4
Title
Cycling to work. Modelling meso-scale spatial variations.
A multiple regression analysis of commuter cycling motives

Journal
Transportation Research Part A (IF = 1.352)
? Transport Policy ?

Outline	finished
Draft	15/01/2009
Final	send tot potential co-authors in januari 2009
Submitted	?

Authors
Gregory Vandenbulcke, Claire Dujardin, Isabelle Thomas,…

Aim:
Explaining the spatial variation of observed bicycle use when commuting at the level of the 589 Belgian communes.

Main results:
Regression techniques are used and special attention is put on autocorrelation, endogeneity and multicollinearity. Results show that most of the inter-municipality variation in bicycle use is related to environmental aspects (relief, accidents, etc.) as well as city size, distance travelled and features of the population.

Abstract
Cycling to work:
Modelling spatial variations within Belgium.
This paper aims at explaining the spatial variation of observed bicycle use when commuting at the level of the 589 communes of Belgium. Explanatory variables are those suggested by transport and urban geography theory (socio-economic characteristics, distances, environmental characteristics, city sizes and characteristics, safety …). Regression techniques are used and special attention is put on autocorrelation, endogeneity and multicollinearity. Results show that most of the inter-municipality variation in bicycle use is related to environmental aspects such as relief, traffic volume and bicycling accidents, as well as city size, distance travelled and features of the population (e.g. share of youngsters or percentage of households with young children).

Comments

Presentation (colloquiums, seminars, …):
- ⇨ ERSA 47th Congress, Aug 27-31, 2008, Liverpool, University of Liverpool
- ⇨ Geographer's day (3rd Edition), October 24-25, Brussels, ULB & VUB
- ⇨ Séminaires de Géographie, Nov. 24, Louvain-la-Neuve, Université Catholique de Louvain-la-Neuve (UCL)

- **Future presentations**:
  - ⇨ ? Vélo-city, May 12-15, 2009, Brussels (Tour & Taxis), Belgium
  - ⇨ ? NECTAR, June 18-20, 2009, Arlington (Washington DC), USA
  - ⇨ ? Bivec-Givet, May 27, 2009, Brussels (VUB), Belgium

N°: 5

Title
Exposure of car drivers and cyclists to PM and UFP

Journal
Science of the Total Environment

Outline	16/1/2009	check whether some of the Bxl and LLN data can be recovered
Draft	15/6/2009	
Final	31/8/2009	
Submitted	30/9/2009	

Authors
Bart Degraeuwe, Luc Int Panis, Nico Bleux, Bas de Geus…

Abstract
Commuter cycling enhances the long-term physical health in the general population. But it is not well understood whether cyclists are exposed to higher risks due to air pollution and accidents. A non-marginal modal shift to cycling helps realizing a better general air quality, a better overall physical condition of the population, and an increased general traffic safety. Quantifying these effects in costs will assist policy makers in their decisions.
In this paper we present a methodology to simultaneously measure fine particles (PM10, PM2.5, PM1 and UFP numbers) and tidal volume while cycling and car driving. We demonstrate that the exposure of cyclists to traffic exhaust depends on

- the inspiration and expiration time and profile influence the exposure to UFP peaks?
- tI and tE were not exported yet. Bas will provide spiro date with these times for some cycling trips. Bart will perform the calculations, superposing the UFP concentration and the instantaneous breath flow.

Even if PM-concentrations in cars are higher, cyclists have a higher exposure due to increased ventilation. We hypothesize that this increased exposure does not offset the cardiovascular health benefits of cycling.

Comments
Based on the conference paper for the Algeria conference (based on Mol data only) but with extended datasets.

The LLN experiment was planned perfectly (1 car drive for each bicycle drive, 8-9 replica's). Unfortunately, the recorded PM data was lost. The experiment needs to be repeated. The Brussels and Mol experiments will also be repeated along the same lines.
Two or three people will be subjected to another max test.

N°: 6

Title
The effect of physical condition and training on the inhalation of UFP while cycling

Journal
?

Outline	31/12/2008
Draft	31/1/2009
Final	28/2/2009
Submitted	9/3/2009 (before the end of the on-line survey)

Authors
Bas de Geus, Bart Degraeuwe, Luc Int Panis, ….

Abstract

- Does exposure depend on cycling speed?
    - Combine needed cycling power equation with power-ventilation relation from max-test.
    - Process data from experiment in Liège (only hard rate available)
    - Plan extra experiment with spiro, limited number of persons cycling at different speeds each.
- Does training level influence exposure.
    - It is suspected (see previous point) that exposure increases with training.
    - Check possible other factors: height (long volume), increase in efficiency, oxygen consumption vs air consumption, …
    - Check with data from PhD Bas: spiro data from untrained people and the same people after 6 months cycling.

Comments

N°: 7

Title
A new survey on accident risks and injuries in commuter cyclists

Journal
?

Outline 15/2/2009
Draft 31/3/2009
Final 30/4/2008
Submitted 15/5/2008 (before the start of the SHAPES & PM²TEN experiments)

Authors
Bas de Geus, Romain Meeusen, everyone…, Luc Int Panis

Abstract

Description of the survey
- introduction overview of existing data in Belgium and neighbouring countries, disadvantages (outdated and minor injuries not recorded)
- methodology
- sociological aspects who cycles, when, where, how long? Did it change ?
- results of the retrospective accident survey
- results of the prospective accident survey
- What is the observed number of cyclist accidents with minor and major injuries per mio km and how does this compare with other modes (car, train, air, motorcycle)?

Comments
We need to find someone (a student at VITO) to make an analysis of the costs involved with the accidents

N°: 8

Title
Observed levels of commuter cycling in Belgium, a spatial analysis

Journal
Transport Policy?

Outline 31/3/2009
Draft 31/5/2009
Final 15/6/2009
Submitted 15/8/2009 (before the end of the on-line survey)

Authors
Bas de Geus, Gregory Vandenbulcke Luc Int Panis, ….

Abstract

- Does the observed level of cycling (mileages from the on-line survey) match the expected mileage from the census? (stratified by commune or region)
    - Make a regression to predict average mileage rather than number of cyclist
    - Does it reflect the hierarchy of the communes as expected? (quid the status of Brussels?)
- Can the deficit of cyclists in e.g. Limburg and Brussel (the observed numbers are lower than the predicted numbers) be explained by the size of the foreign population (or Belgian with foreign roots) ? There is some Dutch data about this that I cannot find anymore.

Comments

N°: 9

Title
Commuter cycling and public health

Journal
Science of the Total Environment? The Lancet
Outline 31/3/2009
Draft 31/5/2009
Final 15/6/2009
Submitted 31/8/2009

Authors
Bart Degraeuwe, Bas de Geus, Luc Int Panis, ….

Abstract
- Is the observed level of physical activity (avg speed x distance x slope) sufficient to maintain good health? In which areas? Commuter cycling or combined with other cycling?
- In which communes is the exposure of cyclists to PM10 most important?
  - Combine level of physical activity (power) with average PM10 by commune. Per cyclist or for all cyclists in that commune.
- Compare the cardiovascular benefits of commuter cycling with the cardiovascular risks of PM exposure. Per commune taking into account the slopes (from NIS) and the distances and speeds (from our own census).

Comments
If we can find a student at VITO to make cost calculations (costs of health, …) this would be beneficial

N°: 10

Title
Physiological effects of cycling under high UFP conditions

Journal
Science of the Total Environment?

Outline	31/5/2009
Draft	31/8/2009
Final	31/10/2009
Submitted	30/11/2009

Authors
Tim Nawrot, Luc Int Panis, Rudi Torfs, Bart Degraeuwe, Bas de Geus ….

Abstract
- Is the observed level of physical activity (avg speed x distance x slope) sufficient to maintain good health? In which areas? Commuter cycling or combined with other cycling?
- In which communes is the exposure of cyclists to PM10 most important?
    - Combine level of physical activity (power) with average PM10 by commune. Per cyclist or for all cyclists in that commune.
- Compare the cardiovascular benefits of commuter cycling with the cardiovascular risks of PM exposure. Per commune taking into account the slopes (from NIS) and the distances and speeds (from our own census).

Comments
Results of the PM²TEN project

Shapes

Interdisciplinair project rond fietsen en volksgezondheid.

Fysieke activiteit en gezondheidsrisico's

van fietsen in verschillende geografische omstandigheden

Shapes

le projet interdisciplinaire va à bicyclette et la Santé Publique

Activité physique et risque en matière de santé

de la pratique du vélo pour différents milieux géographiques