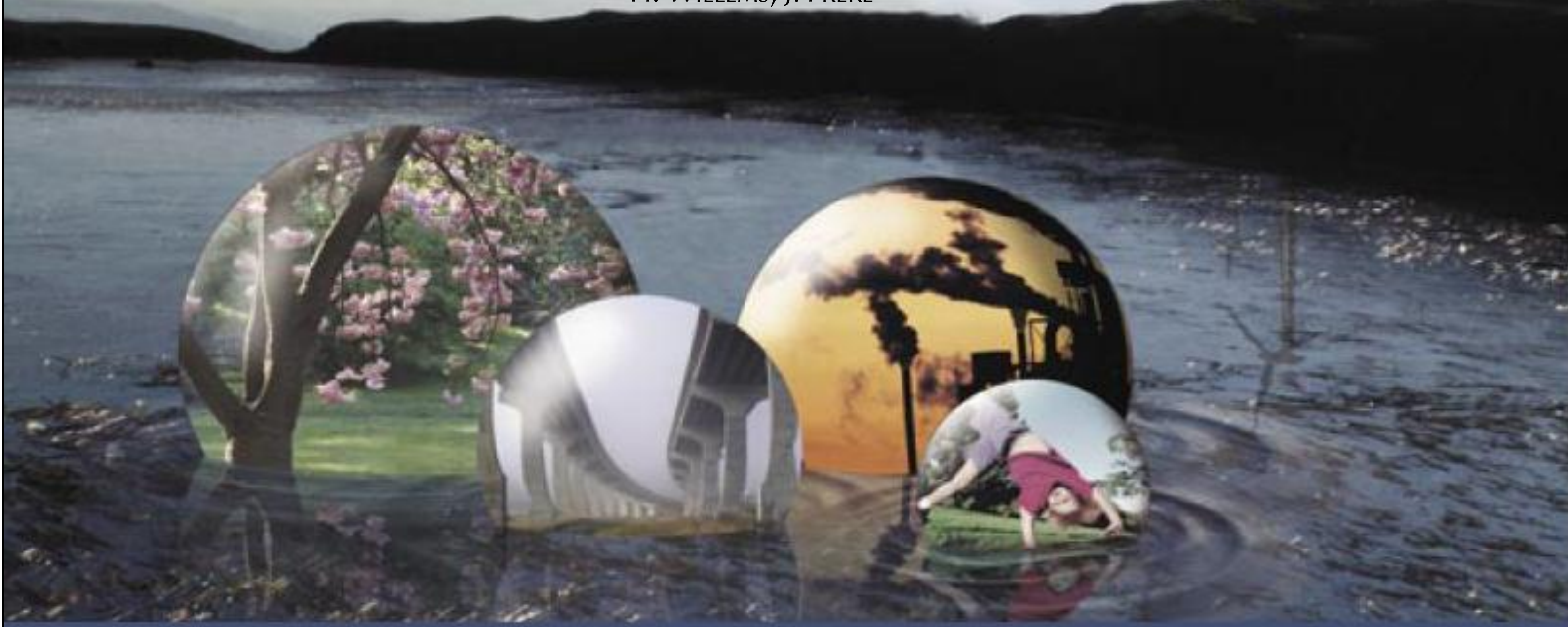
SSD

SCIENCE FOR A SUSTAINABLE DEVELOPMENT

SYSTEMATIC ANALYSIS OF HEALTH RISKS AND PHYSICAL ACTIVITY ASSOCIATED WITH CYCLING POLICIES

«SHAPES »

L. Int Panis, R. Meeusen, I. Thomas, B. de Geus,
G. Vandenbulcke-Passchaert , B. Degraeuwe, R. Torfs, J. Aertsens,
H. Willems, J. Frere



ENERGY
TRANSPORT AND MOBILITY
AGRO-FOOD
HEALTH AND ENVIRONMENT
CLIMATE
BIODIVERSITY
ATMOSPHERE AND TERRESTRIAL AND MARINE ECOSYSTEMS
TRANSVERSAL ACTIONS

SCIENCE FOR A SUSTAINABLE DEVELOPMENT
(SSD)

FINAL REPORT

SYSTEMATIC ANALYSIS OF HEALTH RISKS AND PHYSICAL ACTIVITY ASSOCIATED WITH CYCLING POLICIES

«SHAPES »

SD/HE/03

Promoters

Luc Int Panis
VITO
Romain Meeusen
VUB
Isabelle Thomas
UCL

Researchers

Joris Aertsens, Bart Degraeuwe, Rudi Torfs
& Hanny Willems
VITO
Bas de Geus
VUB
Julie Frère & Grégory Vandenbulcke-Plasschaert
UCL

D/2011/1191/24
Published in 2011 by the Belgian Science Policy
Rue de la Science 8
Wetenschapsstraat 8
B-1000 Brussels
Belgium
Tel: +32 (0)2 238 34 11 – Fax: +32 (0)2 230 59 12

http://www.belspo.be
http://www.belspo.be/belspo/fedra/proj.asp?l=en&COD=SD/HE/03A (SHAPES)
http://www.belspo.be/belspo/fedra/proj.asp?l=en&COD=SD/CL/002 (PM2-TEN)

Contact person: Emmanuèle Bourgeois
+32 (0)2 238 34 94

No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without indicating the reference : L. Int Panis, R. Meeusen, I. Thomas, B. de Geus, G. Vandenbulcke-Passchaert , B. Degraeuwe, R. Torfs, J. Aertsens, H. Willems, J. Frere **- Systematic analysis of Health risks and physical Activity associated with cycling PoliciES «SHAPES » -** Final Report. Brussels : Belgian Science Policy 2011 – 117 p. (Research Programme Science for a Sustainable Development)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Preface / Colofon

This is the final report of the Belgian SHAPES project. It provides an overview of the work that the partners have done from 2007-2011 in the framework of the science for sustainable development programme of the Belgian federal Science Policy.

In 2008-2009 several additional experiments have been carried out in a "cluster" project PM²TEN[1]. The results of those experiments have also been integrated into this report to provide an integrated overview of the new knowledge on commuter cycling resulting from the collaboration between de SHAPES partners.

Luc Int Panis, SHAPES research coordinator. Mol 1 June 2011

Distribution List

Belgian Science Policy
Follow up committee

---

[1] http://www.belspo.be/belspo/fedra/proj.asp?l=en&COD=SD/CL/002
Remark : SHAPES is also involed in the cluster project AIR-QUALITY

SUMMARY

A. Context

Cycling for transportation has important health implications, because it holds the potential of being more physically active on a regular basis. As a consequence commuter cycling (CC) can reduce the risk of cardiovascular diseases, diabetes and hypertension, which are among the leading causes of death and disease. Additionally, cycling is increasingly being promoted as a means to reduce traffic congestion, air and noise pollution and the consumption of fossil fuels. Nevertheless, potential risks like injuries from traffic related accidents, and exposure to air pollutants could potentially outweigh these benefits under certain conditions. To make a proper estimation of the health benefits and risks of cycling for transportation, both health benefits and morbidity risks are included in our analysis.

The SHAPES project is at the crossroads of health, transportation and air pollution research. Its main aim is to provide information to policy makers in these domains to facilitate the implementation of integrated policies in different domains. To achieve that goal, a comprehensive study was set up in which health benefits and risks associated with commuter cycling are investigated. These include:

- a better general air quality but increased exposure to air pollution when cycling;
- the benefit of a better overall physical condition of the population, thus reducing the health risks from a sedentary lifestyle, increased risks for injuries and accidents (for those who shift from car to bicycle), but increased traffic safety (for all road users).

The SHAPES team demonstrates that policies on air pollution, climate, public health, mobility and safety are interrelated when considering commuter cycling in urban areas and that important synergies exist that can be exploited to increase the leverage of single domain policies.

In addition, the potential effect of a policy is likely to be different in different places because all components of the problem have an important spatial heterogeneity. The potential for modal shift, the attitudes towards commuter cycling, the physical effort needed and the spatial constraints are very different in the different Belgian regions and SHAPES therefore proposes policy options at the national scale, but specifically tailored for the spatial constraints in each of the regions. Hence, special attention was put on geographical differentiation in the analysis of risks and benefits; main roads with high traffic densities versus backstreets peri-urban and suburban realities, flat versus hilly regions,...

B. Objectives

The main objective of SHAPES is to enable policy makers to make clear and science-based choices related to commuter cycling and transport modal shift in urban areas. The main outcome of SHAPES is the development of integrated frameworks that explore the main risks (i.e. exposure of cyclists to air pollution, as well as the risks and costs associated to bicycle accidents) and benefits of commuter cycling (i.e. the benefits from regular physical activity).

The initial objectives of SHAPES were to:

- develop a spatial analysis for accident risks at different scales: municipalities (aggregated data, Belgium) and accidents themselves (disaggregated data, Brussels);
- develop a spatial analysis of bicycle commuting in Belgium and identify the main spatial determinants of bicycle use, in order to establish policy recommendations for the three Belgian regions;
- identify the infrastructural and environmental variables that are suspected to influence the accident risk, in the Brussels-Capital Region;
- provide for planners and policy makers a decision tool that accurately pinpoints the locations where a high risk of accident is predicted for cyclists (along a selected road trajectory in Brussels);
- study the influence of the morphology of the urban built-up surfaces on road safety;
- implement an on-line injury registration system to monitor minor bicycle accidents (Prospective and Retrospective study design);
- record data on bicycle usage in Belgium;
- evaluate the exposure to air pollution for cyclists compared to car users;
- evaluate the physical condition of cyclists compared to car users;
- integrate these risk factors into a common framework, to evaluate costs and benefits;
- propose policy options that will contribute to safer and healthier cycling conditions and to lower emissions and social security costs in the long term.

SHAPES succeeded in achieving most of the objectives that were originally specified in the contract established between BELSPO and the SHAPES teams. SHAPES also reports on additional data gathered from two extra studies, published in peer-reviewed journals namely the 'Costs of minor Bicycle Accidents (Aertsens et al., 2010) and a manuscript resulting from the PM²TEN research cluster; 'Subclinical responses in healthy cyclists briefly exposed to traffic-related air pollution: an intervention study' (Jacobs et al., 2010).

Some research is still on-going in the framework of PhD and Post Doc work financed by the partners. Additional results from this report will be converted into PhD theses and scientific papers and submitted for publication in scientific journals in 2011 or 2012.

C. Conclusions

1) The observed differences in the use of the bicycle to commute to work on the national level are influenced by different geographical/spatial variables: e.g. institutional region, urban hierarchy, environmental aspects. Commuters are more inclined to cycle in cities and specifically in regional towns (with 25,000 to 120,000 inhabitants; e.g. Brugge and Leuven). In large cities e.g. Brussel and Antwerpen), less commuting by bicycle takes place. The inter-municipality variation in bicycle use is related to the relief, local traffic volumes and cycling accidents. High rates of bicycle use in one municipality stimulate cycling in neighbouring municipalities, and hence a mass effect can be initiated (more cycling encourages even more people to cycle).

2) A selected sample of regular commuter cyclists (cycling ≥ 2 times/week to work) cycle on average 166 minutes per week, covering a distance of 9.04 km per trip. Men cycle for a longer duration (181 min/week and 138 min/week, respectively), longer distances

(61.6 km/week and 36.3 km/week, respectively) and at a higher speed (19.5 km/h and 15.5 km/h, respectively) compared to women. Large regional differences in bicycle usage are also present implying that cycling policies should be region specific.

3) High proportions of commuter cyclists are correlated with low casualty risks ('safety in numbers' principle). The 'safety in numbers' principle is shown to be applicable for major and minor bicycle accidents. There are strong spatial differences (regional and between different types of towns) in the accident risk. Underreporting of minor bicycle accidents in Belgium is accurately quantified. The combined use of the exposure data and accidents/injured participants allowed us to calculate the overall injury risk and injury rate. The incidence rate of minor bicycle accidents in Belgium is 0.047 (95% CI 0.036-0.059) per 1,000 km cycled. Brussels is the region with the highest IR (0.086; 95% CI 0.054-0.118), with a significantly ($P < .05$) higher IR compared to Flanders (0.037; 95% CI 0.025-0.050). Exposure (bicycle usage) must be taken into account, before making statements about whether or not safety measures are effective.

4) When using a retrospective study design (RETRO) the severity of the reported accidents is higher compared to an unbiased prospective study design (PROS). The incidence proportion (IP) is significantly higher in the RETRO compared to the PROS data collection for the total study population, Brussels and Flanders. The incidence rate (IR /1000 weeks) is significantly higher in PROS compared to RETRO. Only 7% of prospectively and 12% of the retrospectively recorded bicycle accidents were reported in police statistics.

5) Modified bicyclist and driver behaviour (e.g. speeding, biking and riding during the AM peak or in inclement weather), bicycle infrastructure (e.g. conflicts with oncoming traffic and at intersections and keeping cycling surfaces clean) and traffic calming measurements can reduce the number and severity of injuries. At sections where drivers and cyclists or pedestrians could interfere, speed limits should be considered.

6) The average total cost of minor bicycle accidents is estimated at 841 euro (95% CI: 579–1205) per accident or 0.125 euro per kilometre cycled. Overall, productivity loss is the most important component accounting for 48% of the total cost. Intangible costs, which in past research were mostly neglected, are an important burden related to minor bicycle accidents (27% of the total cost). Even among minor accidents there are important differences in the total cost depending on the severity of the injury. The estimated total cost for Belgium (in 2007) is between 57 and 183 million euro.

7) Most studies measure the difference between bicycle and car use exposure as ratios of Particulate Number Count (PNC) or Particulate Matter (PM). These ratios are close to 1 and rarely significant. The size and magnitude of the differences in concentrations depend on the location which confirms similar inconsistencies reported in literature. The SHAPES study took the ventilation aspect into account, using direct measurements of the ventilatory parameters. This demonstrates that bicycle/car differences for inhaled quantities and lung deposited dose are large and consistent across locations (heavy *vs.* calm traffic). Inhaled μg $PM_{2.5}$/km and μg PM_{10}/km is significantly higher (400 to 900%) while cycling compared to driving in a car on the same trajectory. These differences are caused by increased ventilation (VE) in cyclists which significantly increases their

exposure to traffic exhaust. The VE while cycling is 4.3 times higher compared to car passengers.

8) A research conducted at the scale of the Brussels-Capital Region shows that a higher risk of accident is associated with the presence of on-road tram railways, bridges (without any cycling facility), complex intersections (i.e. those with reduced legibility by road users), close shopping centres, garages, and higher volumes of van and truck traffic. Cycling facilities built at intersections (especially suggested cycle lanes at right-of-way intersections) and parked vehicles located next to separated cycling facilities (i.e. in the ‘door zone’) also increase this risk, whereas streets where contraflow cycling is permitted reduce it (outside intersections).
9) Mapping the predicted risk of having a cycling accident along the network provides for planners and policy makers a value-added tool that accurately locates the places at high risk of accident and where cycling accidents might have been unreported (see Section 2.11.3). Such a tool hence pinpoints the places where the cyclists should be more careful when riding and/or where changes in the infrastructures might be performed in order to improve the bicyclist’s safety.
10) The differences in bicycle use and accident casualties suggest that cycling policies should be spatially differentiated. Efforts to implement complementary measures such as improved street environment (e.g. by building well-designed and well-kept cycling facilities at intersections, advanced stop zones for cyclists, etc.), traffic calming schemes, better vehicle design, speed limits, and continuous driver and pedestrian/bicyclist education may also improve the safety for all vulnerable road users and as a result increase the number of commuter cyclists.

Based on our findings, it seems that healthy people should not be discouraged from cycling in traffic (provided it is safe), although from a public health point, cycling tracks should be developed away from busy roads. More importantly, traffic-related pollution should be decreased and traffic safety increased. A string of recent reviews engendered by the SHAPES project (de Nazelle and Nieuwenhuijsen, 2010; de Hartog et al., 2010; Int Panis, 2011; Rabl and de Nazelle, in review) indicate that on average, the estimated health benefits of cycling were substantially larger than the mortality risks (exposure to air pollution and bicycle accidents) relative to car driving for individuals shifting mode of transport. The nature of morbidity impacts remains elusive but sensitivity analyses have invariably indicated that when cycling contributes additional physical activity the health benefits for the cyclist are large. In addition cycling also has positive health impacts for the rest population. Nevertheless SHAPES has also demonstrated that exposure to air pollution and minor accident risks are far higher than assumed before. Policies should therefore be put in place to minimize those risks (and associated costs) and maximize the health benefits.

D. Contribution of the project in a context of scientific support to a sustainable development policy

The SHAPES project is at the crossroads of health, transport and air pollution research. Motorised traffic and in particular private cars dominate as a mode of transport in our modern society. This results in air and noise pollution, traffic congestion, accidents and a sedentary lifestyle all of which have negative implications for public health.

Stimulating more people to use the bicycle as a transport mode and increase the use of the bicycle in those who already cycle could help to overcome some of the problems linked to the improper use of motorised vehicles. The use of the bicycle as a transport mode has the advantage of being a means to maintain or increase the physical condition and general health status. Additionally, cycling will reduce road congestion and traffic-related air pollution since cycling has low space requirements and is a non- polluting transport mode.

Our results should enable policy makers to create a safer cycling environment which should stimulate a shift from car to bicycle and decrease the distress caused by bicycle related traffic accidents. More specifically, our results indicate that more (continuous) bicycle paths should be built in the urban environment where people are most likely to cycle. These paths should be built away from the motorised traffic in order to reduce the exposure of cyclists to air pollution and reduce the risk of contact between motorised traffic and bicycles. When building bicycle facilities, special attention should be paid to intersections. Some studies (e.g. McClintock and Cleary, 1996) suggest that when the distance between the bicycle path and the motorised traffic increases at intersections, the accident risk increases. Indeed, planners and engineers should design the bicycle paths so that they still ensure that cyclists and motorists see each other (e.g. advanced cyclist stop lines ensure both visibility at intersection while reducing exposure to the high emissions of accelerating cars). This would at least avoid an ill-founded feeling of security that 'inexperienced' cyclists could have when they cycle on e.g. separated bicycle paths. Traffic speed should also be limited at 30 km/h for motorised traffic in areas where many people walk and cycle. In areas where cyclists and pedestrians use the same public space, road signs should clearly indicate this.

An effective policy towards a cleaner and safer environment stimulates the use of the bicycle and includes measures to discourage the local use of motorised vehicles. Car use should be discouraged for short distances that have the highest environmental impact per kilometre. Safer and clean bicycle facilities and an increased allowance per kilometre covered by bicycle may help to increase the number of cyclists. Investment costs in safe cycling infrastructure will be partly offset by avoided accident costs and improved health.

Car parks in the peripheries of urban centres combined with more expensive parking in the city centres will lower local flows of motorized traffic and therefore increase cycling (Vandenbulcke et al, 2011). Employers can stimulate the use of the bicycle by providing lockers, racks, showers and changing facilities at the workplace.

E. Keywords

Cycling, Commuting, Health, Ultra Fine Particles, Particulate Matter, Exposure, Air pollution inhalation, Bicycle Accidents, Accident Risk, Prospective, Bicycle Usage (exposure), Costs of Bicycle Accidents, Spatial Determinants, Mapping Bicycle Use, Spatial Lag Model, Spatial Regime, Pro-cycling Strategies, Fractal Indices, Morphology of the Urban Built-Up, Black Spots, Cross-K Functions, Bayesian Model, Case-Control Methodology, Dynamic exposure measurements

1. INTRODUCTION

1.1. Context

Environmental and mobility problems generated by massive peri-urbanisation and the growing use of cars have highlighted the need to develop and encourage more sustainable modes of transport. In addition, an increasingly sedentary lifestyle is expected to take a heavy toll on public health. The promotion of non-motorised modes of transport is increasingly being recognised as an effective way of addressing such concerns. In urban centres in particular, a shift from car to bicycle could reduce road congestion and traffic-related air pollution since cycling has low space requirements and is a non- polluting transport mode (Int Panis et al., 2006; Chapman, 2007; de Nazelle and Nieuwenhuijsen, 2010). It also reduces noise, vibrations, infrastructure costs (e.g. less road maintenance) as well as the dependence on fossil fuels. Furthermore, cycling is a cheap way of being physically active and preventing the health risks of a sedentary lifestyle (Pucher et al., 1999; WHO, 2002; de Geus et al., 2009). When performed on a regular basis, it not only brings health benefits to the cyclist (de Geus et al., 2008) but also to the entire society as bicycles do not emit air pollutants (Pucher et al., 1999; WHO, 2002; Rietveld and Daniel, 2004; Gatersleben and Appleton, 2007). Moreover, the promotion of cycling could help to cope with the current dynamic of social exclusion generated by the unequal accessibility to different modes of transport (Witlox and Tindemans, 2004). Finally, the bicycle could be used as a feeder mode for public transport (bike-and-ride), so that it attracts more consumers and strengthens the economic performance of specific parts of the public transport system (Martens, 2004, 2007). Such a combined use of bicycle and public transport could provide a relatively competitive alternative to the private car and, consequently, deal with negative aspects of car-dependent lifestyles.

For policy makers and planners, promoting commuter cycling is an effective way of solving the numerous negative externalities associated with car use (see Int Panis et al., 2004). However, several barriers prevent people from cycling: fear of crime or vandalism, bad weather, hills, danger from traffic, social pressure and long commuting distances are some of the most frequently cited deterrents (see Pucher et al., 1999; Rietveld, 2001; Rietveld and Daniel, 2004; Gatersleben and Appleton, 2007; Parkin et al., 2008). Safety concerns and the lack of an adequate infrastructure are major hindrances to bicycle use (Pucher et al., 1999; Parkin et al., 2007; confirmed by analyses in SHAPES. Within this context, the provision of an extensive and appropriate cycling network —combined with other measures— could certainly decrease the reservations that some people have about cycling. Thus, making bicycle use safer is one of the most essential elements in initiating a substantial shift from car to bicycle. It is recommended that policy makers and planners take steps such as reducing the amount of motorised traffic in urban centres, developing traffic-calming areas, constructing an infrastructure for cycling (e.g. cycle paths, cycle lanes, lockers, racks, showers, changing facilities at the workplace, etc.), and promoting bike pooling (Pucher et al., 1999; Rietveld, 2001; Pucher and Dijkstra, 2003). Such measures reduce the risks of being involved in traffic accidents and improve the individuals' overall perception of cycling. Consequently, they have great potential to encourage more people to cycle for commuting trips. This could result in a virtuous circle, since more cyclists on the road improves the safety of all cyclists (Jacobsen, 2003) and may increase cycling even in neighbouring towns (Vandenbulcke et al., 2009).

1.2. Structure of the report

The SHAPES project is structured in such a way that we first aim at exploring the variation of bicycle use when commuting in function of the level of urban hierarchy (from the largest cities to rural communes). We also discuss the relationship between bicycle use and accident risk on the scale of the 589 Belgian municipalities. A national wide overview of the use of bicycles in Belgium was provided by the 2001 population census (collected by the National Institute for Statistics, NIS). This census is the most recent database covering the entire population, and provides exhaustive information about the demographic, social, mobility, professional and housing characteristics of the population. The National Institute for Statistics (NIS) also provides road accident statistics and – using mobility data about cyclists in the 2001 census – allows the risk of a bicycle accident to be computed for each municipality.

In a second step, we examined which factors have the greatest influence on bicycle commuting in Belgium. We therefore carried out multivariate analyses at the scale of all 589 Belgian municipalities. A large set of "explanatory" variables was included in the analysis, with specific attention to environmental as well as demographic components (e.g. topography, income, accident risks, satisfaction with bicycle infrastructure, and motorized traffic volumes are some of these (suspected) explanatory variables).

Third, the SHAPES project constructed an **online registration system** in order to collect data on bicycle usage and traffic-related bicycle accidents. This online registration system has the advantage to update and complete the information we have about the travel patterns of cyclists, since the 2001 Census is the most recent database (and is hence out-dated). Furthermore, the online registration system allows to obtain prospectively collected accident data from minor bicycle accidents and overcome the under registration currently reported in the literature. A **Retrospective bicycle accident questionnaire** (RETRO) was filled out by all participants in order to make a comparison between a prospective and a retrospective study design. During the online registration, participants filled out **travel diaries** during one year in order to collect data on bicycle usage. If an accident occurred during this period, participants had to fill out a **Prospective bicycle accident questionnaire** (PROS). Both the PROS and RETRO questionnaires were exploited in three ways: 1) a detailed analysis was made of the context and circumstances of the accident and the resulting injuries; 2) a detailed analysis was made on the **costs** generated by minor bicycle accidents and 3) a comparison of the spatial distribution of bicycle accidents was made between the SHAPES (Prospective and Retrospective surveys) and the NIS data (2006-2008), for the Brussels-Capital Region.

Participants who took part in the online registration system and filled out at least 2 travel diaries were stratified and invited to participate in **field measurements**. During these field measurements, participants were first driven a specific trajectory in a car and then cycled the same trajectory. Ventilatory parameters, Particle Number Concentrations (PNC) and Particulate Matter (PM) were simultaneously measured. A randomised sample was selected in order to

investigate the effect of the exposure to air pollution on **lung** and **systemic inflammatory parameters**.
An overview of the study design of the field measurements can be found in Annex 3, Figure 28.

Fourth, the infrastructural and environmental variables suspected to influence the accident risk were identified for the Brussels-Capital Region at a very detailed spatial level. A Bayesian logistic implementation of a conditional autoregressive (CAR) model is proposed to model such a risk. Due to the numerous methodological and technical issues associated with the creation of such a binary dependent variable, this part of the report is quite innovative and is hoped to open up new horizons in traffic safety research. In the seek for explanatory variables, special attention was put on fractal morphometric variables related to built-up patterns as well as to the road network. Tests were performed in order to see if some built-up fabrics are more prone to generate accidents than others.

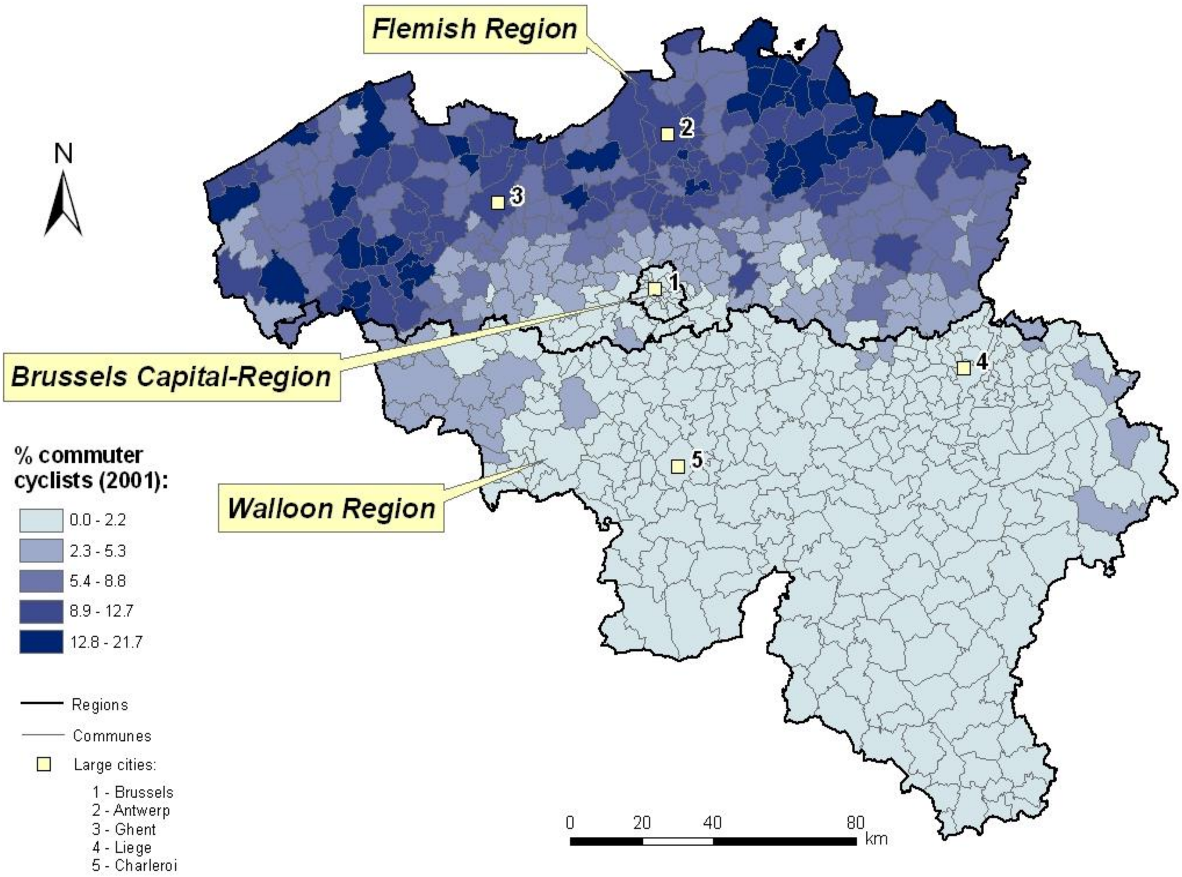
1.3. Study area

The SHAPES project was conducted in Belgium. Belgium is a small and highly urbanised European country covering approximately 30,000 km^2 and has approximately 11 million inhabitants. It is subdivided into three institutional regions: the Brussels-Capital Region (BCR, central), the Flemish (north, Dutch-speaking) Region and the Walloon Region (south, French-speaking) (Figure 1). Belgium has a tight network of towns, dominated by Brussel/Bruxelles (Brussels) with more than 1 million inhabitants; the second largest city is Antwerpen (Antwerp), which has approximately 500,000 inhabitants. Cities tend to sprawl into their peripheries. This urban spread favours car use and often leads to more and longer commuting trips, which are not convenient for cycling or walking. However, bicycle use is still relatively common in Belgium (especially in Flanders), compared to other industrialised countries, although the average rates are well below those in the Netherlands and Denmark. At the European level (EU 15), Belgium is ranked fourth, with a bicycle share of 2.42% (in traveller-km/person/yr), and stands out as one of the countries with the highest share of cyclists (Germany: 2.47%; Denmark: 5.48%; the Netherlands: 6.66%) (EU, 2003; Rietveld and Daniel, 2004).

Data from the Belgian 'National household survey' (NIS, 2001) showed a clear-cut north-south division in bicycle usage (Figure 1). In Flanders 12% of all trips were made by bicycle, compared to 2% in Wallonia and 1% in BCR (NIS, 2001). These strong regional differences within Belgium are a microcosm that reflects similar differences between e.g. northern and southern European countries. On average, bicycle use for utilitarian purposes is rather common in the north, while it is relegated to a marginal role in the south (mainly recreational activities). Such a stark division is explained not only by the culture, but also by a number of political, physical and historical factors (Rietveld and Daniel, 2004; Rodríguez and Joo, 2004; Vandenbulcke et al, 2009). From the 80's, local and regional policies in Flanders played a key role since they early recognised the potential of the bicycle (in terms of sustainability) and paid attention to integrate it in mobility plans and strategies. Measures favouring cycling – such as the construction of cycling infrastructures – were hence implemented by the Flemish authorities and contributed to increase (and maintain) bicycle use. Besides this, some specific physical features also encouraged cycling. Similar to the Netherlands, Flanders is a flat and highly urbanized region, where most employment is concentrated in city centres. This generates short and, hence, 'bikeable' commuting distances. Also, during the 20's and 30's (and still nowadays), the lack of an extensive public transport system in several Flemish cities probably explained the fact that bicycle use was preferred and historically rooted in the Flemish culture (de la Bruhèze, 1999; Mérenne-Schoumaker et al., 1999; MF, 2002).

Traffic legislation is the same throughout Belgium for most aspects such as mandatory use of lights and reflectors and the non-mandatory use of the bicycle helmet or other protective measurements. Nevertheless, the regions have a certain liberty to adopt a different policy. In Flanders traffic calming measures are more frequent, traffic speed limits on secondary road are often lower and bicycle infrastructure is much more available.

Figure 1: The percentage of commuters who use the bicycle as their only mode of transport to work



Source: NIS, 2001; Vandenbulcke et al., 2009

2. METHODOLOGY AND RESULTS

In this section of the Final Report the most important results are shown as well as a brief description of the methodology that was used to work out the study.

Additional tables can be found in Annex 3, subdivided in the same chapter titles as the main document of Final Report itself.

All studies were published in peer reviewed journals unless indicated otherwise (some are still under review). A list of the peer reviewed papers resulting from the SHAPES and PM²TEN projects can be found in paragraph 4.1.1 and in Annex 1.

2.1. Mapping bicycle use and the risk of accidents for commuters who cycle to work in Belgium

2.1.1. Introduction

We explore the variation of bicycle use when commuting in places ranked according to the level of urban hierarchy (from the largest cities to rural communes). We also focus on the relationship between bicycle use and accident risk on the scale of the 589 Belgian municipalities. After describing the materials and methods, we analyse the link between urban hierarchies and bicycle use, and then propose a clustering of the communes according to bicycle practice and accident risk. We end up with a map that pinpoints the communes that combine low (or high) proportions of cyclists with high (or low) risks of accidents. This map offers some clues for policy makers and planners to identify which communes need specific attention in terms of traffic safety for cyclists.

2.1.2. Materials & methods

(a) Population Census:

For this study we use the NIS population census (NIS, 2001). Interestingly, 6.2% of all commuters use the bicycle as their only means of transport between home and workplace, while 68.6% of commuters use a car (Verhetsel et al., 2007). On average, bicycle use is higher in the northern part of the country (Flanders). Indeed, 91% of Belgian commuter cyclists live in Flanders (Wallonia: 6.4%; Brussels: 2.6%). The census is used to compute:

(1) the proportion of commuter cyclists in each commune/municipality;
(2) the **average total commuting travel time** (return trip), used as a measure of exposure to (bicycle accident) risk;
(3) the **average total commuting distance** (km), used to analyse the (deterrent) impact of distance on the use of different modes of transport, and more particularly on the use of a bicycle.

(b) Road accident statistics:

Annual road accident statistics are kept by the National Institute for Statistics. 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 4 year period (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, especially when the cyclist is the only person involved and/or when no hospitalisation is involved. Earlier studies estimated that in Belgium, 15 to 30% of cycling accidents are officially reported (see Doom and Derweduwen, 2005; De Mol and Lammar, 2006; BRSI, 2006). SHAPES presents more accurate estimates in paragraph 2.5.3.)

An index of risk (R_i) was computed and used as a proxy for cyclists' exposure to casualties:

$$R_i = N_i / T_i$$

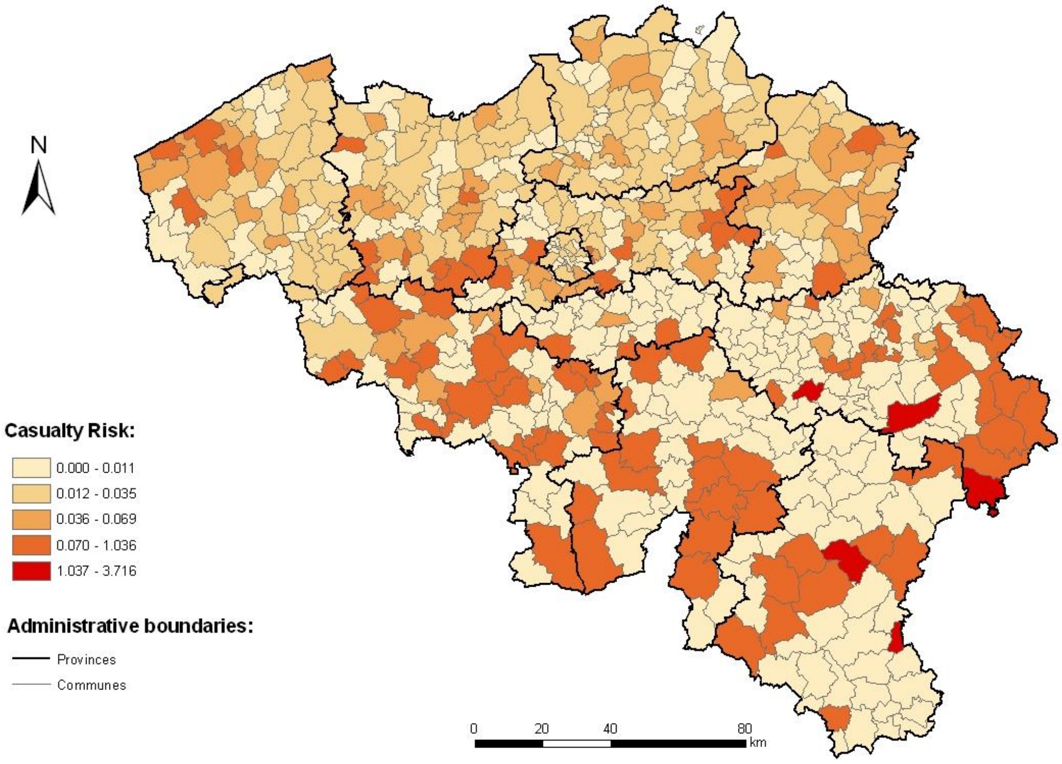
where N_i is the average annual number of injuries to cyclists aged between 18 and 65 years, between 2002 and 2005 and occurring on weekdays in commune *i*.

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.

Figure 2 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 province, 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 is observed in most 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, 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 2: Casualty risk, defined as the average number of casualties per 100 000 bicycle-minutes, by commune



Source: Vandenbulcke et al., 2009

(c) Urban hierarchy:

Ranks are associated to the communes on the basis of an index computed by Van Hecke (1998) and based on the degree of equipment of the commune as well as on its attractiveness. The degree of equipment was calculated using both the quantitative (e.g. number of hospitals) and qualitative importance of the facilities (e.g. presence of universities), while the attractiveness was estimated on the basis of the visitor flows attracted by these facilities (and using them). They are denoted H_j (j = 1,…8) and range from H_1 for the largest cities (more than 200 000 inhabitants; e.g. Brussels or Antwerpen) to the smallest and least-populated communes H_8 (rural municipalities).

Table 32 in Annex 3 lists some of the socio-economic and environmental features of each rank. In particular, it indicates that population and job densities as well as urban land use are high in communes in the first three ranks of the hierarchy (H_1 to H_3). The opposite situation is true for rural communes (H_8). This to a large extent explains the differences in the commuting distances between towns (where the proximity of different activities is high) and rural areas: the shortest average commuting distances are found in the largest cities. Finally, high traffic volumes are observed along the municipal and regional road networks in urban communes. The large number of activities (e.g. jobs, leisure, public services) and inhabitants make such communes highly attractive, leading to high traffic densities.

2.1.3. Results

(a) Cycling and urban hierarchy:

Exploratory data analyses suggest that the observed differences in the use of the bicycle for commuting are strongly linked to the urban hierarchy: commuters are more inclined to cycle in cities and specifically in regional towns (H_2, with 25,000 to 120,000 inhabitants; e.g. Brugge or Leuven). In large cities (H_1, more than 200,000 inhabitants; e.g. Brussels or Antwerpen), less commuting by bicycle takes place.

The presence of a densely built-up environment generates short commuting distances and hence encourages cycling. At the opposite, commuters who live in low-density areas usually have to cover longer distances to work, and consequently depend more on motorised transport (especially private cars) since public transport is frequently poor in less-urbanised areas (due to its high costs). However, regional towns H_2 have higher bicycle use than the largest cities H_1, which may be explained by the high quality of public transport and the dominance of short commuting trips in H_1 communes, which encourages walking (see Figure 26 and Figure 27 in Annex 3). We also suspect that factors such as high volumes of traffic and the risk of bicycle theft deter potential cyclists in large cities.

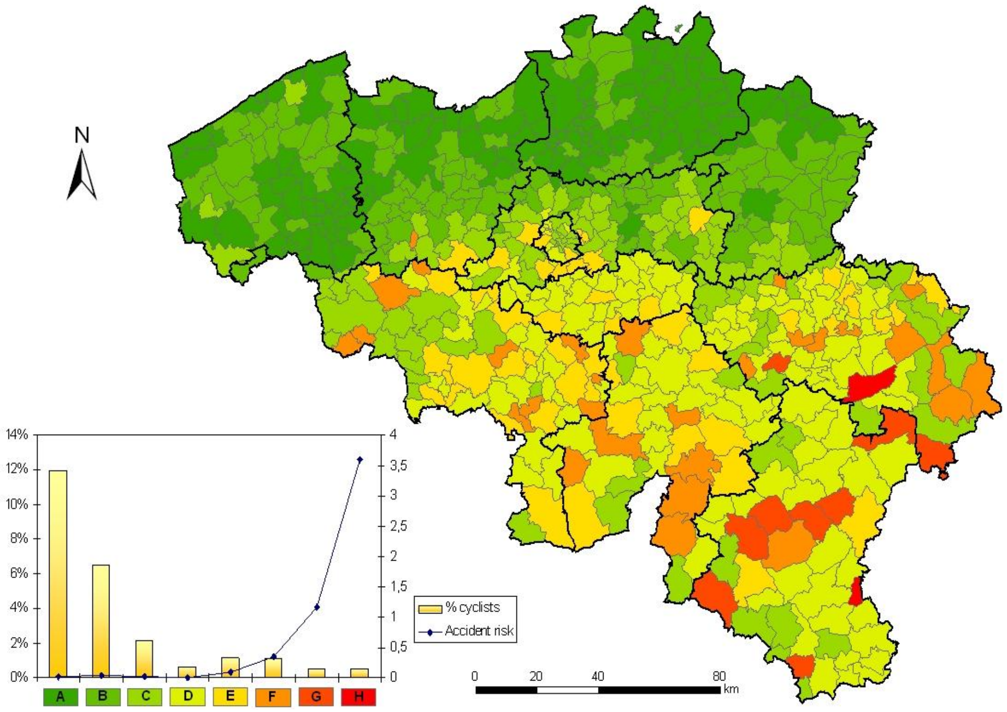
(b) Bicycle use and risk:

A classification of communes (Figure 3) 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.

Figure 3 shows interesting spatial patterns, and emphasises the regional differences. Communes in clusters A–C provide the most ''bikeable'' environments (i.e. high and safe bicycle use) while those in clusters F–H are regarded as the least bikeable (i.e. low and unsafe bicycle use). The map also indicates that the most and least bikeable environments cluster spatially, hence leading to a clear-cut north–south division. Such a division could be indicative to the fact that different (regional) policies are implemented in terms of bicycle promotion and safety.

In Flanders, most communes have a high percentage of cyclists and low risks of being seriously injured or killed while cycling to work. The availability of cycling infrastructure, the flat terrain, the high population and job density, as well as the presence of pro-cycling policies may be some of the factors that make this environment quite attractive and safe for cyclists. Cycling is also part of the Flemish lifestyle and cyclists are generally expected and respected by motorists in Flanders. This produces a virtuous circle since better road safety encourages more cycling, which in turn makes the environment even safer. Moreover, Flemish policy makers invest more in cycling infrastructures, owing to a greater number of cyclists (high demand).

Figure 3: Classification of communes based on bicycle use and the risk of cyclists being injured



Source: Vandenbulcke et al., 2009

In contrast, the low proportion of commuters cycling to work in Wallonia is often associated with a high accident risk. Topography, high driving speeds, long commuting, distances as well as car-oriented policies and lifestyles are associated with this scenario. High accident risks also deter bicycle use: they make the Walloon environment unsafe and consequently unattractive to (potential) cyclists. The lack of high-quality infrastructure as well as the fact that car drivers generally do not expect to see cyclists on the road probably explain the high observed casualty risks. In addition, motorists may be less respectful towards cyclists, partly because they have never themselves experienced commuter cycling.

Lastly, inter-municipality differences are observed: casualty rates for cyclists are higher in less-urbanised environments, while the reverse is true in urban areas. In the latter, the presence of features such as physical barriers (e.g. road humps), congestion, low speed limits and high numbers of pedestrians force motorists to slow down and adapt their driving behaviour, which improves the safety of all road users. In particular, it reduces the differential between the speed of fast and slow modes of transport, and hence decreases the risk of cyclists being involved in accidents within urban areas.

2.2. Commuting by bike in Belgium: Spatial determinants and 're-cycling' strategies

2.2.1. Introduction

In Belgium, while approximately 21% of commuters live within a cycling distance (i.e. less than 5 km) of their work, and 39% make trips of less than 10 km, only 6% of all commuting trips are carried out with a bicycle as the main method of transport (Verhetsel et al., 2007). The percentage of commuters living within 5 km of their workplace using the bicycle is relatively low (19%), and the majority (more than 53%) use their car. There is hence a great potential for a shift from car to bicycle for short commuting trips. However, there are several societal, economic and environmental factors that dissuade people from cycling. These include e.g. a lack of cycling infrastructure, the topography, weather, road accidents, dress code and company-related constraints.

These factors need to be clearly identified to help policy makers to mitigate them and to promote bicycle use in Belgium. Such findings could then support the implementation of adequate policies in favour of a modal shift from car to bicycle commuting, at least for short distances.

This part of the SHAPES project aimed at examining which factors have the greatest influence on bicycle use for commuting to work in Belgium, and at testing if their influence varies spatially. We therefore carried out multivariate analyses at the level of all 589 Belgian municipalities. In the model, the dependent variable y is the proportion of commuters who travel by bicycle. Explanatory variables used in the multivariate analyses were identified owing to an extensive review of the literature (see Vandenbulcke et al., 2011) and fall into three main categories (demographic and socio-economic, policy-related, and environmental).

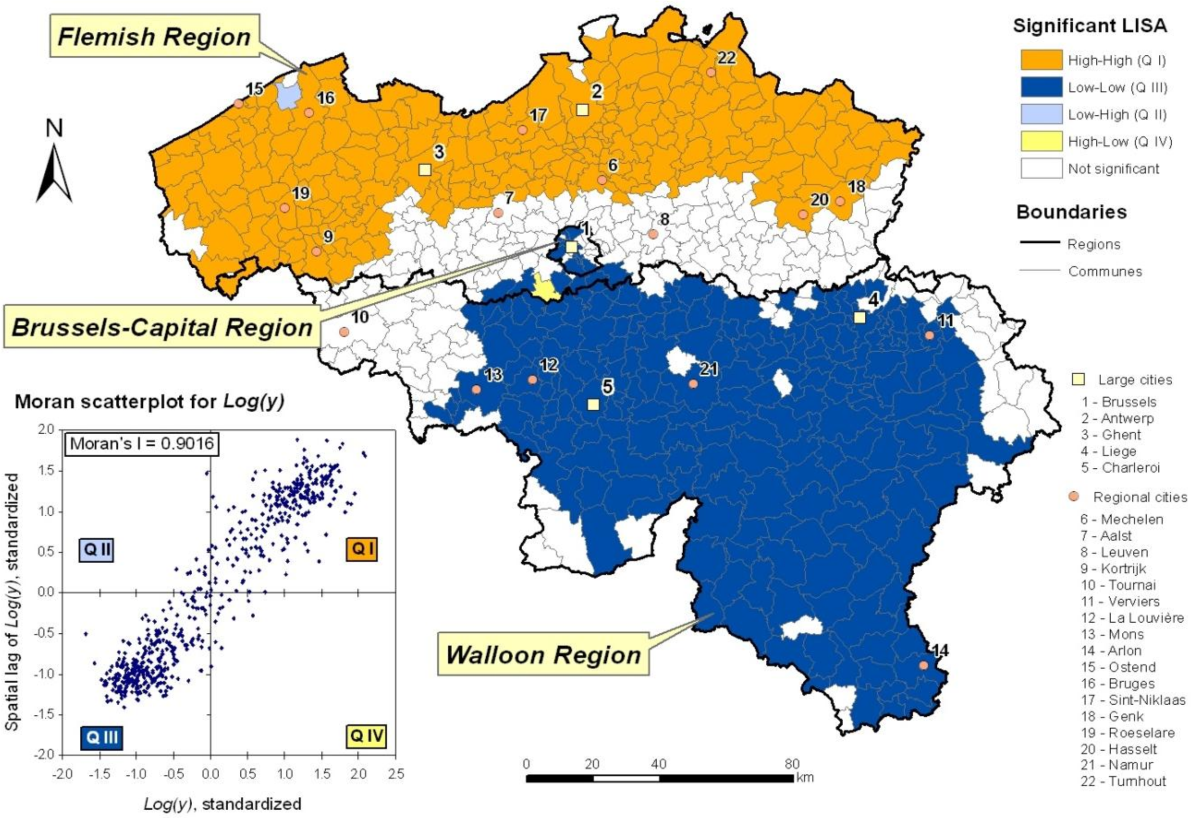
2.2.2. Material & methods

Table 33 in Annex 3 lists and describes the explanatory variables. Most of the demographic and socio-economic variables come from the 2001 census (a self-administered questionnaire), carried out by the National Institute for Statistics (NIS, 2001). The census provides data on individual and household features such as age, gender, level of education, presence of young children in the household, and subjective health which can be aggregated by municipality. Data related to income and car availability were also extracted from the NIS website.

Environmental and policy-related variables come from a wide range of sources. The variables selected for use in this paper not only result from policy decisions (e.g. land-use and transport-related measures), but also characterise the "environment" in which commuters live and travel. Some of these variables (such as population and job densities, average commuting distance, distance to the nearest town, town size, the percentage of commuters living within 10 km of their workplace, the percentages of urban/forest/agricultural land, and the percentage of the land dedicated to public/recreational services) are proxies for the urban structure, land use and accessibility of activities/facilities in the municipality. Others (such as the risk of cycling accidents, traffic volumes, the risk of bicycle theft, the dissatisfaction with cycling facilities, hilliness, and air pollution) are representative of the overall convenience of cycling in the municipality.

Regression techniques were used and special attention was paid to spatial autocorrelation, heteroskedasticity, structural instability and multicollinearity, with the aim of improving the results. Spatial lag models were used to correct for the presence of spatial dependence. The presence of structural instability in the model (as suggested by Figure 4) also means that the parameter estimates would take on different values in the northern and southern parts of the country (here, the orange and blue areas, respectively) if no correction is made. A disaggregated modelling strategy was hence adopted for these two distinct parts of the country (i.e. the analysis was made on 2 "spatial clusters": (1) Flanders, (2) Wallonia + Brussels).

Figure 4: Moran scatterplot and LISA cluster map for the spatial clustering of commuting by bicycle



Source: Vandenbulcke et al., 2011

2.2.3. Results

Results show that much of the inter-municipality variation in bicycle use is related to environmental aspects such as topography, traffic volumes and cycling accidents. Town size, distance travelled and demographic aspects also have some effect. In addition, there are regional differences in the effects of the structural covariates on bicycle use: the impact of variables such as traffic volume and cycling accidents differs substantially between the north and the south of the country.

High rates of bicycle use in one municipality stimulate cycling in neighbouring municipalities, and potentially a mass effect could be initiated, i.e. more cycle commuting encourages even more commuters in the area to cycle. These findings provide some recommendations for decision-makers wishing to promote a shift from car to bicycle use.

Table 34 in Annex 3 indicates that income, age and gender have a significant impact on the rate of cycle commuting in Flanders: low median income, low proportions of working women, and a young (under 45) workforce are all associated with high rates of cycling to work. Having one or more young children (0–5 years old) in the household decreases the likelihood of cycling to work in both regions. The presence of many highly-qualified people also matters, particularly in the southern periphery of Brussels. Highly qualified commuters living in Wallonia and having high incomes, can afford a car, and use it to travel large distances. They are hence less likely to use a bicycle for their commuting trips (Jensen, 1999; SSTC, 2001; Hubert and Toint, 2002).

Among the environmental and policy-related variables (Table 33 in Annex 3), flat terrain, high-quality cycle ways and a low risk of accidents can encourage commuter cycling in both regions. However, heavy traffic (on municipal roads) does not have any significant impact in Flanders, whereas it strongly discourages cycling in Wallonia and Brussels. In Flanders, the high visibility of cyclists in the traffic (because there are so many of them) and the presence of appropriate cycling infrastructure probably give commuter cyclists a feeling of personal security and, hence, offset the deterrent effect of traffic volume. Policies in Flanders do indeed provide more high-quality infrastructure (e.g. continuous and separate cycle ways) and facilities (e.g. changing facilities at work) with the intention of improving the safety and convenience of cycling. Flanders also stimulates bicycle use through regulations restricting motorised traffic in urban centres (e.g. through the introduction of traffic calming areas), so that the risk and annoyance of heavy traffic is greatly reduced. Finally, motorists show more respect for cyclists because they often cycle themselves and/or are used to sharing the road with large numbers of cyclists.

The opposite situation is observed in Wallonia and the Brussels region where the terrain is more hilly and discourages cycling. Also, motorists are seldom mindful of commuter cyclists and still consider them less important than car drivers (especially in Wallonia). Due to a lack of cycling infrastructure in the Walloon municipalities, the risk of being seriously injured or killed is high (especially in rural areas), and confirms residents' fears of cycling. This is not, however, the case in Brussels, where casualty rates are low (Vandenbulcke et al., 2009); indeed, the urban environment, with its large number of obstacles, forces drivers to reduce their speed.

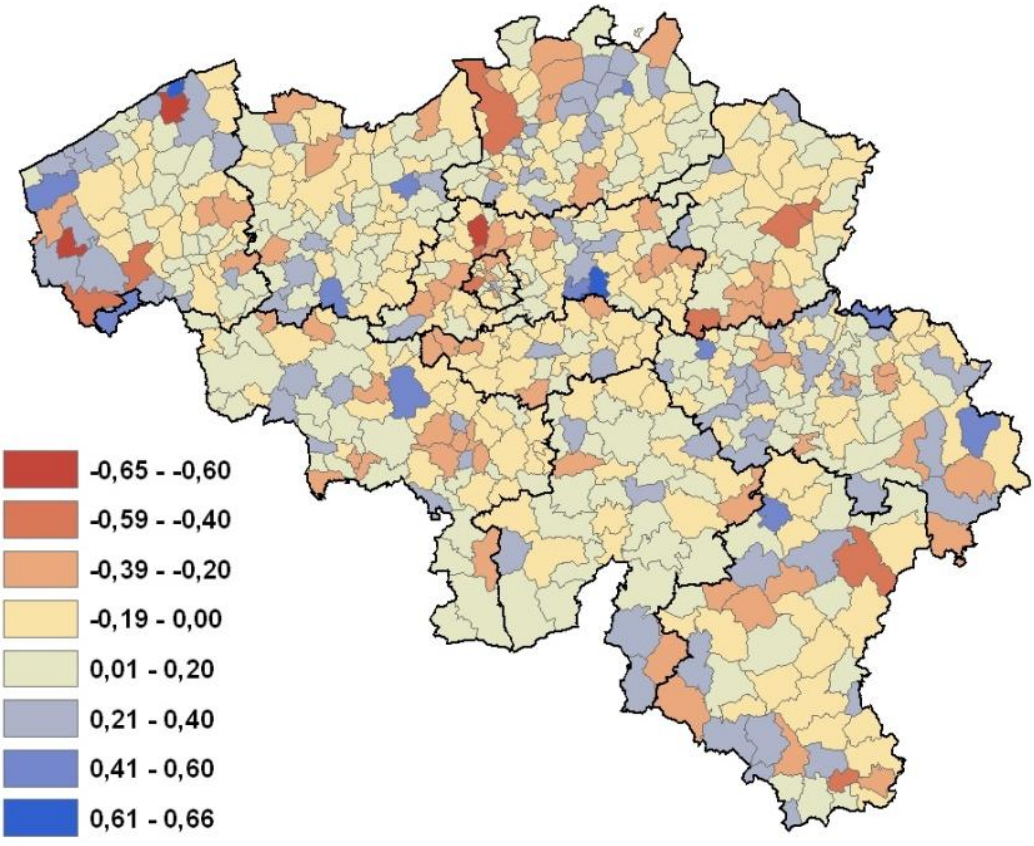
Finally, the size of the town also matters, and this is probably associated with the provision of good facilities for cycling. The proportion of commuters cycling is highest in the cities (well-equipped municipalities), and lowest in small municipalities. Large urban areas generally provide high-quality public transport and benefit from the proximity of different activities and the good connectivity between them, so that commuting distances are shorter and more bikeable.

2.2.4. Over-performing policies or potential for more bicycle use?

Figure 5 provides a useful tool for planners and policy makers since it pinpoints both the municipalities that 'over-perform' in terms of bicycle use and those where there is still potential to develop the use of the bicycle for commuting trips further. This potential exists in the municipalities characterised by negative residuals (predicted values > observed values). *Given the current environment*, such municipalities could perform better in terms of bicycle use but, something (e.g. an inadequate or unambitious cycling policy, high-quality public transport) holds it back. Examples of municipalities with negative residuals are Antwerpen, Brussels, Genk, Gent and Kortrijk. The last two are surprising, in view of their pro-cycling policies and relatively high rates of cycle commuters, but suggest that there is still potential to encourage more people to cycle to work.

At the other end, municipalities characterised by positive values of the residuals excel in terms of bicycle use (given their environment). The examples of Leuven and Brugge are important in this respect, since they have more pro-cycling policies (in terms of engineering, traffic education and enforcement) than other Flemish municipalities. Several municipalities in Wallonia (e.g. Mouscron, Perwez, Hotton) also perform better than expected, despite their low absolute rates of cycle commuting. Given their environment (steep slopes, rural setting , etc.), they "over-perform", for example by adopting mobility strategies that encourage bicycle use (SPW, 2008).

Figure 5: Residuals of the spatial regime specification



Source: Vandenbulcke et al., 2011

2.3. SHAPES online registration system

The SHAPES online registration system was designed to create a platform where regular commuter cyclists were invited to register minor bicycle accidents and bicycle usage data (cycling frequency, time spent cycling and distance cycled). Those who matched the in- and exclusion criteria were invited to report their bicycle exposure week after week for a period of maximum one year.

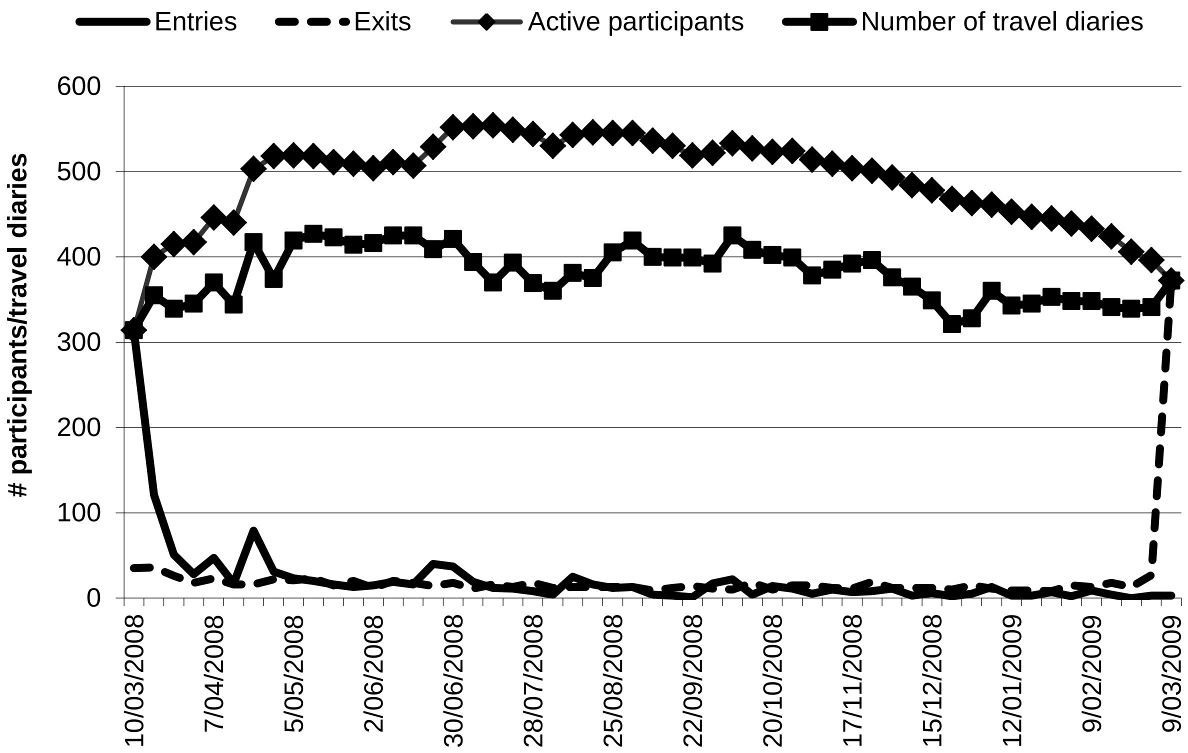
2.3.1. Study design of the SHAPES online registration system

Before the start of the SHAPES project, the most recent data on bicycle usage was collected nationwide during the 2001 Population Census (NIS, 2001). Although this data collection is useful because it covers the entire Belgian population, the data are outdated. Data on traffic accidents from police reports are continuously collected by the National Institute for Statistics and analysed by the Belgian Road Safety Institute (BRSI). Earlier studies on the registration of bicycle accidents in official statistics in Belgium estimated that 15% to 30% of cycling accidents are registered (Doom and Derweduwen, 2005) as only major and fatal injuries are collected. By this means only the 'tip of the iceberg' is analysed in available data and hence SHAPES started a new dedicated registration system.

A web and email-based registration system to establish a cohort of commuter cyclists was incorporated in the website of the SHAPES project (www.shapes-ssd.be) and conceptualised for different purposes. The first purpose was to collect demographic data and traffic related aspects of utilitarian cycling. The second purpose was to register data on bicycle use. The third purpose of the online registration system was to collect data on (minor) bicycle accidents in a prospective way.

The SHAPES online registration system was open-based, so that anyone could access the website and participate if passing the inclusion and exclusion criteria. The number of participants and travel diaries remained relatively stable throughout the year (Figure 6).

Figure 6: Weekly evolution of new entries, exits, active participants, and number of travel diaries over the total study period (Source: Degraeuwe et al., in prep.)



The main dataset for this study was collected between March 10th 2008 and March 16th 2009. After entering their e-mail address, an automatically generated mail was sent to the tentative participant. In this first e-mail information related to the purpose of the online registration system was given. The inclusion criteria were: (1) age between 18-65 years; (2) having a paid job outside the home; (3) cycling to work at least 2 times a week during the preceding year; (4) live in Belgium.

2.3.2. Questionnaires

2.3.2.1. General Questionnaire

Those who fulfilled the inclusion criteria, further referred to as participants, got access to the General Questionnaire (GQ) (see section 2.3.3) that was included in the first e-mail. The GQ is based on the 2001 Population Census (NIS, 2001) and recent literature (e.g. Kim et al., 2007). Aspects related to cycling habits between home and workplace or 'other' destinations are recorded, e.g. main transport mode, and circumstances (e.g. seasonal differentiation, presence of bicycle paths and lanes), postal code associated with the place of residence and work. The last part of the GQ was used to collect demographic data (gender, age, height, weight, level of education, job category, perceived health, and living situation).

2.3.2.2. Travel diary

Together with the GQ a second automatically generated e-mail was sent including the first Travel diary (TD), which was re-sent to all participants on a weekly basis (see section 2.4).

2.3.2.3. Prospective Questionnaire and Retrospective Questionnaire

The last question of the TD asked whether accidents occurred during the past 7 days. If an accident occurred, the participant got access to the Prospective Questionnaire (PQ) (see section 2.5). One week after the first e-mail was sent all included participants received the Retrospective Questionnaire (RQ) (see section 2.7). The RQ and PQ are designed to collect detailed information on the (1) circumstances of the accident (e.g. purpose of the trip, weather conditions, time of day and visibility, type of road, road and traffic conditions), (2) cause of the accident and injury, (3) presence and (supposed) cause of possible physical injuries, (4) type of injury (e.g. which part(s) of the body, nature of the damage), (5) protective measures taken at the time of the accident, (6) presence of material damage, (7) medical care, (8) registration by police, insurance company, hospital, (9) possibility of avoiding the accident.

For the PQ the accident had to occur in the past 7 days before filling out a travel diary whereas the RQ collects data on accidents that occurred in the 12 months before filling out the first TD. Inclusion criteria for the registration of an accident and injury were: (1) the accident had to occur during commuting to or from work or during commuting for transport; (2) acute injury; (3) with corporal damage; (4) injury had to be more than a muscle cramp or bruise. Accidents were categorized as 'minor' or 'major' bicycle accident according to the definition used by the Belgian National Institute for Statistics. 'Minor' is defined as accidents where the person is hospitalized for less than 24 hours. 'Major' is defined as hospitalization of more than 24 hours.

2.3.2.4. Cost Questionnaire

In order to calculate the costs of minor bicycle accidents a Cost Questionnaire (CQ) was made (see section 2.6). The CQ was used to collect information on 7 different types of costs: (1) direct

medical costs, (2) direct non-medical costs, (3) productivity loss, (4) leisure time loss, (5) costs related to permanent invalidity, (6) costs related to pain and (7) costs related to negative psychological consequences.
The entire registration system was available in Dutch and French (the two major languages in Belgium).

2.3.3. SHAPES study population

The results presented in this section are intended to draw the participants' portret in the different SHAPES sub-projects. After one year of open-access, 1849 participants had left their e-mail address on the server. After applying the in- and exclusion criteria, 1203 (65.1%) participants were included in the SHAPES project and filled out the GQ (Annex 3, Table 35).

The characteristics of our study population were compared with those of the Belgian National Census (NIS, 2001) (Table 1). The SHAPES study population is a particular cohort composed of mostly male (68%) regular commuter cyclists (74.5% use the bicycle the whole year through) who are in good health (92.8% indicate to be in good to very good health), had a higher level of education (89.2%) and have a higher job status (only 2.5% blue collar workers).

Our study population is overrepresented in the Brussels Capital Region (BCR) compared to what could be expected from the Belgian population (NIS, 2009) and Belgian cyclist population (NIS, 2001) (Figure 7).

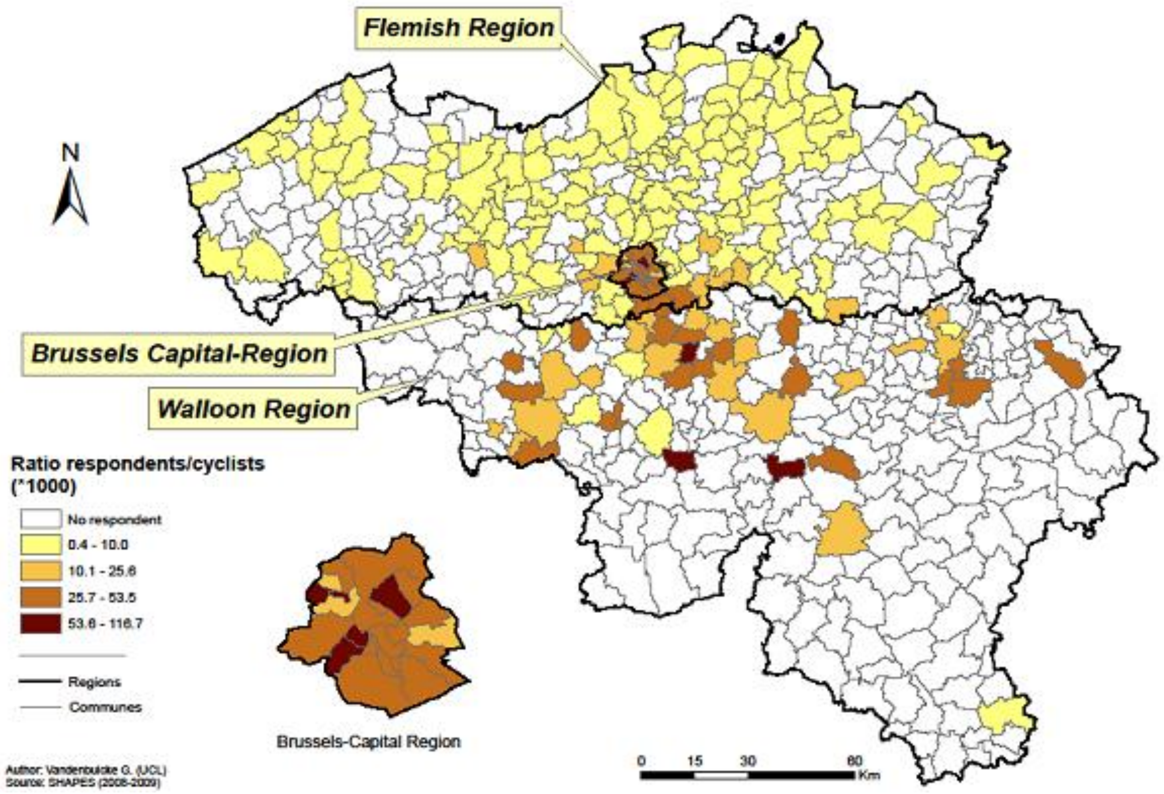
Table 1: Comparison between SHAPES participants and NIS commuter cyclists (NIS, 2001)

	SHAPES participants			NIS (2001)		
	men + women	men (68%)	women (32%)	men + women	men (55.2%)	women (44.8%)
age (mean) (year)	39.8	40.7	37.7	38.8	39.2	38.3
length (mean) (cm)	175.9	179.8	167.3	?	?	?
weight (mean) (kg)	72.2	77.0	61.8	?	?	?
BMI (mean) (kg/m^2)	23.3	23.8	22.1	?	?	?
education (% of total)§						
lower (primary/secondary)	10.8	13.1	5.8	69.3	72.5	65.3
higher(high-school/university)	89.2	86.9	94.2	30.7	27.5	34.7
job status (% of total)*,§						
students (with a paid job)	1.8	0.9	3.8	?	?	?
employee	49.9	48.5	53.2	40.8	31.7	52.2
functionary	26.0	25.8	26.3	23.9	26.7	20.4
freelance	5.6	5.8	5.1	3.7	4.3	3.0
executive	9.3	11.0	5.5	0.7	1.0	0.4
workman (blue collar)	2.5	3.2	1.0	28.9	35.3	20.8
other	5.0	4.9	5.1	2.0	1.0	3.4
perceived health (% of total)						
very good	43.0	42.5	44.0	-	-	-
good	49.8	50.4	48.5	-	-	-
average	6.9	6.8	7.2	-	-	-
poor	0.3	0.3	0.3	-	-	-
very poor	0.0	0.0	0.0	-	-	-
living situation (% of total)						
with partner	72.7	77.8	61.8	-	-	-
without partner	27.3	22.2	38.2	-	-	-

NIS (2001) – population of cyclists with a paid job outside their home (18-65 years)
§ : significant difference between NIS and SHAPES: (Chi ^{2}) $P<0.05$

* : definitions not entirely in accordance with these of the Census (NIS, 2001). To be interpreted with caution
- : definitions not in accordance with these of the Census (NIS, 2001). Cannot be used for comparison
? : data not available

Figure 7: Number of SHAPES participants compared to Belgian cyclists (NIS, 2001)



Source: NIS 2001 & SHAPES questionnaires

On the question "How often per week do you travel to work by bicycle?" 85.6% indicate to cycle more than 2 times per week to work. The bicycle is used by 49.1% of the participants to cycle to 'other' destinations more than 2 times a week.

46.4% of the participants prefer the shortest route for their trip between their home and the workplace. 25.3% of the participants select a longer route because they feel it is safer. Another 21.0% take a longer route because it is more pleasant (e.g. to ride through a green environment). Among those who have children (52.6% of the total group), 8.5% take a longer route to drop their children at school.

Bicycle paths and lanes are an important incentive to motivate people to take the bicycle for commuting to work or for transport in general. For Belgium as a whole, it is shown that those who have a bicycle path near their home cycle significantly more ($P<0.01$) in terms of travelled time (95% CI: -46.6; -17.5) and distance (95% CI: -17.7; -6.3) per week to work. The average single trip distance (95% CI: -2.43; -0.34) and cycling speed (95% CI: -1.45; -0.13) to work is significantly ($P<0.01$) higher in those who have a bicycle path near home.

Significantly fewer (Chi^2: $P<0.001$) participants in Flanders wear a helmet and protective clothes in comparison with those living in the BCR and Wallonia (Table 2).

Table 2: Self-reported use of helmet, reflective and/or fluorescent clothing and light and reflectors

	total study population	Brussels	Flanders	Wallonia
helmet	32.5	37.0	27.8	37.4
reflective and/or fluorescent clothing	35.2	44.5	24.7	47.1
lights and reflectors	72.4	68.9	77.9	61.5

Values are % of participants who indicate to 'always' wear a helmet or protective equipment

2.4. Bicycle usage in Belgium: one year prospective study

2.4.1. Introduction

To make an estimation of the health benefits (e.g. being physically active on a regular basis) and risks (e.g. traffic related bicycle accidents and inhalation of air pollution) of cycling for transportation, a detailed and accurate collection of bicycle usage data (exposure) is fundamental (Christie et al., 2007). Only when we understand the differences in how much people walk, cycle or travel by car, and then express the risk of injury per unit of exposure, we can measure how safe these activities are, and the specific policies that contribute to improved safety.

In most countries, statistics on the amount of cycling are not collected in a systematic way. Exceptions are the UK (UK Dept. of Transport) and the Netherlands (Centraal Bureau voor de Statistiek - CBS). If available, these data are often restricted to modal share or trip share and thus represent a weak and unusable indicator of exposure (Stone & Broughton, 2003). In Belgium, the most recent dataset on bicycle usage was collected during the Population census carried out in 2001 by the National Institute for Statistics (NIS, 2001). Although exhaustive and covering the entire Belgian population, these data have become outdated (e.g. due to the recent changes in the modal shares in some urban areas such as Brussels).

Therefore the purposes of this section of the study are: 1) to report on utilitarian bicycle usage and investigate differences between the three institutional regions in Belgium; 2) define which parameters/factors predict bicycle usage.

These results for Belgium are relevant for other European regions as well because the large spatial variation in topographical and urban structure between the 3 regions reflects similar situations in other countries.

2.4.2. Materials and Methods

Travel diaries (TD) were filled out in a prospective study design in order to collect data on bicycle usage. All participants that fulfilled the inclusion criteria received an automatically generated e-mail every week at the same moment (Monday at 2 AM) with the question to fill out one unique TD. These self-reported electronic diaries were used to collect data on the weekly travel frequency, time spent cycling and distance travelled over the past 7 days. Cycling speed was calculated using the time spent cycling and the distance travelled over one week. A distinction was made between 'commuting to and from work' and cycling to 'other' destinations (e.g. cycling to the grocery shop, but excluding cycling for leisure or sport). 'Utilitarian cycling' is used as a general term for cycling to/from work and 'other' destinations.

The speed was converted to a Metabolic Equivalent (MET) score, according to Ainsworth et al. (2000). Estimated total energy expenditure (MET*min/week) for each participant was calculated by multiplying the time spent cycling and the MET values.

Multivariate linear regression (MLR) models are used to define which correlates predict bicycle usage. Therefore, individual (gender, age, BMI, perceived health, education, work situation and children) and environmental (availability of bicycle paths, urban hierarchy of the place of residence and the work place, region of the place of residence and work place) correlates on cycling usage are studied.

Body mass index (BMI) was calculated by dividing the self-reported height in metres by the square of the weight in kilograms. The distributions of all raw variables were examined. Responses on 'perceived health' were collapsed into a dichotomous variable. 'Good, average or poor health' were collapsed into one variable and served as a reference. For the variable 'children', participants had to indicate if (yes or no) they had at least one person under the age of 18 years living in the same house. Variables 'education' and 'work situation' were discharged because only 10.2% of the respondents did not finish university studies and only 2.5% were blue collar workers.

Participants were asked to report on (i) bicycle paths near their home, (ii) on the way to work and (iii) near their workplace. The three responses were then collapsed into one, new variable namely 'bicycle paths'. Participants indicating to have no bicycle paths anywhere received a score '0' and those having bicycle paths near home, on the way to work and near work received a score '3'. 'Region' is defined as one of the three Belgian institutional regions. Urban hierarchy is based on functional and morphological criteria and is allocated to the different commuter zones of the urban regions (i.e. city centre, agglomeration and urban fringe) (Luyten and Van Hecke, 2007).

Prior to regression analysis, univariate correlations were calculated. Correlations between individual and environmental variables and MET*min/week were assessed by computing Spearman's rho, if linear relationship was confirmed, Pearson's correlation coefficient.

To determine the correlates of cycling usage, a multivariate linear regression (MLR) was performed with MET*min/week as the dependent variable. Factors were only entered in the regression models if they showed significant correlation ($P<0.01$) in the univariate correlation analysis to give an indication of the magnitude of association (co-linearity) between independent variables.

A separate MLR analyses was performed for (1) 'cycling to work' and for (2) 'cycling to other destinations'. This distinction was made because previous research indicated the importance of differentiating between context-specific behaviours (Giles-Corti et al., 2005). For 'cycling to work' three separate MLR analyses were performed. First a model was made where only the individual factors were included. In the second model only the environmental variables were included. In the final MLR, the individual and environmental variables were entered at the same time. For 'cycling to other destinations', 'region of the work place' and 'hierarchy of the work place' were not included in the analysis.

2.4.3. Results

1187 people filled out 1 or more travel diary (TD). In total 20,107 TDs were retained for data analysis. Within the first 6 weeks almost 50% of the total number of participants had registered.

After these 6 weeks, the number of new entries and participants who stopped their participation (exits) stayed nearly constant for the rest of the study period. Over the whole year, on average 387 TDs per week were filled out, representing 20.3 ± (16.7) TDs per participant. In Brussels and Wallonia, every participant filled out 18.8 ± (16.4) and 18.6 ± (15.5) TDs respectively. In Flanders (21.9 ± (17.1) TDs) significantly more ($P<0.05$) TDs were returned per participant.

Table 3 shows the total number of trips, time and distance for the total study population and stratified per gender.

Table 3: Total number of trips, time and distance for the total study population and stratified per gender

	total study population (N=1187) (#TD=20,107)		**men (N=750) (#TD=14,032)**		**women (N=332) (#TD=5,566)**	
	Work	All trips	Work	All trips	Work	All trips
# trips	128,766	214,644	90,395	149,346	35,350	60,592
time (hours)	57,235	78,099	42,961	57,633	13,160	18,891
distance (km)	1,116,295	1,474,978	881,993	1,143,299	213,951	304,164

#TD: number of travel diaries
all trips = sum of trips to work ('Work') and trips for 'other' destinations (e.g. grocery shop)

TDs were averaged per participant (Table 4 and Table 6) so that those who participated for a longer time period would not bias the results. Participants cycle on average 3.2 one-way trips to work each week, covering an average trip distance of 9.0 km. 50% of the participants cycle a mean trip distance of 6.5 km. This makes them cycle on average 166 min and 53 km per week at an average speed of 18.2 km/h.

Both genders use the bicycle at a same frequency (Table 4). For the trips to work, men cycled significantly more ($P<0.01$) in terms of travelled time and distance and cycled significantly faster ($P<0.01$) than women. Except for time per week the same was true for cycling to 'other' destinations than work.

In the General Questionnaire participants also had to specify the zip code of their place of residence. Table 5 shows the total cycling frequency (# trips), time and distance stratified per region.

Table 4: Averaged cycling characteristics and energy expenditure for the total study population and stratified per gender

	total study population (N=1011)	men (N=583)	women (N=265)
work			
frequency (#trips/week)	3.2 (1.4)	3.2 (1.4)	3.3 (1.3)
time (min/week) **	166 (109)	181 (113)	138 (85)
distance (km/week) **	52.9 (42.9)	61.6 (46.2)	36.3 (26.6)
distance (km/trip) **	9.04 (7.70)	10.61 (8.53)	6.10 (4.73)
speed (km/h) **	18.2 (4.9)	19.5 (4.8)	15.5 (3.8)
EE (MET*min/week) **	1204 (1070)	1424 (1171)	740 (568)
other destinations			
frequency (#trips/week)	2.3 (2.3)	2.3 (2.3)	2.6 (2.2)
time (min/week)	71 (82)	73 (88)	66 (69)
distance (km/week) **	20.0 (24.8)	22.0 (28.0)	16.8 (18.2)
distance (km/trip) **	5.37 (6.93)	6.00 (7.42)	3.79 (2.50)
speed (km/h) **	16.9 (4.5)	17.72 (4.6)	15.4 (3.9)
EE (MET*min/week) **	441 (568)	489 (655)	353 (387)

values are mean (SD)
significant gender difference: *P<0.05; **P<0.01.
note: 163 (16%) participants could not be attributed to a specific gender

Table 5: Total cycling frequency (# trips), time and distance stratified per region

	Brussels (N=376) (#TD=5,992)		Flanders (N=520) (#TD=10,328)		Wallonia (N=160) (#TD=2,588)	
	work	all trips	Work	all trips	work	all trips
# trips	39,561	64,337	67,695	115,830	14,750	22,727
time (hours)	13,696	20,153	34,424	45,190	6,128	8,540
distance (km)	226,427	325,210	712,990	909,033	117,440	160,873

#TD: number of travel diaries
all trips = sum of trips to work ('Work') and trips for 'other' destinations (e.g. grocery shop)

Flanders is the region where the mean time and distance per week and per trip is significantly higher (P<0.05) compared to the two other regions (Table 6). BCR has the lowest cycling speed (P<0.01). Participants from the Walloon region make the smallest number of trips per week (P<0.01). The same tendencies are present when looking at men and women separately.

The regional differences shown with this registration system are consistent with the data shown in section 2.1 (Mapping bicycle use and the risk of accidents for commuters who cycle to work in Belgium).

Table 6: Averaged cycling characteristics and energy expenditure stratified per region

	BCR (N=316)	Flanders (N=467)	Wallonia (N=138)
work			
frequency (#trips/week) §§,¥¥	3.3 (1.3)	3.4 (1.3)	2.9 (1.6)
time (min/week) **,¥¥	134.1 (78.7)	198.8 (114.7)	138.1 (116.8)
distance (km/week) **, §§, ¥¥	35.9 (25.7)	67.5 (47.1)	45.8 (43.3)
distance (km/trip) **,§§	5.6 (3.5)	11.2 (8.2)	9.6 (9.9)
speed (km/h) **, §§	15.8 (4.1)	19.6 (4.8)	19.0 (4.7)
EE (MET*min/week) **,§§	747 (611)	1546 (1190)	1079 (1043)
other destinations			
frequency (#trips/week) §§,¥¥	2.2 (1.9)	2.6 (2.7)	1.6 (1.8)
time (min/week)	72.6 (85.8)	72.2 (78.7)	62.3 (93.2)
distance (km/week) *	18.3 (20.5)	21.8 (26.6)	18.5 (29.8)
distance (km/trip) **,§§	4.3 (3.4)	5.6 (7.3)	6.3 (7.3)
speed (km/h) **,§§	15.3 (4.0)	17.9 (4.4)	17.3 (4.9)
EE (MET*min/week) **	377 (427)	488 (626)	439 (698)

values are mean (SD)
significant difference between Brussels and Flanders: *P<0.05; **P<0.01
significant difference between Brussels and Wallonia: §P<0.05; §§P<0.01
significant difference between Flanders and Wallonia: ¥P<0.05; ¥¥P<0.01

Table 7: Predictors of bicycle usage during trips to work assessed by multivariate regression model

Dependent: MET*min/week_work	B	SE	β	T	Sig
(Constant)	-431.473	327.467		-1.318	0.188
gender	-465.278	78.408	-0.199	-5.934	0.000
age	5.299	3.815	0.048	1.389	0.165
BMI	26.177	12.532	0.071	2.089	0.037
children	-47.920	73.427	-0.022	-0.653	0.514
cycle paths	171.120	33.505	0.166	5.173	0.000
region Home	145.934	69.734	0.088	2.023	0.043
urban hierarchy Home	253.092	35.733	0.291	7.554	0.000
region Work	-53.393	69.734	-0.033	-0.766	0.444
urban hierarchy Work	-42.641	35.733	-0.044	-1.193	0.233
R = 0.478; R^2 = 0.237; adjusted R^2 = 0.228; F = 26.363; P<0.001					

B: indicates the individual contribution of each predictor to the model; SE: standard error of B; β: standardized version of the B-value; Sig: *t*-statistic

Prior to the regression analysis, univariate correlations between MET*min/week, individual and environmental variables were performed for cycling to work. Apart from 'health', all variables showed significant correlations with MET*min/week, but correlation size was notable only for 'gender' (r=0.318, P<0.001) and 'urban hierarchy of the place of residence' (r=0.356, P<0.001). All variables that showed a significant correlation were entered into the multivariate regression analysis with MET*min/week as the dependent variable.

'Hierarchy of the home' (β=0.276, P<0.001), 'gender' (β=-0.197, P<0.001) and 'cycle paths'(β=0.175, P<0.001) are the strongest predictors of the model with all independent variables (Table 7). The predictors account for 23% of the variation in bicycle usage for trips to work, indicating that revealed predictors still leave a notable amount of variation of the dependent variable unexplained.

Prior to the regression analysis, univariate correlations between MET*min/week, individual and environmental variables were performed for cycling to 'other' destinations. Only 'age' ($r=0.143$, $P<0.001$) and 'urban hierarchy home' ($r=0.111$, $P<0.001$) showed significant correlations with MET*min/week. Therefore, only one MLR was built for 'cycling to 'other' destinations, including 'age' and 'urban hierarchy home'.

All variables that showed a significant correlation were entered into the multiple regression analysis with MET*min/week as the dependent variable (Table 8). 'Age' ($\beta=0.129$, $P<0.000$), and 'urban hierarchy home' ($\beta=0.063$, $P=0.079$) are the strongest predictors of the model. The predictors account for 2% of the variation in bicycle usage for trips to other destinations, indicating that revealed predictors leave a notable amount of variation of the dependent variable.

Table 8: Predictors of bicycle usage during trips to 'others' assessed by multivariate regression model

Dependent: MET*min/week_other	B	SE	β	T	Sig
(Constant)	68.704	86.613		0.802	0.423
age	7.345	2.030	0.129	3.618	0.000
urban hierarchy Home	28.563	16.236	0.063	1.759	0.079
$R = 0.151$; $R^2 = 0.023$; adjusted $R^2 = 0.020$; $F = 9.284$; $P<0.000$					

B: indicates the individual contribution of each predictor to the model; SE: standard error of B; β: standardized version of the B-value; Significant: *t*-statistic

2.5. Minor bicycle accidents in commuter cyclists in Belgium: a prospective study

2.5.1. Introduction

The modern traffic system is designed primarily for motorized vehicles and often fails to make provision for other road users. Pedestrians and cyclists incur higher crash risks than motorists (in particular car drivers) in terms of accidents/distance covered (Pucher and Dijkstra, 2000; Elvik, 2009). In Norway, the risk of injury when cycling is about 7.5 times higher than for car drivers (Pucher and Dijkstra, 2000; Elvik, 2009). In the Netherlands, there are about 5.5 times more traffic deaths per kilometre travelled by bicycle than by car for all age groups combined. Young adults (age 15- 30y) have about 9 times more deaths among those younger than 15y , and 17 times more deaths among those older than 80y (CBS, 2008).

It is well known that most road accident statistics strongly underestimate the total number of cycling accidents meaning that only the 'tip of the iceberg' is investigated (Dhillon et al., 2001; De Mol & Lammar, 2006), particularly when there is no hospitalisation and the cyclist is the only party involved (Veisten et al., 2007; Vandenbulcke et al., 2009). Comparison of hospital admissions related to cycling accidents and police registrations show the latter register only 50% in Europe (De Mol & Lammar, 2006) and only 10% in the US (Pucher and Dijkstra, 2000). Moreover the practice of registering and criteria for being admitted to hospital differ between and within countries. Because the 'safety in numbers' (Jacobsen, 2003; Robinson, 2005) effect is based on existing statistics including only major injuries and fatal accidents, it is not known if the safety in numbers effect also applies to the unreported accidents, like minor accidents and accidents only involving a single vehicle (Elvik, 2009).

Most surveys on bicycle accidents found in the literature are of a retrospective nature (Jacobson, 2003). Retrospective data collection has the advantage of being easier and less costly than prospective cohort designs. The major weaknesses of a retrospective analysis include; the selection and recall bias (resulting in the fact that especially the more serious injuries will be remembered), and the fact that no precise recording of exposure data (bicycle usage) is possible. The prospective cohort design overcomes some of these weaknesses. In prospective studies a group of individuals is followed prospectively in time during which the occurrence of minor and major injuries are monitored and recorded unbiased in 'real time'. Another advantage of prospective study designs is that exposure data (travel time, distance, frequency) can accurately be reported in diaries on a regular (weekly) basis. The registration of exposure data is essential for the calculation of the injury risk and injury rate. Data on the numerator (accidents) and denominator (exposure) separately are inadequate to determine an incidence rate, making comparisons between countries or regions within one country difficult (Jacobsen, 2003). Exposure-based injury rates will help us to understand whether policies reduce exposure or whether they increase safety (less injuries), given a similar level of exposure (Christie et al., 2007).

For the assessment of injury costs and for the implementation of safety measures a complete and accurate recording of minor and major accidents and the registration of the cycling exposure is essential. So far, no studies focused on minor bicycle accidents and studies where exposure data are recorded in a prospective way are lacking.

Therefore the purpose of this study was to monitor minor bicycle accidents in a prospective study design to get insight in minor bicycle accidents, investigate which factors influence these accidents and to overcome underreporting. The data from this part of the SHAPES project are combined with the exposure data (see section 2.3.4) to allow us to calculate the injury risk and injury rate of minor bicycle accidents.

2.5.2. Materials & methods

As mentioned in section 2.3.1, participants who passed the in- and exclusion criteria, received an e-mail including one unique travel diary(TD) with the question to report their bicycle usage of the preceding week. The last question of the TD asked whether accidents had occurred during the past 7 days. If an accident had occurred, the participant got access to the Prospective Questionnaire (PQ). For the in- and exclusion criteria of the participants and for the registration of an accident, see section 2.3.2.

Incidence was defined as the number (*N*) of injuries during the 1-year follow-up period. Incidence rates (IR) and corresponding 95% confidence intervals (95% CI) were calculated as the number of injuries reported per (i) 1000 trips; (ii) 1000 hours; and (iii) 1000 kilometers of exposure. The use of multiple denominators (e.g. both participant-hours of exposure and total participants) provides the most precise information about injury rate and injury risk (Goldberg et al., 2007).

Exposure data were limited to trips, hours and kilometers cycled by every participant. The accident and exposure data were assigned to gender and region of the place of residence.

Incidence rates for the various types of road infrastructure, environmental characteristics (urban *vs.* rural), cause of the accident, and medical consequences could therefore not be calculated.

The International Classification of Diseases (ICD-9-CM) Injury Severity Score (ICISS) was used to measure the severity of injuries. Each lesion was coded with ICD-9-CM and the corresponding exclusive Survival Risk Ratio (SRR) was assigned according to Osler et al. (1996).
A given ICD-9s SRR thus represents the likelihood that any individual person will survive that particular ICD-9 injury. The ICISS is defined as the product of all the SRRs for each of an individual person's injuries and scores range from 0 (death) to 1 (complete recovery). It is the product of SRRs from each injury sustained: $\text{ICISS} = P_{\text{Surv Inj 1}} \times P_{\text{Surv Inj 2}} \times \ldots \times P_{\text{Surv Inj last}}$. For more details we refer to Osler et al. (1996) and Rutledge et al. (1998).

2.5.3. Results

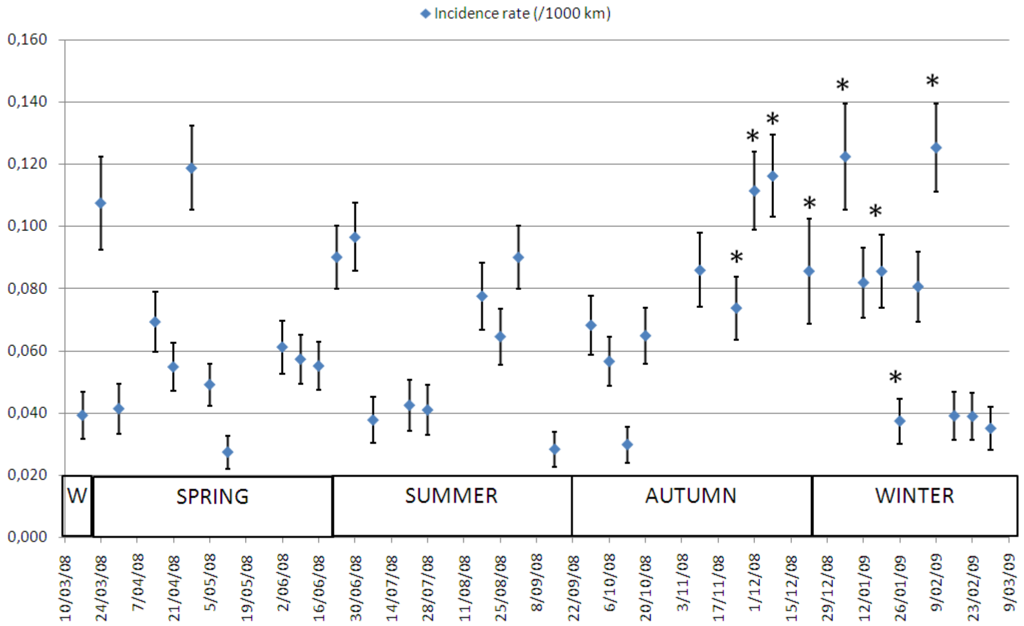
Descriptive data of the injured participants in comparison with the total study population are listed in Table 36 in Annex 3. No significant differences were found between the total study population and the participants who had an accident and were included in this study. During the study period of one year 20,107 weeks were covered in which 62 participants were injured and 70 accidents were registered. One participant was injured 3 times and 6 participants were injured 2 times.
Those involved in an accident cycled significantly ($P<0.05$) more kilometers per week (63.2 ± (46.3) km/week) and cycled significantly ($P<0.05$) faster (19.4± (4.9) km/h) compared to those participants not involved in an accident (51.2 ± (43.2) km/week and 18.0 ± (5.0) km/h, respectively). These results were true for the total sample and for men, but not statistically significant for women. The cycling speed, mentioned here is not the speed at the moment of the accident, but the average speed calculated by dividing the total kilometers cycled per week and the total cycling time per week.

The overall incidence rate (IR) was 0.324 per 1000 trips (95% CI 0.248-0.400), 0.896 per 1000 hours (95% CI 0.686-1.106) and 0.047 per 1000 kilometers (95% CI 0.036-0.059) of exposure. In other words, 1 accident occurred every 3,066 trips, 1,116 hours or 21,071 kilometers cycled.

The absolute number of injuries in every week and the distance cycled during that same week were used to calculate the incidence rate per 1,000 kilometres. Although participants cycled a more kilometres during spring (440,830 km), than in winter (295,695 km), the injury rate was not significantly different between the 4 seasons. When looking at the injury rate (/1,000 km) on a weekly basis (Figure 8), the IR in the weeks with snow or icy roads was 0.099 (95% CI 0.053-0.145) and in weeks without snow or icy roads the IR was 0.048 (0.036-0.060).

Data from this study, counting mostly minor accidents, showed a higher incidence in Flanders, followed by BCR and then Wallonia (Table 9). These results could make us wrongly conclude that cycling in Flanders is unsafe compared to BCR and Wallonia. Brussels is the region with the highest IR, with a significantly ($P<0.05$) higher IR compared to Flanders.

Figure 8: Incidence rate (95% CI) per 1,000 kilometres for the total study period



*: weeks with snow or icy roads

Table 9: Incidence, exposure and incidence rate per region

	Brussels	Flanders	Wallonia
INCIDENCE			
number of injuries (*N*)	28	34	8
EXPOSURE			
frequency (# of trips)	64,982	116,262	22,920
time (h)	20,153	45,190	8,540
distance (km)	325,210	909,033	160,873
INCIDENCE RATE (95% CI)			
/1,000 trips	0.431 (0.271-0.590)	0.292 (0.194-0.391)	0.349 (0.107-0.591)
/1,000 h	1.389 (0.875-1.904)	0.752 (0.499-1.005)	0.937 (0.288-1.586)
/1,000 km	**0.086 (0.054-0.118)**	**0.037 (0.025-0.050)**	0.050 (0.015-0.084)

Values in Bold indicate a significant difference (P<0.05)
Note: 511 (2.54%) travel diaries could not be attributed to a specific region

These results, together with the results shown in section 2.1 show that the so called 'safety in numbers' principle (Jacobsen, 2003; Robinson, 2005; Elvik, 2009) is applicable for major and minor accidents.

44 men and 18 women were involved in an accident. Men cycled more frequently, during a longer time and larger distances compared to women and had more accidents during the 1-year follow-up period (Table 10). Although women have the highest IR per 1,000 hours and per

1,000 kilometers, differences between genders were not statistically significant, probably due to the wide confidence intervals and insufficient power.

Table 10: Incidence, exposure and incidence rate per gender

	Men	Women
INCIDENCE		
number of injuries (*N*)	44	18
EXPOSURE		
frequency (# of trips)	149,346	60,592
time (h)	57,633	18,891
distance (km)	1,143,299	304,164
INCIDENCE RATE (95% CI)		
/1,000 trips	0.341 (0.248-0.435)	0.314 (0.173-0.455)
/1,000 h	0.885 (0.642-1.128)	1.006 (0.554-1.458)
/1,000 km	0.045 (0.032-0.057)	0.062 (0.034-0.091)

Note: 509 (2.53%) travel diaries could not be attributed to a specific gender

SHAPES recorded 9 accidents in the month of June, followed by 7 accidents in December, January, February and April. Monday (21%), Wednesday (29%) and Thursday (21%) are the days when most of the accidents occurred. 53% of the accidents took place during the morning peak hours (6:45-9:15 AM) and 17.1% during the evening peak hours (17:45-19:15 PM). 57 (82.9%) accidents occurred during a trip to or from work. 69% of the participants were riding on the road, while 21% were on a bicycle lane and 10% on a bicycle path at the moment of the accident. Table 11 further divides the type of road (bicycle lane/path) in relation to the place of the accident (urban planning). Injuries were mainly caused by 'slipping' (35.7%) and 'direct contact with a car' (18.6%) (Table 12).

Fifty-nine percent of the accidents took place inside the built-up area while traffic was perceived as 'calm'. Another 26% of the accidents occurred inside the built-up area with traffic perceived as busy. Also, the location of the bicycle accidents were allocated to the different commuter zones of the urban regions (i.e. city centre, agglomeration and urban fringe, which are defined on the basis of functional and morphological criteria) (Luyten and Van Hecke, 2007). Overall, most of these accidents occurred in municipalities of the urban agglomeration (41%) and in the city centre (30%), rather than in the suburbs (13%) or outside the urban regions (8%).

Table 11: Bicycle path/lane – urban planning

	cross road	continuing street	other
bicycle lane	1.4	8.6	0.0
bicycle path	2.9	18.6	0.0
public road without any markings for bicycles	31.4	21.5	15.7

values are a % of total

Table 12: Cause of the accident and the injury

	accident	injury
slipping	32.9	35.7
direct contact car	11.4	18.6
direct contact pedestrian	5.7	4.3
direct contact cyclist	4.3	4.3
hindrance on the road (constructions)	7.1	1.4
direct contact road sign	1.4	5.7
no priority	4.3	0.0
fall	0.0	2.9
inattentive	7.1	0.0
other	22.8	24.3

values are % of total

In 28 participants (40%) only 1 type of injury was registered. The accidents caused mainly abrasions (42%) and bruises (27%). Only two participants had a concussion, one lost consciousness and one was in shock (Table 13).

Table 13: Type of the injury

	number count	% of total number of injury types
abrasion	57	41,6
bruise	37	27,0
muscle torn	11	8,0
bone fracture	8	5,8
sprain	8	5,8
cut	7	5,1
burn	5	3,6
concussion	2	1,5
loss of consciousness at scene	1	0,7
in shock	1	0,7
TOTAL	**133**	**100**

From the 179 body parts that were injured, the knee was hurt in 20% of the cases (Table 14). Injuries were mainly located on the lower extremity (45%) and upper extremity (41%). Head injuries are relatively rare. Twenty four participants (34%) were injured only at one body part.

Table 14: Body region injured

	number count	% of total number of injury types
hip and leg	81	45.3
shoulder and arm	74	41.3
head and neck	19	10.6
back	4	2.2
trunk (front side)	1	0.6
TOTAL	**179**	**100**

56% of the participants indicated that they could not have avoided the accident. On the question "could you have avoided the accident", 37% said that they could have avoided the accident. Imprudence from the cyclist caused in 26% of the cases the accident. Distraction was responsible for 11% of the accidents.

Only 7.1% of the accidents were reported in official police statistics. Table 15 represents the accidents that were officially reported by police, hospitals or insurances. In a second analysis, we linked the severity of the injury (those with an ICD-code) with police, hospital and insurance data.

Table 15: Reported in official statistics

	% of total within each category	% within each item with an ICD-codes*
police		
with official record	7.1	40.0
without official record	4.3	33.3
no police intervention	88.6	6.5
hospital		
self-care	47.1	0.0
ambulant	25.7	16.7
emergencies	10.0	57.1
no medical intervention	17.1	0.0
insurance		
yes	30.0	28.6
no	70.0	2.0

* indicates which percentage of the accidents within each item had an ICD-code.

2.6. Commuting by bike in Belgium, the costs of minor accidents

2.6.1. Introduction

In Belgium in 2007, out of all 8048 officially registered victims from bicycle accidents, 7013 were due to "minor bicycle accidents", 926 due to "major accidents" and 88 victims died within 30 days after the accident (BRSI, 2009). When considering these official statistics it is important to realize that most road accident statistics strongly underestimate the total number of cycling accidents (Bickel et al., 2006; De Mol & Lammar, 2006). Especially when there is no hospitalisation and/or when the cyclist is the only party involved, accidents do not appear in accident statistics (Elvik & Vaa, 2004; Vandenbulcke et al., 2009). Veisten et al. (2007) estimated that in Norway the official statistics only cover 13% of all bicycle accidents and that light injuries in particular are strongly under-registered (only 12% of all light injuries were reported compared to 33% of the serious injuries and 71% of the severe injuries). In Belgium, only 7% of cycling accidents are officially reported (Table 15), even less than previously assumed (Doom & Derweduwen, 2005; De Mol & Lammar, 2006).

A top down estimation of the total cost of cycling accidents in general and for minor accidents in particular, based on the official statistics is therefore problematic. In contrast, our survey applies a bottom-up approach and is much better suited for studying the frequency and costs related to minor bicycle accidents. Earlier calculations of the cost of bicycle accidents in Belgium are therefore based on many assumptions and riddled with uncertainty (De Nocker et al., 2006). Veisten et al. (2007) have thoroughly studied the costs of bicycle accidents. Their estimation is based on the number of bicycle accidents in different categories according to the Abbreviated Injury Scale (AIS an indicator of the severity of the injury in relation to the probability of decease). They calculated that the average cost for a bicycle accident resulting in a minor injury was 42,990 Norwegian Kroner (2004 prices) or approximately 5804 euro (2010 prices). According to Veisten et al. (2007) the total cost for such a minor injury is composed of costs for a reduced quality of life (57%), productivity loss (12%), administrative costs (13%), medical costs (10%), property damage (8%) and traffic delays (0.5%).

The specific aim of this part of the SHAPES project is to estimate the costs related to "minor bicycle accidents" as a step towards a complete cost–benefit evaluation of commuter cycling. Direct costs, including the damage to bike and clothes as well as medical costs and indirect costs such as productivity loss and leisure time lost and costs related to pain and psychological suffering (intangible costs) and costs for other parties involved in the accident are calculated.
Focussing on minor accidents in this study is meaningful for three reasons: (1) they are by far the most numerous among all accidents, (2) they are strongly under-registered in official statistics and (3) very little is known about the related costs.

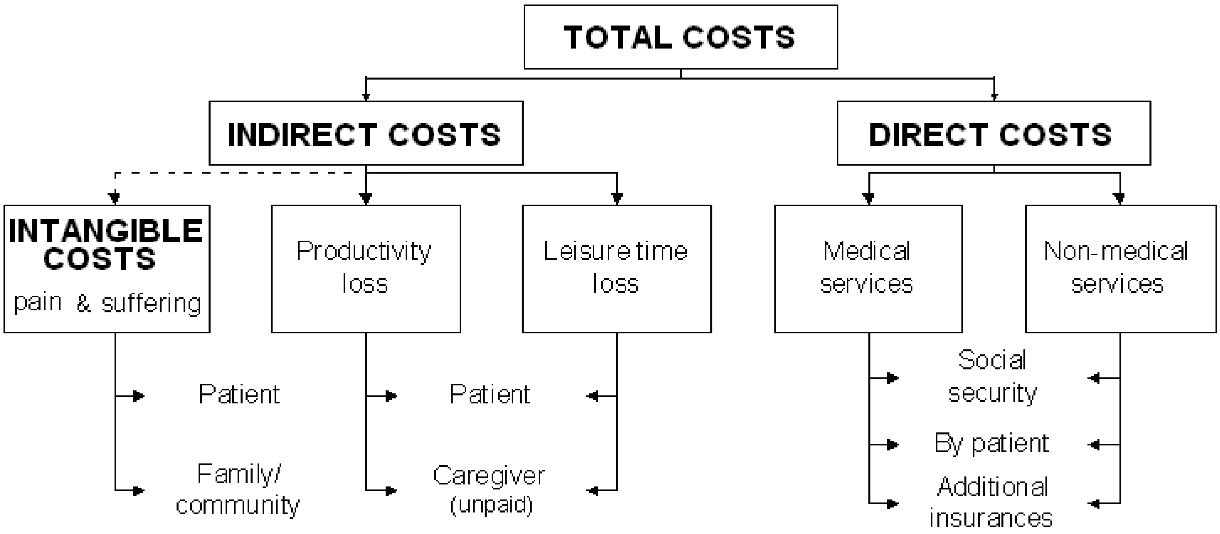
2.6.2. Materials and methods

For this part of the SHAPES study and in line with the national databases in Belgium, minor bicycle accidents were defined as "bicycle accidents not involving death or heavily injured persons, implying that possible hospital visits lasted less than 24 hours". As shown in Annex 3, Table 35, 293 participants reported an accident in the one-year that the registration system was online. The 223 participants had an accident that occurred during a trip for utilitarian cycling (not for recreational purposes). Four participants were not taken into account because they stayed in the hospital for more than 24h. The 219 remaining were contacted again in October 2009, and asked to complete a Cost Questionnaire (CQ) specifically aimed at determining the costs resulting from their accident. 118 victims (54%) completed the CQ.

To analyze the relationship between the severity of the injuries and the costs we distinguish 4 groups of accidents: (1) Without injuries: NO_I (n=13); (2) With light injuries limited to a bruise or cramp: LIGHT_I (n=57); (3) Acute Body Injury with only Short Term (<9 months) consequences: ABI_ST (n=41); (4) Acute Body Injury with Long Term (>9 months) consequences: ABI_LT (n=7). The response rate among those with an Acute Body Injury (ABI) is higher (73%), than for those who only reported material damage (27%).

A cost of illness approach was applied to estimate the different cost categories as defined by the US Environmental Protection Agency (EPA, 2006) as presented in Figure 9. The total cost of illness and injuries encompasses direct costs and indirect costs. Direct costs include damage to bike and clothes as well as medical costs. Indirect costs involve productivity loss, leisure time lost and costs related to suffering. Costs related to suffering, e.g. pain or psychological suffering, are also referred to as intangible costs. Productivity loss was calculated by multiplying the hours lost with the average value added per hour worked in Belgium provided by the OECD (2010). The following sources of time loss are accounted for: time invested in (1) repairing or replacing the material damage, (2) taking care of injuries (3) actions for getting a refund, (4) lower efficiency when performing household activities due to injuries, (5) time lost due to later arrival at home on the day of the accident. The value of a marginal time saving is often measured by a willingness to pay (WTP) approach (Hague Consulting Group, 1990). When compensating the costs of permanent corporal damage, we distinguish between (1) a possible permanent disability to perform certain tasks that leads to economic losses and (2) a permanent corporal invalidity for which a "moral" compensation is paid which is equal for all individuals. Based on Rowe et al. (1996), in our Cost Questionnaire, respondents were asked questions related to possible physical and psychological suffering related to their bicycle accident. Specific questions were asked for the willingness to pay (WTP) in order not to have suffered the pain, while all other consequences would remain the same.

Figure 9: Composition of the total cost for society related to illnesses and injuries



Source: EPA, 2006

2.6.3. Results

Among the 170 accidents with injuries, 59 also involved material damage. There were thus a total of 108 accidents with material damage (49%). This corresponds to 73 bicycle accidents with material damage per million kilometres cycled.

The average total cost of these accidents is estimated at 841 euro (95% CI: 579–1205) per accident. The average total cost of an accident with ABI_LT is about 11 times higher than one with ABI ST, which is in turn 2.5 times higher than one with light injuries (Table 16). The average total cost of an accident without injuries in our sample is about 8% lower than one with light injuries.

Table 16: Distribution of the total cost (euro) for the four categories

	ABI_LT	ABI_ST	LICHT_I	NO_I
N	7	41	57	13
average	9348	820	322	295
median	6460	152	134	304
SD	9115	1899	502	217
min	356	1	0	45
max	25525	9569	2465	643

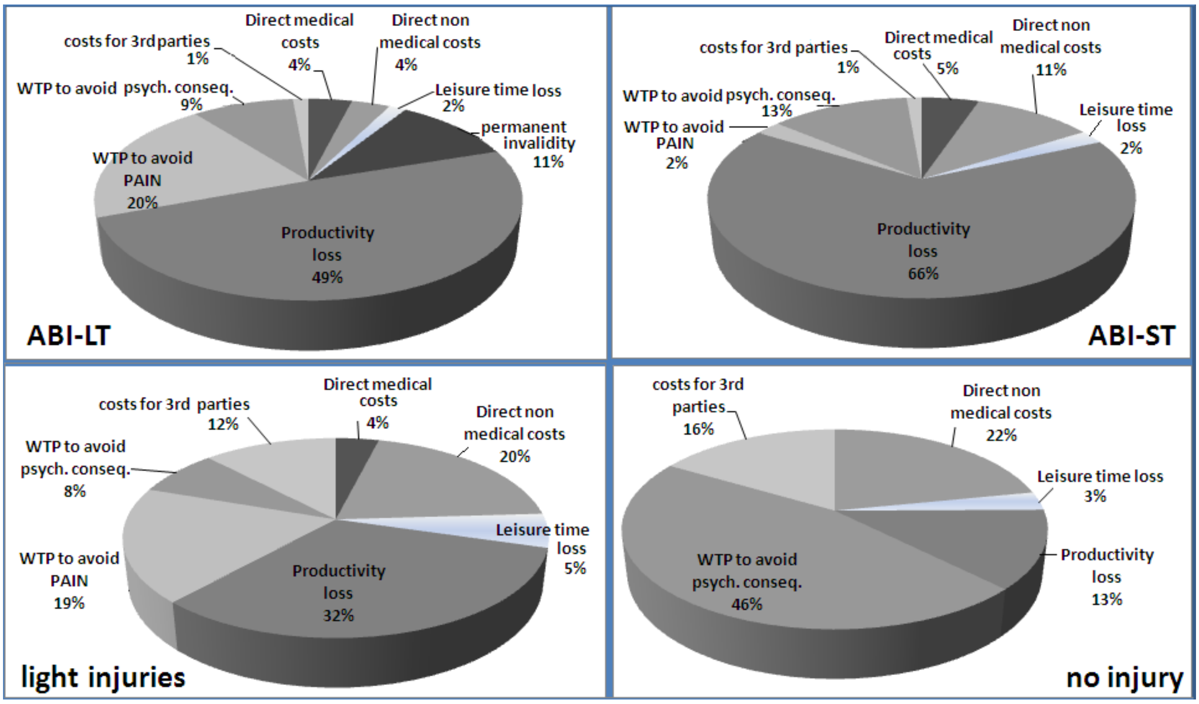
NO_I: without injuries; LIGHT_I: with light injuries limited to a bruise or cramp; ABI_ST: Acute Body Injury with only Short Term (<9 months) consequences; ABI_LT: Acute Body Injury with Long Term (>9 months) consequences.

Source: Aertsens et al., 2010

In Figure 10 it can be seen that the composition of the total cost is strongly different for each of the 4 groups. For ABI_LT, ABI_ST and LIGHT_I productivity loss is the main cost category with a share of respectively 49%, 66% and 32% in the total cost, while for NO_I productivity loss is less important (13% of total cost). For ABI_LT "permanent invalidity" with a share of 11% is an important cost component, while for the other groups it is non-existent. A detailed overview of the average cost for different cost categories and for the 4 groups is presented in Annex 3, Table 37.

Productivity loss is by far the main component (399 euro; 47%) of the total cost of an average minor bicycle accident. Intangible costs are the second most important costs. We estimate the WTP to avoid pain and the WTP to avoid psychological consequences at 14% and 13% respectively of total costs. Direct medical costs and permanent invalidity only account for 4% and 5% respectively.

Figure 10: Share of each cost component in the total costs per group



no injury: without injuries; light injuries: with light injuries limited to a bruise or cramp; ABI_ST: Acute Body Injury with only Short Term (<9 months) consequences; ABI_LT: Acute Body Injury with Long Term (>9 months) consequences.

Source: Aertsens et al., 2010

Overall, productivity loss is the most important component accounting for 48% of the total cost. Intangible costs, which in past research were mostly neglected, are an important burden related to minor bicycle accidents (27% of the total cost). Even among minor accidents there are important differences in the total cost depending on the severity of the injury. In Table 17 the costs over the whole group are calculated per million kilometres cycled. This is done by weighting the costs for the four severity groups (ABI_LT, ABI_ST, LIGHT_I and NO_I), by their share in the total population of accidents and by a correction factor for the total kilometres cycled in the whole population (for this calculation, the travel diary data were used (see section 2.4)). The average total cost of minor bicycle accidents is 124,861 euro per million kilometres cycled or 0.125 euro per kilometre. Though the share of accidents with ABI with an impact on the long term is very small (4.5%), their contribution to the total cost of minor bicycle accidents is high (49%). The contribution of ABI_ST, LIGHT_I and NO_I is respectively 25%, 18% and 8%. The importance of ABI_LT is responsible for the relatively wide confidence interval on the average total cost of a minor bicycle accident.

Table 17: Total cost over all groups per 1,000,000 km cycled – main cost categories

	ABI_LT	ABI_ST	LICHT_I	NO_I	TOTAL	TOTAL %
direct medical costs	2405	1629	891	0	**4924**	**4**
direct non medical costs	2132	3405	4577	2140	**12254**	**10**
productivity loss	30121	20526	7307	1239	**59194**	**47**
leisure time loss	937	695	1244	292	**3168**	**3**
permanent invalidity	6643	0	0	0	**6643**	**5**
WTP to avoid pain	12301	726	4231	0	**17257**	**14**
WTP to avoid psych. Consequences	5601	3937	1719	4500	**15757**	**13**
costs for 3rd parties	858	429	2759	1618	**5663**	**5**
TOTAL	**60997**	**31347**	**22728**	**9789**	**124861**	**100**
TOTAL %	**49**	**25**	**18**	**8**	**100**	

costs are presented in euro (€)

NO_I: without injuries; LIGHT_I: with light injuries limited to a bruise or cramp; ABI_ST: Acute Body Injury with only Short Term (<9 months) consequences; ABI_LT: Acute Body Injury with Long Term (>9 months) consequences.

Source: Aertsens et al., 2010

Minor bicycle accident costs per kilometre are higher than expected. What does this imply for society? Based on our data, we can extrapolate the number of accidents in our sample to Belgium by two approaches. First: In Belgium in 2007, out of all 8048 officially registered bicycle victims 7013 were related to "minor accidents". As we have found that only 7.1% of the minor cycling accidents with ABI are officially reported, we estimate that 98,775 victims suffered from minor bicycle accidents in Belgium in 2007. Second: During the weekly registration, in total, 20,107 weeks have been recorded during which 219 minor bicycle accidents occurred. The data of the National Institute of Statistics (NIS, 2001) registered 290,995 cyclists that commuted regularly by bike. Assuming that this number did not change by 2009, and that these cyclists commute 48 weeks per year, our weekly survey has registered about 1/695 of all commuting by bike. If we use this ratio the number of minor bicycle accidents in 2007 for Belgium is extrapolated to 152,205. As we calculated the average cost of a minor accident to be 841 (579–1205) euros we estimate the total cost for Belgium between 57 and 183 million euro.

2.7. Retrospective versus Prospective accident registration

2.7.1. Introduction

The aim of this section is to look at the differences between Retrospective and Prospective study designs. All the results of the RQ (e.g. the circumstances of the accidents, the cause of the accidents, ...) are not reported in detail if they were not statistically different from the PQ. We refer to section 2.3.6 for the details about the Prospective data collection of minor bicycle accidents.

To monitor bicycle accidents, different study designs can be used, both having their strengths and weaknesses. In prospective studies a group of individuals is followed prospectively over time during which the occurrence of injury and exposure (frequency, time spent and distance travelled) is accurately monitored and recorded on a regular basis. The disadvantage is that it is time consuming and expensive. Sometimes the research question may require an immediate answer, which the prospective cohort design cannot provide. In this case, the retrospective cohort may be used. Retrospective data collection has the advantage of being easier and less costly to administer than prospective cohort designs. The weakness of the RQ is e.g. the selection and recall bias, resulting in the fact that more serious injuries will be remembered.

2.7.2. Materials and methods

As indicated in section 2.3.2 all participants that fulfilled the in- and exclusion criteria were asked to fill out the Retrospective Questionnaire (RQ). From the 924 participants that correctly responded to this questionnaire, 69 accidents were reported in the 12 months before their participation at the study that fitted the in- and exclusion criteria.

2.7.3. Results

All accidents were compared with the Injury Severity Score as a measure of human trauma. The International Classification of Diseases (ICD-9-CM) Injury Severity Score (ICISS) was used to measure the severity of injuries. Each lesion was coded with ICD-9-CM and the corresponding exclusive Survival Risk Ratio (SRR) was assigned according to Osler et al. (1996).

According to Cryer and Langley (2006), no participants had a ‘serious injury’ defined as an ICISS of ≤0.941, that is, having a probability of death of at least 5.9%. Six participants (RETRO) indicated that their accidents caused a permanent body damage. At the time of fill out the questionnaires, 30.0% (PROS) and 21.7% (RETRO) of the participants indicated that it was not yet possible to say if the accident had caused permanent damage.

In the PROS, 7 out of 70 (10.0%) cyclists had an injury with a SRR < 1 (small risk of mortality). In the RETRO this was 19 out of 69 (27.5%) (Table 18). The proportion of injuries with a SRR < 1 was higher in the RETRO than in the PROS survey (Fisher exact test, 2-tailed: p<0.01). No relation was found between the severity of the accident and the cause of the accident.

Table 18: Outcome of the ICISS score

	PROS	RETRO
number of injured participants	70	69
total number of subjects with ICD-codes	7	19
total number of ICD-codes	185	175
sum of ICISS (expected number of deaths) **	0.084	0.269

significant difference between PROS and RETRO: Fisher exact test, 2-tailed: P<0.01

That retrospective surveys register accidents which result in more serious injuries can also be confirmed by the fact that in the RETRO more accidents resulted in hospital interventions (ambulant: PROS: 25.7% vs. RETRO: 50.7% and admission in an emergency department: PROS: 10.0% vs. RETRO: 13.0%) and more often the insurance was involved (PROS: 30.0% vs. RETRO: 52.2%) (Table 19).

Table 19: Representation in official statistics

		PROS	RETRO
police			
	with official record	7.1	11.6
	without official record	4.3	2.9
	no police intervention	88.6	85.5
hospital **			
	self-care	47.1	23.2
	ambulant	25.7	50.7
	emergencies	10.0	13.0
	no medical intervention	17.1	13.0
insurance **			
	yes	30.0	52.2
	no	70.0	47.8

values are a % of total within PROS or RETRO

significant difference between PROS and RETRO: Chi^2: **$P<0.01$

The incidence proportion (IP), defined as the number of injured participants/number of participants at risk, is significantly higher ($P<0.05$) in the RETRO compared to the PROS data collection for the total study population (Table 20). The same results are present when only looking at the data of Brussels and Flanders separately. The incidence rate (IR; /1000 weeks) is significantly higher in the Prospective data collection compared to the Retrospective for the total study population. The same results are present when only looking at the data of Brussels and Flanders separately.

The conclusion of this comparative study between a prospective and a retrospective study design is that people who had an accident in the past (RETRO) are probably more likely to fill out questionnaires to report their accident. The accidents that are reported in the RQ are more serious in nature compared to the PQ. When taking the number of weeks into account (for the calculation of the incidence rate) the prospective study design registers twice as much accidents compared to the retrospective study design.

In other words, in Retrospective surveys minor lesions get probably lost because people tend to remember the more serious injuries and in Prospective surveys people report even the smallest accidents. These data also illustrate the importance of the choice of the denominator when formulating conclusions about safety measurements and the 'risk' of cycling.

Table 20: Comparison between Prospective and Retrospective for IP and IR

	PROSPECTIVE				RETROSPECTIVE			
	Total study population	Brussels	Flanders	Wallonia	Total study population	Brussels	Flanders	Wallonia
exposure								
weeks	20107	5992	10328	2588	48048	15756	23140	6760
study population								
total # participants	1187	376	520	160	924	303	445	130
# injured participants	62	24	32	8	69	29	36	6
# injuries	70	28	34	8	69	29	36	6
IP and IR (95% confidence intervals)								
IP *	0.052 (0.052-0.053)	0.064 (0.063-0.065)	0.062 (0.061-0.062)	0.050 (0.047-0.053)	0.075 (0.074-0.075)	0.096 (0.094-0.098)	0.081 (0.080-0.082)	0.046 0.043-0.049)
IR /1000 weeks *	0.0348 (0.0267-0.0430)	0.0467 (0.0294-0.0640)	0.0329 (0.0219-0.0440)	0.0309 (0.0095-0.0523)	0.0144 (0.0110-0.0178)	0.0184 (0.0117-0.0251)	0.0156 (0.0105-0.0206)	0.0089 (0.0018-0.0160)

IP: incidence proportion; IR: incidence rate

Significant difference between Pros and Retro in the total study population, Brussels and Flanders: *$P<0.05$

In Wallonia the difference is not significant

Note: 511 (2.54%) week books could not be attributed to a specific region

2.8. Exposure to particulate matter in traffic: A comparison of cyclists and car passengers

2.8.1. Introduction

Adverse health effects of exposure to air pollution have traditionally and consistently been associated with ambient measurements at fixed monitoring stations (Nawrot et al., 2007; Pope et al., 2009). Increased exposure in traffic is a consequence of the fact that vehicles typically emit high quantities of pollutants under a limited number of specific driving conditions (Int Panis et al., 2006; Beusen et al., 2009). Close proximity to traffic therefore leads to peak exposure when trailing vehicles or cyclists cross the tailpipe plume. Studies (e.g. Rank et al., 2001) indicate that cyclists are exposed to lower concentrations of traffic related air pollutants than car drivers. At this moment it is not clear what the health effects of short bursts of high exposure are relative to the effects of chronic exposure which are well known from epidemiological studies.

Only a few studies (van Wijnen et al., 1995; O'Donoghue et al., 2007; Zuurbier et al., 2009) have taken into account that cyclists have a variable and increased minute ventilation (VE) compared to other commuters (e.g. car drivers, bus passengers), influencing their inhaled dose of air pollutants.

In this part of the SHAPES study we present the results of measurements of concentrations of Particulate Matter (PM) inside a car and on a bicycle. Ventilatory parameters (VE) are simultaneously measured to assess the amount of pollutants actually inhaled during each trip. Models are then used to calculate the lung deposited dose. Different trajectories were taken along busy traffic roads and calm rural roads to see what the influence is of traffic density.

2.8.2. Material and methods

Concentrations (PNC, $PM_{2.5}$ and PM_{10}) and ventilatory parameters (minute ventilation (VE), breathing frequency and tidal volume) were simultaneously measured in three Belgian locations (Brussels (Bxl), Louvain-la-Neuve (LLN) and Mol) (Table 21). The Brussels route loops through the European district. Its southern leg includes part of the Rue de la Loi, a busy 4 lane street canyon (N3; ~50000 vehicles per day). The routes that were chosen in Louvain-la-Neuve and Mol included very quiet residential areas as well as a busier street in the eastern section with mostly local traffic and few heavy duty vehicles (N4 and N18; ~15000 vehicles per day). The route in Louvain-la-Neuve includes some slopes, similar to the route in Brussels, whereas the route in Mol is flat. The Brussels route was cycled twice to obtain a similar sampling time and number of measurements as for the longer rural routes.

Table 21: Route characteristics, meteorological and environmental conditions

average* date		route length (meters)	relat. humid. (%)	avg. temp. (°C)	avg. wind speed (km/h)	wind direction	avg. Ozone ($\mu g/m^3$)	avg. relat. humid. (%)	avg. air press. (hPA)	avg. PM_{10} ($\mu g/m^3$)
4/06/2009	BxL	2*2400	39	13.5	12.9	NW	92.8	49.5	1005.8	22.6
5/06/2009	BxL	2*2400	47	13.5	7.3	W	70.4	64.7	999.0	26.9
8/06/2009	BxL	2*2400	46	16.5	9.1	S	94.9	53.3	996.4	16.1
9/06/2009	BxL	2*2400	56	17.8	21.2	S	77.9	71.9	994.3	19.0
11/06/2009	LLN	5450	75	15.5	17.1	WSW	72.7	80.7	1004.7	12.3
12/06/2009	LLN	5450	47	18.2	9.5	W	90.3	53.7	1009.9	21.8
30/06/2009	Mol	6800	39	28.1	12.2	WNW	140.8	47.8	1020.0	14.6
1/07/2009	Mol	6800	46	25.3	8.9	NE	113.9	55.8	1021.0	18.3

* averages in the nearest station of the automatic monitoring networks (ISSeP; BIM; VMM): For PM10 and O_3, station Uccle/Ukkel, Corroy-le Grand and Dessel were used for Bxl, LLN and Mol respectively. Meteorological data; station Uccle-Ukkel for Brussels and LLN, station Luchtbal was used for Mol. There was no precipitation.
Source: Int Panis et al., 2010

Fifty-five persons (38 men and 17 women) that participated in the SHAPES online registration and filled out travel diaries volunteered to participate in these field measurements. The test persons were stratified by their place of residence relative to one of the three case-study locations. The descriptive statistics of the participants and cycled routes stratified by location and gender are summarized in Table 22.

Test persons were first driven by car and then cycled along identical routes in a pairwise design. The bike trip always followed the car trip to avoid an effect of the bike ride on the ventilation and heart rate during the car ride. The same car (Citroën Jumpy, model year 2007) was used for all tests. The car was always driven with the windows closed, air conditioning off and the fanned ventilation system in mode 1. The TSI DustTrak DRX model 8534 (TSI Inc, USA), a portable optical dust monitor, was used to simultaneously measure $PM_{2.5}$ and PM_{10}. Particle number concentrations (PNC) at 1-sec resolution were measured using P-Trak UFP Counters (TSI Model 8525, USA), for particles in the size range 0.02-1 μm (maximum 500,000/cm^3). Breathing frequency, tidal volume and oxygen uptake were measured using a portable cardiopulmonary indirect breath-by-breath calorimetry device (MetaMax 3B, Cortex Biophysik, Germany) fixed into a chest harness. The same instruments were used for each pair of trips to sample air within the breathing zone (i.e. approximately 30 cm from the mouth). Test persons were asked to cycle at the same average speed as during their trips to and from work.

Inhaled amounts were calculated by multiplying PNC and $PM_{2.5}$ and PM_{10} mass with VE. The lung deposited fraction was determined based on published deposition factors (DF) (Daigle, 2003; Chalupa et al., 2004).

Table 22: Descriptive statistics of the participants and cycled routes stratified by location and gender

route	# subject	age (years)	BMI (kg/m²)	avg. speed; time based (km/h)	avg. speed; GPS based* (km/h)	total cycling time (minutes)	total driving time (minutes)
Bxl	men N = 21	42.9 (9.4)	23.7 (2.0)	18.8 (1.5)	20.6 (1.8)	15.4 (1.3)	16.9 (2.5)
	women N = 10	40.9 (11.1)	24.3 (4.2)	16.5 (1.8)	17.9 (1.9)	17.6 (1.9)	16.2 (3.6)
LLN	men N = 8	41.5 (11.0)	23.8 (2.2)	20.1 (1.5)	20.9 (1.8)	16.3 (1.2)	10.6 (0.3)
	women N = 1	29.0 (.)	20.7 (.)	22.2 (.)	24.6 (.)	14.7 (.)	10.8 (.)
Mol	men N = 9	44.7 (8.1)	24.3 (2.6)	22.1 (3.0)	22.1 (3.7)	18.8 (2.8)	9.5 (1.0)
	women N = 6	49.8 (3.2)	22.5 (3.1)	19.4 (1.8)	20.1 (1.7)	21.1 (2.0)	10.2 (1.2)

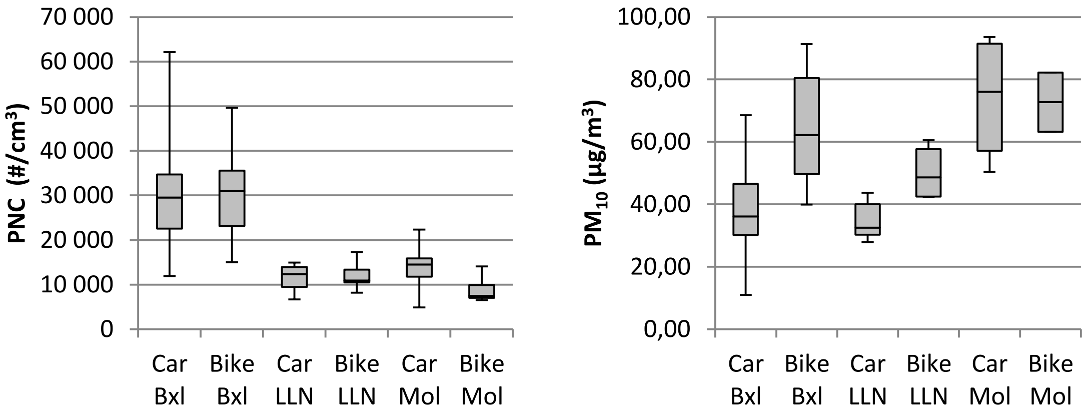
values are mean (SD)
* distance based average speed while cycling (excluding zero speeds during stops at intersections etc.)
Source: Int Panis et al., 2010

2.8.3. Results

In order to evaluate the external validity of the field experiments, the cycling speed was compared with the cycling speed reported in the travel diaries. The cycling speed during the experiment was comparable to the average commuting speed that was reported in the weekly diaries (men: 19.5 ± (4.8) km/h, women: 15.5 ± (3.8) km/h; $P<0.001$). Time based cycling speeds recorded in Brussels were somewhat lower than in both rural towns (Louvain-la-Neuve and Mol) because of traffic lights and pedestrians. Otherwise average (self-selected) cycling speeds were similar for both rural locations.

PNC were approximately three times higher in Brussels than in both other locations. Levels of PM were elevated in Mol due to specific meteorological conditions which did not occur at the other locations. High temperatures, combined with sunny weather and low relative humidity caused an increase in both ozone and PM concentrations (Table 21). PNC were significantly higher inside the car than on the bicycle in Mol whereas differences at similar levels in Louvain-la-Neuve and at much higher levels in Brussels were not significant. The opposite result was found for particulate mass. Average PM2.5 and PM10 levels were significantly lower inside the car in Brussels and Louvain-la-Neuve, but not in Mol. Mean bicycle/car ratios for PNC and PM are close to 1 and rarely significant. Figure 11 shows a summary of all measurements for the three locations.

Figure 11: PNC measurements (left, #/cm^3) and PM$_{10}$ measurements (right, μg/m^3)



Source: Int Panis et al., 2010

Women breathed significantly more frequently and had lower tidal volumes than men (t-test $P<0.01$; $P<0.0001$). As a result men inhaled about 17% more air while cycling ($P<0.01$). Ventilation frequency was 1.6 times higher and tidal volume increased by a factor of 2.6 while cycling. VE increased by a factor of 4.1 in women and 4.5 in men. Differences between the three routes were not significant. A summary of the respiratory data is shown in Table 23.

Table 23: Respiratory parameters during cycling

	breathing frequency (breaths/min)	tidal volume (L)	minute ventilation (VE) (L/min)	heart rate (beats/min)	total inhaled volume during trip (L)
bike	27.9 (4.2)	2.2 (0.4)	59.1 (13.7)	129.6 (12.8)	924.8 (182.3)
	32.7 (7.0)	1.4 (0.3)	46.2 (10.6)	140.0 (13.6)	801.4 (98.2)
car	18.3 (3.0)	0.8 (0.2)	13.4 (1.7)	71.9 (9.7)	176.8 (55.8)
	21.3 (4.8)	0.6 (0.1)	11.3 (1.8)	74.8 (9.0)	153.4 (62.7)
bike/car ratio	1.6 (0.3)	2.8 (0.6)	4.5 (1.1)	1.8 (0.2)	5.8 (2.3)
	1.6 (0.2)	2.6 (0.4)	4.1 (0.6)	1.9 (0.3)	5.9 (2.0)

Values are mean (SD)

Source: Int Panis et al., 2010

The bicycle/car differences for inhaled quantities and lung deposited dose are large and consistent across locations. Quantities of particles inhaled by cyclists were between 400 and 900% higher compared to car passengers on the same route. The longer duration of the cycling trip also increased the inhaled doses. These differences are caused by increased VE in cyclists which significantly increases their exposure to traffic exhaust. Inhaled quantities are shown in Table 24.

Table 24: Average inhaled quantities of PNC, PM_{10} and $PM_{2.5}$

		PNC (#inhaled/m)	PNC (#dose/m)	*μg* PM_{10} (inhaled/km)	*μg* PM_{10} (dose/km)	*μg* $PM_{2.5}$ (inhaled/km)	*μg* $PM_{2.5}$ (dose/km)
Bxl	Bike	5,580,195 (1,924,800)	4,631,562*	11.5 (4.5)	2.6	3.4 (1.3)	0.8
	Car	1,335,467 (83,365)	841,344** 965,696***	1.6 (0.6)	0.4	0.6 (0.2)	0.1
	bike/car ratio	4.50 (2.17)		**7.3 (3.0)**		**5.9 (2.1)**	
LLN	Bike	2,023,702 (594,881)	1,679,673*	8.4 (1.6)	1.9	3.8 (0.8)	0.9
	Car	305,095 (83,365)	192,210** 214,045***	0.9 (0.1)	0.2	0.5 (0.1)	0.1
	bike/car ratio	6.83 (1.68)		**9.0 (1.0)**		**8.0 (0.8)**	
Mol	Bike	1,135,046 (435,493)	942,088*	8.5 (0.2)	1.9	5.2 (0.2)	1.2
	Car	216,768 (75,832)	136,564** 135,956***	1.2 (0.2)	0.3	0.7 (0.1)	0.1
	bike/car ratio	6.05 (3.46)		6.6 (0.3)		7.4 (0.6)	

values are mean (SD)

* avg DF = 0,83 Daigle, 2003; ** avg DF = 0,63 Daigle, 2003; *** variable DF Chalupa et al., 2004

Source: Int Panis et al., 2010

2.8.4. Conclusion

Although there are obvious differences in exposure between cyclists and car drivers, this aspect has often been ignored for lack of measured data. Three differences influence the exposure of cyclists to air pollution. The most important one is a large increase in breathing frequency and tidal volume which increases the total inhaled volume (the VE while riding a bicycle is 4.3 times higher compared to car passengers). Secondly, for the same inhaled quantity, the amount of particles that remains in the respiratory tract is higher while exercising because of increased deposition. Finally, the time needed to complete the route is often (but not always) longer for the cyclist. Nevertheless it is mainly the differences in ventilation (and associated deposition) that matter. Integrated health risk evaluations of transport modes or cycling policies should therefore use exposure estimates rather than concentrations.

The remaining question however is whether this difference, which occurs only for relatively short periods during the journey to work, entails any significant health risks (Int Panis, 2011)? To investigate this hypothesis, members of SHAPES and PARHEALTH started a new experiment (see next section: Subclinical responses in healthy cyclists briefly exposed to traffic-related pollution).

2.9. Subclinical responses in healthy cyclists briefly exposed to traffic-related pollution

2.9.1. Introduction

Within the framework of the PM^{2}TEN cluster project, members of SHAPES and PARHEALTH joined forces to set up a field measurement campaign to investigate if cycling near a busy road would induce changes in biomarkers of pulmonary and systematic inflammation. In a controlled experiment, physically fit, non-asthmatic test persons cycled during two exposure scenarios: near a major bypass road with busy traffic (road test) and in a room with filtered air (clean room).

2.9.2. Materials and methods

For this field study, 38 adults, selected from those who participated at the SHAPES field measurements (see section 2.8) cycled for about 20 minutes in real traffic near a major bypass road (road test; mean UFP exposure: 28,867 particles/cm³) in Antwerpen and in a laboratory with filtered air (clean room; mean UFP exposure: 496 particles/cm³). The road test was a pre-selected route in Antwerpen on a dedicated cycling path parallel to a major bypass road (a very busy 10 lane motorway with up to 200,000 vehicles per day and a major flow of heavy duty diesel vehicles). The total trajectory is 5750 meters long and mostly situated between 10 and 100 meters from the edge of the motorway. The exercise intensity (heart rate) and duration of cycling were similar for each participant in both experiments. The same devices for the measurement of ventilatory parameters and Particulate Matter (PM_{10}, $PM_{2.5}$, UFP) were used as for the SHAPES field measurements (see section 2.6) during the road test and clean room test. To create a ‘clean room’, three devices were used simultaneously and continuously (i.e. 24 hours a day) during the whole testing period, in a laboratory.

A venous blood sample was drawn for the determination of plasma interleukin-6 (IL-6), platelet function, Clara cell protein in serum and blood cell counts and exhaled nitric oxide (NO) was measured, before the exercise. After the exercise, participants rested for 30 minutes in a seated position followed by the post-cycling examination, which included exhaled NO measurement and a venous blood sample collection.

2.9.3. Results

The descriptive statistics of the participants are summarized in Table 25.

The average concentrations of particles to which the participants were exposed, during the road test and in the clean room are given in Table 26. By design, concentrations of particles were higher during the road test. Average temperature was higher and relative humidity was lower in the clean room. By design the duration of cycling and the heart rate did not differ between the two exposure scenarios (road test and clean room) (Table 26). Baseline values (before cycling) of the clinical parameters were not significantly different between the road test and the clean room (Table 27).

Table 25: Participants characteristics

anthropometrics	
men/women	28/10 (74%/26%)
age (years)	43.0 (8.6)
BMI (kg/m²)	23.7 (3.1)
lifestyle	
former smoker	16 (42%)
exposure to environmental tobacco smoke	3 (8%)
regular alcohol use	20 (53%)
medication use	
antiplatelet medication	0 (0%)
lipid-lowering medication	1 (3%)
antihypertensive medication	3 (8%)

values are mean (SD) or number (%)

Source: Jacobs et al., 2010

Table 26: Exposure measurements during the road test and in the clean room

	road test	clean room	P-value[*]
PM_{10} ($\mu g/m^3$)	62.8 (23.6)	7.6 (3.3)	<0.0001
$PM_{2.5}$ ($\mu g/m^3$)	24.2 (8.7)	2.0 (0.78)	<0.0001
UFP (particles/cm³)	28,867 (8479)	496 (138)	<0.0001
duration of cycling (min)	20.8 (1.6)	20.2 (1.9)	.20
temperature (C°)	15.2 (1.6)	21.6 (1.0)	<0.001
relative humidity (%)	57.0 (9.5)	45.7 (6.6)	<0.001
heart rate (beats/min)	131 (15.0)	131 (14.6)	.90
% of maximal heart rate	74.0% (8.6)	74.1% (8.8)	.90

values are mean (SD)

Source: Jacobs et al., 2010

Table 27: Comparison of baseline values between the road test and the clean room

	road test	clean room
exhaled NO (ppb)	29 (19 - 41)	24 (15 - 39)
PFA closure time (s)	163 (135-197)	154 (125-176)
plasma IL-6 (pg/mL)	1.47 (0.99-2.28)	1.53 (1.20-1.90)
clara cell protein (μg/L)	7.7 (5.6-11.5)	7.7 (5.6-10.3)
blood leukocyte counts (per μL)	4964 (1208)	4883 (1174)
blood neutrophil counts (per μL)	2937 (874)	2888 (884)
percentage blood neutrophils (%)	59 (8.0)	59 (7.1)

data are geometric mean (25-75 percentile) for non-normally distributed variables or mean (SD) for normally distributed variables

Paired t-test : $P > .08$

Source: Jacobs et al., 2010

Table 28: Percent change (pre/post) per exposure scenario (road test or clean room)

	road test		clean room		p-value for interaction		
	percent change (95%CI)	p-value	percent change (95%CI)	p-value	exposure scenario*	UFP[†]	$PM_{2.5}$[‡]
exhaled NO,	-4.4% (-8.3% to -0.37%)	**0.04**	-1.3% (-6.5% to 4.1%)	0.63	0.37	0.63	0.50
PFA closure time	6.7% (-0.79% to 14.8%)	0.09	5.1% (-1.0% to 11.6%)	0.11	0.73	0.60	0.56
plasma IL-6	17.4% (-6.8% to 47.9%)	0.18	-3.4% (-19.6% to 16.0%)	0.71	0.21	0.38	0.40
Clara cell protein	1.6% (-10.8% to 15.8%)	0.81	-3.9% (-15.0% to 8.7%)	0.95	0.87	0.91	0.81
blood leukocyte counts	1.3% (-2.0% to 4.6%)	0.44	2.5% (-1.1% to 6.1%)	0.19	0.75	0.98	0.71
blood neutrophils counts	4.6% (0.51% to 13.1%)	**0.03**	2.4% (-2.3% to 7.2%)	0.33	0.36	0.34	0.18
percentage blood neutrophils	3.9% (1.5% to 6.2%)	**0.003**	0.22% (-1.8% to 2.2%)	0.83	**0.004**	**0.02**	**0.01**

analysis adjusted for heart rate

* pre/post-cycling measurements and exposure scenario (road test or clean room)

[†] pre/post-cycling measurements and UFP concentrations

[‡] pre/post-cycling measurements and $PM_{2.5}$ concentrations

Percentage of blood neutrophils increased significantly more (P=.004) after exercise in the road test (3.9%; 95% CI: 1.5 - 6.2%; P=.003) than after exercise in the clean room (0.2%; 95% CI: -1.8 - 2.2%, P=.83) (Table 28). The pre/post-cycling changes in exhaled NO, plasma IL-6, platelet function, serum levels of Clara cell protein and number of total blood leukocytes did not differ significantly between the two scenarios.

In test persons free of lung and cardiovascular disease, a small, immediate (30 minutes after moderate exercise) increase in the percentage of blood neutrophils was observed in response to cycling in traffic-related exposure. Platelet function and a biomarker of lung permeability (Clara cell protein) did not show rapid changes between pre/post-cycling measurements in either exposure scenario. The change in pre/post-cycling measurement of exhaled NO did not differ significantly between the two scenarios. The health impact of this isolated change is unclear.

2.10. Evaluating the physical condition of cyclists compared to car users

2.10.1. Introduction

Cycling to work has the advantage of being physically active on a regular basis, compared to sitting in a car. One could state that the physical condition, and by this means the general health status, of those who cycle on a regular basis is better than the physical condition of car drivers, considering that those who travel by car do not perform any physical activity in their profession or during their free time.

2.10.2. Materials and methods

To investigate this hypothesis, two cohorts of commuters were compared: 1. a cohort of commuters who travel by bicycle to work more than two times a week (=active commuters; group 1); 2. a cohort of commuters who travel by car on a daily basis and who do not cycle as sport or recreational hobby or perform more than 3 hours of physical activity in 1 week during the last 6 months (= passive commuters; group 2). For the group of regular commuter cyclists (group 1) we used the 81 SHAPES participants. For the cohort of passive commuters (group 2) we used the data from the study of de Geus et al. (2009).

In both cohorts the maximal physical performance was determined with a maximal incremental exercise test on an electrically braked cycle ergometer under laboratory conditions. During the test the maximal external power (Wmax), maximal oxygen uptake (VO$_2$max) and maximal heart rate (HFmax) were measured.

For details about the precise procedure of the maximal exercise test and the description of the participants of group 2 we refer to de Geus et al. (2009).

2.10.3. Results

No significant difference was found for mean age between both groups. The BMI of group 2 (25.6) was significantly ($P<0.01$) higher than the BMI of group 1 (23.6).

The results show that those who cycle to work on a regular basis produce significantly ($P<0.01$) more external power (Wattmax and Wattmax/kg) and have a significantly ($P<0.01$) higher maximal oxygen uptake capacity (VO$_2$max and VO$_2$max/kg) (Table 29). The maximal heart rate was not statistically different indicating that both groups attained their maximal exercise capacity.

Table 29: Maximal exercise test

	active commuters	passive commuters
Wattmax**	259 (69)	201 (60)
Wattmax/kg**	1.46 (0.34)	2.66 (0.60)
VO$_2$max**	3.189 (0.742)	2.379 (0.619)
VO$_2$max/kg**	43.26 (7.90)	31.67 (5.91)
HFmax	179 (12)	177 (13)

values are mean (SD)

significant difference between both groups: **$P<0.01$

With the above mentioned results we demonstrate that those who cycle to work are in a better physical condition then those who use the car as a mode of transport. These results not show any cause and effect relationship. To show a cause and effect relationship, intervention studies (Oja et al., 1991; Hendriksen et al., 2000; de Geus et al., 2009) were set-up to investigate if those who are physically inactive can increase their physical performance and gain a better physical and mental health by increasing their daily amount of physical activity. Oja et al. (1991), Hendriksen et al. (2000) and de Geus et al. (2009) showed in their unsupervised intervention studies that cycling to work on a regular basis (≥3x/week) at a self-chosen, moderate, intensity improves physical performance (Wmax and VO$_2$max) in previously untrained middle-aged men and women. Additionally, Oja (1991) and de Geus et al. (2008)

showed that not only the physical performance increased by cycling to work on a regular basis, but that the risk of coronary heart diseases decreased and the quality of life increased. In the Oja et al. (1991) and de Geus et al. (2008) studies, fasting blood samples were taken, from the umbilical vein, for sedimentation, uric acid, triglyceride (TG), total cholesterol (TC), LDL cholesterol, very low-density lipoprotein cholesterol (VLDL), high-density lipoprotein (HDL), and C-reactive protein (CRP) determination. The mental health (Quality of Life - QOL) status was assessed with the self-administered SF-36 Health Status Survey (Ware et al., 1993). The SF-36 taps both physical and mental health aspects of QOL using the respondents' perceptive on their health and functional status.

With these results and the available studies form the literature (Oja et al., 1991; Hendriksen et al., 2000; de Geus et al., 2008; 2009) it is shown that those who cycle to work on a regular basis have a better physical condition than those who travel to work by car. Take the car commuters out of their car and make them cycle on a regular basis will increase their physical condition and their general health status.

2.11. Modelling the risk of having a bicycle accident in Brussels

2.11.1. Introduction

Bicycle use is increasingly recognized as one of the most effective ways to address health, environmental and mobility concerns in urban areas. However, the risk of cycling accident strongly deters people from cycling. In Belgium, the risk of having an accident for a cyclist is high compared with other modes of transport: cyclists account for approximately 9% of the total number of traffic fatalities (EU, 2003; Rietveld and Daniel, 2004; BRSI, 2009), while the bicycle share is estimated at 2.42% in terms of traveller-km/person/year (Belgium is ranked fourth at the EU-15 level). Cyclists are hence vulnerable road users in the streetscape. In particular, the Brussels-capital Region (urban area) exhibits low proportions of cyclists and high risks of accident (Figure 1 and Figure 2), although casualty risks are low for cyclists owing to the urban nature of the region.

Contrary to most of the previous research aiming at modelling crash severity or frequency, the purpose of this research is to develop a statistical model explaining the *risk* of having an accident for a cyclist on the whole Brussels' road network, using local risk factors as covariates and a gravity-based methodology to account for the exposure of cyclists in the traffic. The specific aims of this research consist in: (1) identifying the most significant spatial variables/factors (expected to be) associated with the occurrence of a bicycle accident in Brussels, (2) identifying which areas are expected to carry the highest risk to cause bicycle accidents (based on model predictions), and (3) provide policy recommendations based on our results. The methodology applied here is innovative in the sense the modelling framework uses an auto-logistic model combining geocoded accident data *and* control points (i.e. exposure of cyclists) in order to predict the *risk* of having a cycling accident.

2.11.2. Materials & methodology

2.11.2.1. Implementation of a case-control strategy

Literature in ecology and epidemiology provides well-founded methodological concepts that could be easily replicated to road safety research, for which only case events (i.e. road accidents) are registered. In order to make possible the use of logistic modelling (and, then, the estimation of the accident risk), a case-control strategy is here applied, based on group discrimination techniques (ecology) and case-control methodologies (epidemiology). In particular, case events are locations where a bicycle accident occurred on the Brussels' network during the period of study (2006-2008), while controls are locations where no accident is *supposed* to have occurred on the network and during the 2006-2008 period.

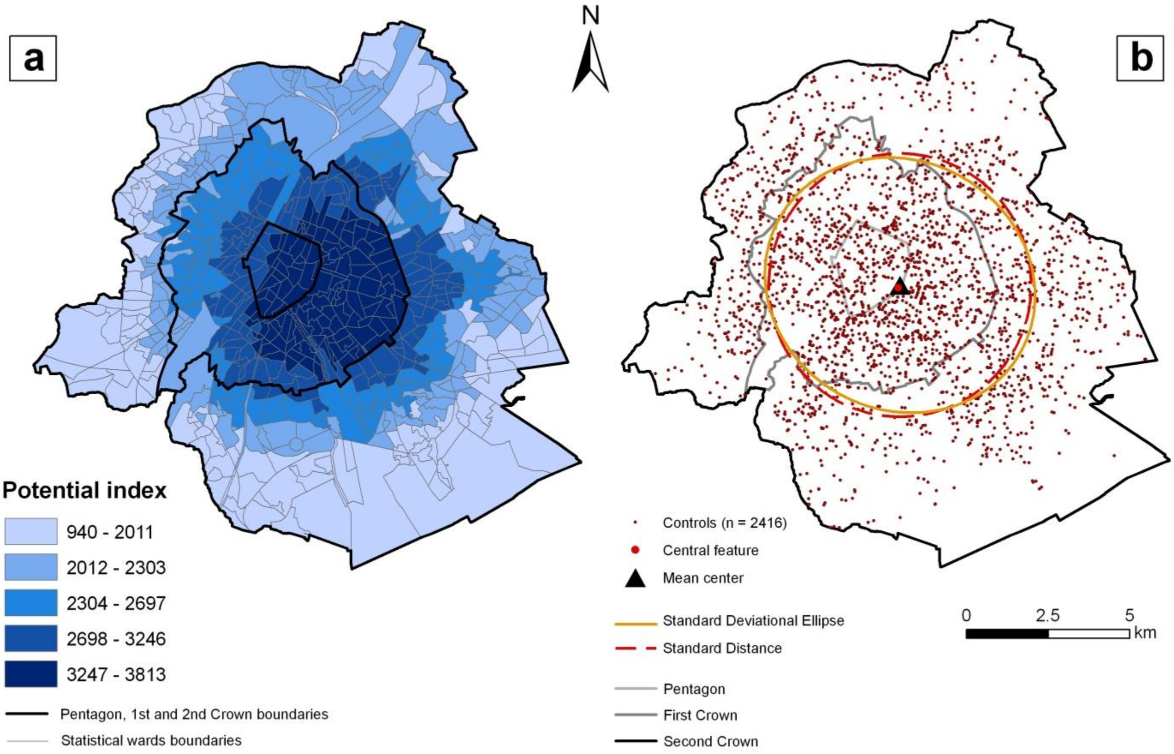
The only impediment to the replication of such a case-control strategy comes from the availability of an ***exposure variable***, from which controls can be sampled as point events. A solution here proposed to obtain such an exposure variable is derived from the "gravity-based" (or "potential") theory, as conceptualised previously in accessibility research (see e.g. Geertman and Ritsema van Eck, 1995; Geurs and Ritsema van Eck, 2001; Geurs and van Wee, 2004; Vandenbulcke et al., 2007). In this study, the potential index specification is adapted to estimate the potential bicycle traffic per spatial unit *i*, i.e. the (potential) background frequency of the exposure of cyclists to accidents. Such an adapted specification is here called the "***Potential Bicycle Traffic Index***" (**PBTI**). Based on the 2001 socio-economic Census, the PBTI (noted P_i^*) is defined as:

$$P_i^* = a_i + \sum_{j=1}^{n} a_j . \left(\alpha_j . exp\left(-\lambda_j . d_{ij}\right) + \beta_j . d_{ij} . exp\left(-\varepsilon_j . d_{ij}\right) \right)$$

where *i* is the statistical ward of interest (*i* = 1,..., *n*), *j* are the statistical wards in the neighbourhood of *i* (*j* = 1,..., *n* and *j* ≠ *i*), a_i is the number of commuter cyclists living in the statistical ward of interest *i*, a_j is the number of commuter cyclists living in the statistical ward *j*, d_{ij} is the distance measured along the "bikeable" network (expressed in kilometres) between *i* and *j*, and α_j, λ_j, β_j, ε_j are parameters attributed to the statistical ward *j* and calibrated on the basis of the 2001 census, at the scale of the old municipality *k* containing *j* (for statistical significance purposes, since the number of cyclists in the statistical ward *j* is lower than in an old municipality *k*). A visual check of Figure 12 suggests that the PBTI is close to the actual spatial patterns of the bicycle traffic, despite the fact that no preferential direction is assumed for cycling trips. Interestingly, the locations where large numbers of cyclists are reported by the yearly bicycle traffic counts (e.g. European district) all correspond to maximum values of the PBTI.

Just as for ecological modelling, the random selection of controls is weighted as a function of the PBTI. Hence, the number of controls to be drawn will vary from one spatial unit to another, proportionally to this index (i.e. in proportion to the bicycle traffic transiting in each statistical ward). In other words, the number of controls will be the highest in areas where the (potential) bicycle traffic – i.e. the exposure – is the highest (and inversely). Given that bicycle accidents generally happen on a road network, control points are constrained to be drawn on this same network, at the exclusion of non-bikeable roads (e.g. motorways, funnels, etc.) and linear buffered zones around the accidents in order to preclude the sampling from these zones. Such linear buffers correspond to the black spots of accidents as obtained, e.g. using the Network Kernel Density Estimation provided by SANET v.4 (Okabe et al., 2009).

Figure 12: (a) Potential Bicycle Traffic Index (PBTI), (b) Control points, generated from the PBTI and constrained to be drawn along the bikeable network (without black spots)



2.11.2.2. *Modelling approach*

The dependent variable used for modelling is derived from the combination of case events (i.e. the occurrence of a bicycle accident at location *i*) and controls (i.e. no bicycle accident at *i*). Case events are noted ‘1’ and controls are noted ‘0’; the dependent variable is hence binary, which makes the use of (auto-)logistic regression modelling possible if risk factors (or covariates) are identified for both cases and controls. Logistic, autologistic and intrinsic conditional autoregressive models are here performed within a Bayesian framework, accounting for multicollinearity, heteroskedasticity and spatial autocorrelation. By trial and error (using diagnostic and goodness-of-fit statistics), the best models were selected and then used to compute predictions for a specific “bikeable” trajectory of the network.

The Bayesian computational approach provides several advantages over the estimation based on a conventional frequentist perspective. Its ability to incorporate prior expert knowledge and to deal with nuisance/random parameters in complex models is one of the key assets of the Bayesian approach (Koop, 2003; Miaou et al., 2003; Bolstad, 2007; Kéry, 2010). Unlike frequentist inference that gives fixed estimations when using the maximum likelihood (ML) approach, the Bayesian approach allows the parameters to be characterised as random variables and provides direct probability statements about these (Bolstad, 2007; Kéry, 2010; Pei et al., 2010). Probability is hence expressed as the uncertainty we have about the magnitude of a parameter, which makes the Bayesian inference more intuitive compared with the conventional approaches. Last but not least, ML may also be biased when using finite sample sizes, whereas Bayesian computational methods give exact inference for any sample size (Kéry, 2010).

2.11.2.3. *Data collection of risk factors*

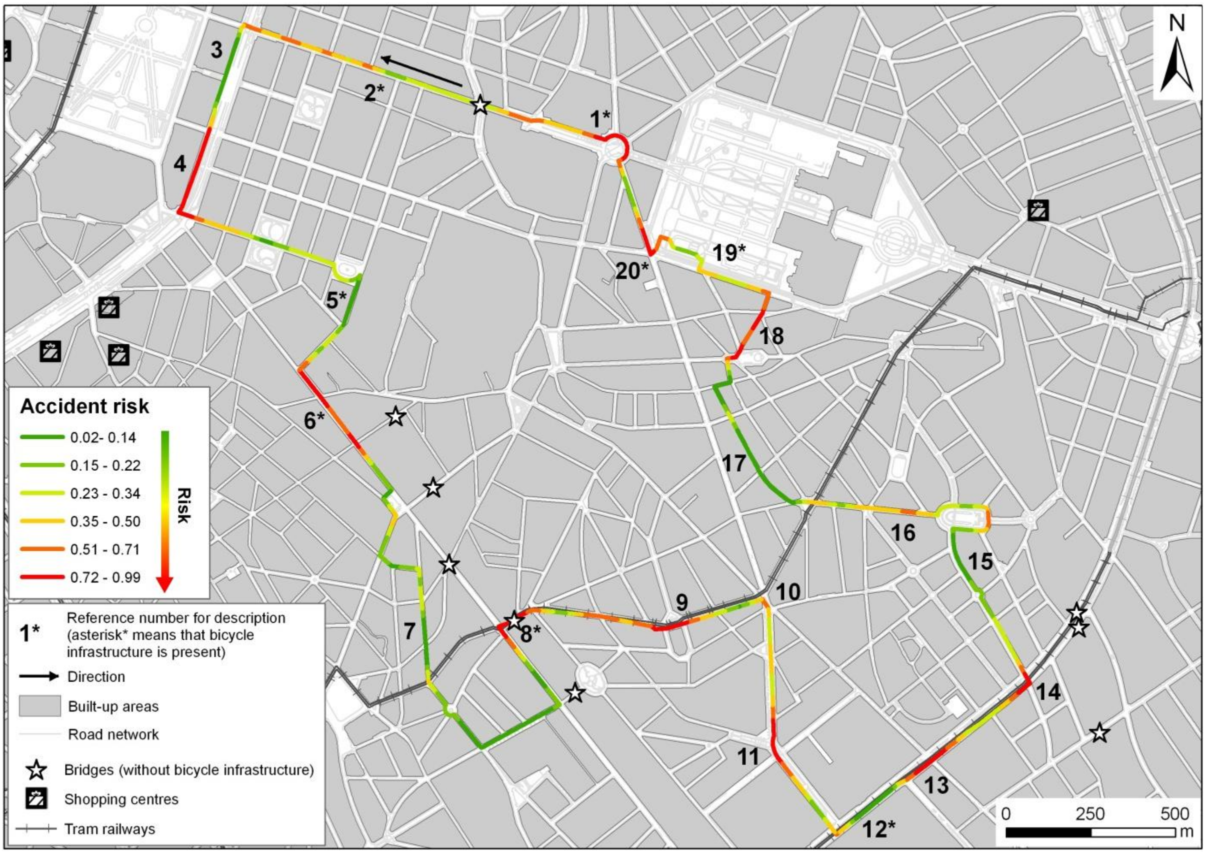
Bicycle accidents – and more generally, road accidents – generally result from the interaction between five categories of risk factors: human factors (e.g. driver behaviour, driver error), vehicle-related factors (e.g. size or state of the vehicle), infrastructure factors (e.g. crossroad design, pavement type), traffic conditions (e.g. density, speed), and environmental factors (e.g. lighting, weather) (Miaou et al., 2003; Li et al., 2007; BRSI, 2008). Here, we mainly focussed on infrastructure factors and traffic conditions, since the data associated with the other risk factors are generally not available for the controls. Some environmental factors are also considered, but they turned out to be insignificant in the results. Table 38 in Annex 3 lists all risk factors used in this study as well as their definition, units and data sources. Most of these data were manually digitalized/created at UCL-CORE and collected for the 2006-2008 period, at the scale of the Brussels-Capital Region. While digitalizing the data, special attention was paid to the direction, year and type of some spatial data (e.g. cycling facilities), thus allowing a categorization of the latter.

2.11.3. Results

Mapping the predicted risk of having a bicycle accident – on the basis of the results of the final model (Table 39) – may be quite interesting since it not only validates the results of the model, but it also provides a useful tool for planners, decision makers and cyclists' advocacy groups. As illustrated in Figure 13, predictions are computed for a specific road trajectory, passing through the Brussels' European district (Schuman roundabout (numbered 1^*) and Rue de la Loi / Wetstraat (2^*)) and in the close proximity of the Pentagon (Royal Palace and Park (3–4)) and Brussels' University (ULB–VUB (12–13)). These predictions identify the most 'risky' parts of the network for the cyclists, and hence the places where cyclists should be more careful when riding and/or where changes in the infrastructures might be performed in order to improve the bicyclist's safety. In particular, red colored links correspond to locations where the accident risk for cyclists is the highest, whereas green colored links represent locations where this risk is the lowest. Our results suggest that the risk of bicycle accident is higher for 'complex' intersections (i.e. those numbered 1^*, 8^*, 10–11, 15–16, 18, 20^*), roundabouts with marked cycle lanes (1^*), roads with on-road tram railways and tram crossings (8^*– 9, 12^*, 14), as well as roads with dense van and truck traffic volumes (1^*, 2^*, 4, 6^*, 8^*, 11, 13–14, 18, 20^*). At the opposite, the lowest accident risks are mainly observed for streets located in residential wards (characterized by low van/truck traffic volumes (5^*, 9, 16)), where contraflow cycling is allowed (5^*, 7, 17), or where no garage is observed within 100m (1^*, 5^*, 12^*, 19^*).

In Table 39 (Annex 3), the complexity index (which is a proxy for road legibility) is the factor that has the greatest effect on the risk of having a cycling accident. This suggests that driver errors (and then accidents) may be more frequent for cyclists – as well as for other road users – at locations with a higher complexity, i.e. at locations where there is a large number of information (e.g. due to a high number of road legs, signs, road users, etc.). Although significant at 93% only, the parameter estimate corresponding to bridges unequipped with cycling facilities is also suggestive of an increased risk of accident for cyclists. The sudden change in terms of road width (i.e. narrow space) and visibility (low due to the curving of the bridge) is expected to be at the root of such an increased risk, especially if no dedicated facility is built for cyclists on the bridge. Contrary to popular belief, the findings also suggest that streets where contraflow cycling is allowed reduce the risk of having an accident for cyclists. We hypothesized that such a lower risk of cycling accident results from a risk compensation effect, i.e. drivers may tend to behave in a more cautious way due to an increased perceived risk in streets where such a contraflow cycling is permitted. Interestingly, the fact that intersections are excluded from the definition of streets with contraflow cycling indicates that motorists entering into such streets may be surprised to be in front of (exiting) cyclists and may collide with these latter.

Figure 13: Predictions of the risk of cycling accident (2008), computed from the parameter estimates (posterior means) reported in Table 39



As regards the cycling facilities, the results are in line with the literature (see e.g. McClintock and Cleary, 1996; Rodgers, 1997; Aultman-Hall and Hall, 1998; Räsänen and Summala, 1998; Aultman-Hall and Kaltenecker, 1999; Pucher et al., 1999; ERSO, 2006) and indicate that some of these facilities lead to an increased risk of having a bicycle accident when associated with a specific type of intersection. In particular, right-of-way intersections equipped with suggested cycle lanes lead to the highest accident risk for cyclists, probably because of the non-respect of the right-of-way by motorists and the very discontinuous character of the facility (i.e. chevrons and bicycle logos only, instead of a 'continuous' lane or path). Yield/stop intersections with separated cycle lanes also seem to carry a danger, especially when the cyclist rides on a bidirectional facility in the opposite direction of the (parallel) traffic. The reasons are twofold: on the one hand, cyclists often have an ill-founded feeling of safety caused by the physical segregation of the facility, while on the other hand motorists often have an inappropriate visual search pattern (i.e. they often look at one direction only) and do not expect to cross a cyclist coming from an opposite direction (BRSI, 2006). It seems that the same accident mechanisms also apply to the cycling accidents at yield/stop intersections equipped with unidirectional separated lanes, where the cyclists sometimes ride in the wrong way (i.e. not permitted by law) (*ibidem*). Given that such facilities are frequently built on either side of multi-lane and divided roads, we assumed that – in this case – the cyclist was often constrained or deterred to cross the (wide and busy) road in order to be in the right way. As expected, high accident risks were also observed for cyclists riding on marked cycle lanes built in roundabouts (outer lane). In such a context, collisions often occur when the motorist leaves or enters into a roundabout and cuts in on the cyclist riding on the marked facility. Such a design even leads to a higher accident risk for cyclists compared to roundabouts without any cycling facility (where the cyclist is merged into the stream of motorized traffic). Intersections equipped with traffic lights and marked cycle lanes are also found to increase the risk of accident for cyclists. This higher risk is probably due to motorists turning to an adjacent road and cutting in on the cyclist's trajectory on the marked facility. This may also be explained by the fact that cycle lanes are generally designed in such a way that they position cyclists in the blind spots of the (large) motorised vehicles at signalised intersections. However, it is worth of note that the accident risk is here lower compared with the above mentioned designs (it is about 7 times less risky than right-of-way intersections equipped with suggested lanes). This is probably the result of a reduced number of conflicting movements and lower vehicle speeds at signalized intersections. Also, the presence of advanced stop zones for cyclists is expected to mitigate the accident risk at signalized intersections. Such zones not only put the cyclists into the view of motorists (and outside blind spots of cars and large vehicles), but also allow cyclists preparing to turn to take up a proper position on the road.

The close proximity ($\leq$0.8 m) between separated cycle lanes and parking facilities is also identified here as being a significant risk factor. Cyclists riding on such separated lanes and alongside close parked vehicles may indeed run into (suddenly) opened car doors. Also, the presence of parked vehicles generates a (close) pedestrian activity that may sometimes occur on the adjacent cycle lane (due e.g. to the absence of sidewalk) and may potentially lead to an accident. Besides the risk associated with close parked vehicles, Table 39 suggests that the presence of garages (within 100m) increases the risk of having a bicycle accident. This may be explained by the fact that motorists leaving/entering into a garage may collide with cyclists riding straight ahead on the road (*ibidem*). Concerning tram railways, our findings indicate that on-road railways and tram (railway) crossings significantly increase the risk of having a bicycle accident. The cyclists may indeed get stuck in the tram tracks, resulting in a loss of control of the bicycle (and then to a fall, in some cases).

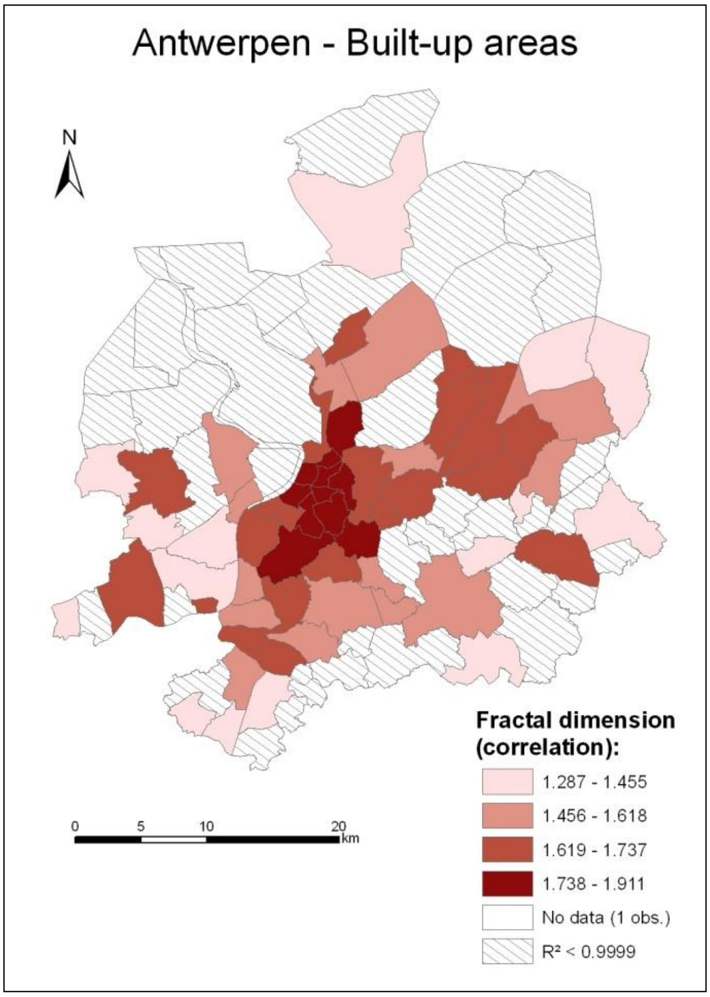
The presence of a shopping centre in the close proximity of the cyclist's trajectory is also associated with an increased risk of accident. An intense pedestrian and motorized activity is indeed commonly observed in the neighbourhood of shopping centres. This hence increases the number of potential conflicting partners and situations, and then leads to a higher risk of accident.

Among all traffic-related factors, those referring to the different levels of van and truck traffic provided the best improvement of the model fit. Our results indicate that rising levels of van and truck traffic increase the risk of cycling accident. Whatever the type of road user, the legibility of the traffic context is indeed as much reduced as the traffic is denser. Furthermore, the large vehicle dimensions of vans and trucks often obstruct the field of vision of all neighbouring road users (i.e. cyclists, motorists, etc.) and – as a result – may lead to conflicting situations between these latter. It is also assumed here that vans and trucks are more prone to blind spot problems when turning and leave narrow safety margins to cyclists when overtaking, which clearly increases the risk of accident for cyclists.

2.12. Impact of urban morphologies on road safety: Fractal evidences from Antwerpen

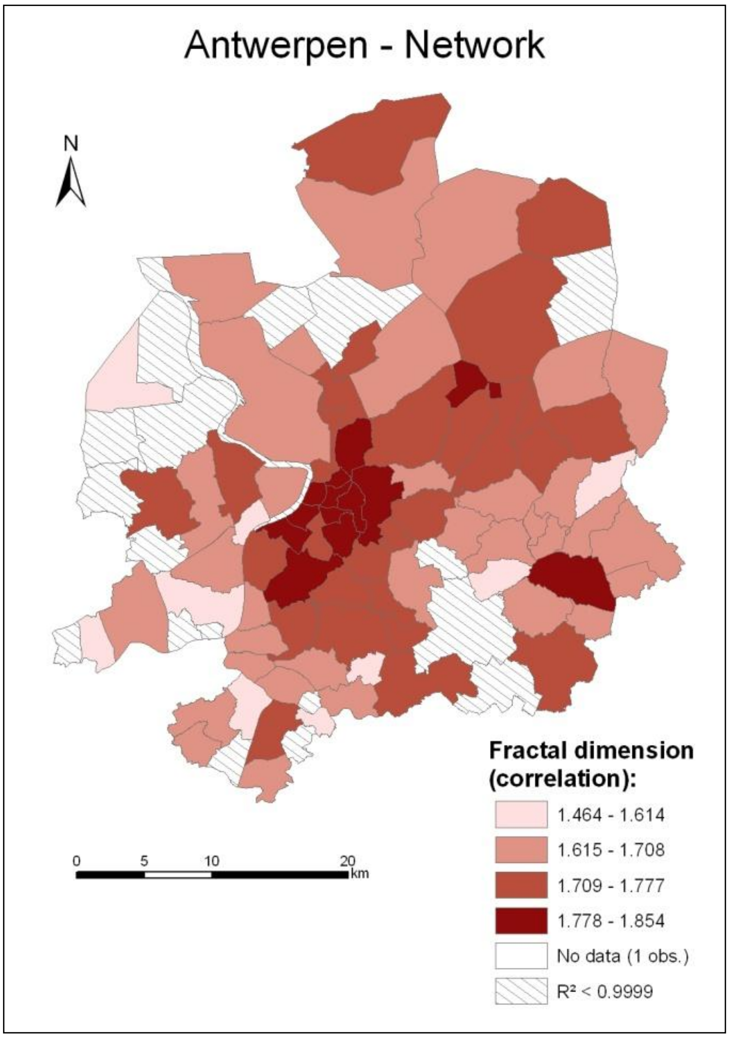
While searching for variables explaining the location of accidents, we studied how far the *morphology of the urban built-up surfaces* could influence road safety, and specifically at finding quantitative indices for measuring this morphology. Tests were performed on several Flemish and Walloon urban patterns and in-depth analyses were conducted on the agglomeration of Antwerpen (city + suburbs) (see Figure 14 and Figure 15 as illustration).

Figure 14: Spatial distribution of the fractal values obtained in the urban agglomeration of Antwerpen for the built-up surfaces



Source: UCL, 2010

Figure 15: Spatial distribution of the fractal values obtained in the urban agglomeration of Antwerpen for the road network



Note : if $R^2 < 0{,}9999$ the structure is considered as not fractal
Source: UCL, 2010

Fractal indices were chosen for characterizing urban built-up patterns. Built-up fabrics are indeed complex systems whose geometrical characteristics cannot properly be defined by tools based on Euclidean geometry (see e.g. Batty, 2005; Frankhauser, 1998). Fractal geometry reveals how an object with irregularities of many sizes may be described by examining how the number of features of one size is related to the number of similarly shaped features of the other sizes. These morphometric indices enable one to measure the shape of the urban patches, their spatial organization, their rank-size distribution as well as their spatial arrangement. Hence, we here used *surface fractal dimension* as well as *network fractal dimension* for measuring the two-dimensional geometrical complexity of built-up surfaces (the surface “footprint” of the buildings, as well as the road network).

Several methodological and technical issues were encountered and solved. The values obtained were then correlated to road accident occurrences as well as cycling practices: the objective is to show how far some built-up environments (and hence urban land use planning rules) are more prone for “generating” accidents, how far homogeneity/heterogeneity influence road safety. Statistical analyses were also performed for controlling density, distance to CBD or estimation/proxies of traffic conditions. This exercise is in line with that of Dumbaugh and Rae (2009) who, by means of examples, examine the relationship between community design and crash incidence, or that of Cho et al., 2009 that analyses perceived and actual crash risk with respect to built environment; however, they limit themselves to density and land use mixes variables while we here suggest a morphometric index.

We here confirm that for our Belgian case studies (1) *density* matters for explaining accident occurrences while cycling to work, but that built-up morphology adds an interesting explanatory component that is different from density (see e.g. results at another scale of analysis in Thomas et al., 2007). Homogeneity of the built-up surfaces (large fractal dimension) are indeed associated with more accidents whatever the density (in depth analyses have to be performed in order to explain this result) and, (2) as expected, there is a strong *centre-periphery* structure within urban agglomerations as peripheries are more heterogeneous. (3) Practically, some *data* are really missing in Belgium: we encountered many problems in getting the built-up surfaces data and we are still confronted with the problem of getting intra-urban traffic values that would enable to work with *risk* data instead of occurrences data (see also Vandenbulcke for Brussels). There is a real need for detailed traffic data within urban agglomerations. (4) If the fractal measurements are interesting in characterizing 2D urban built-up footprints, we showed that *mesoscale analyses* (corresponding here to the communes of before 1977) are more difficult to interpret and that the definition of the measurement window biases the final results and the *3D* fractal measurements would also be a real progress to be made in further analyses.

Hence these tests not only lead to interesting and promising practical results in the SHAPES project but also contribute to a better understanding of the usefulness of fractal analyses in understanding city structures and city planning (see e.g. Frankhauser, 2008).

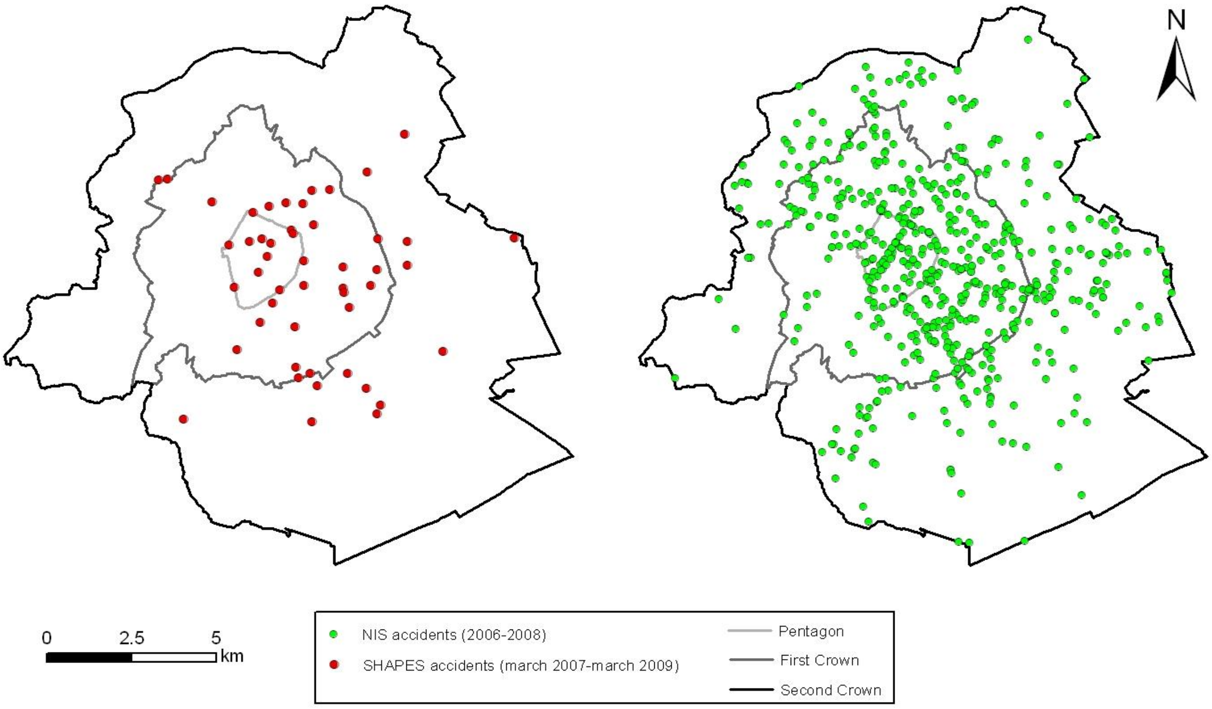
2.13. Ongoing studies – additional information

Besides the above mentioned studies we also performed additional studies. These studies are ongoing and this section of the report will be part of further publications in scientific journals. The preliminary results are briefly summarised below.

2.13.1. Bicycle accidents in Brussels: SHAPES and NIS locations

The analyses performed here are descriptive and aim at: (1) comparing the spatial distribution of bicycle accidents censussed by NIS (2006-2008) with those collected by the SHAPES survey (March 2007-March 2009), in the Brussels-Capital Region (see Figure 16); (2) identifying black spots of bicycle accidents (for both databases), and (3) exploring the spatial characteristics of accident locations (distribution, environmental and infrastructural features, etc.), as a first step before modelling the risk of having a bicycle accident in Brussels (see following section).

Figure 16: Spatial distribution of bicycle accidents in the Brussels-Capital Region



left: SHAPES data basis; right: NIS accidents

Source: NIS (2006-2008) & SHAPES questionnaires

Figure 17: Black spots of bicycle accidents in the Brussels' Central Business District (CBD), 2006-2008

Method: Network kernel densities (Equal Split Discontinuous Function), accounting for the presence of elevations (e.g. bridges)

Source: Vandenbulcke, in prep. (UCL 2011)

Black spots of bicycle accidents were detected by taking advantage of recent advances in spatial analyses on networks, using the equal-split discontinuous kernel function available in the SANET software (Okabe et al., 2009) (Figure 17). In a forthcoming research (April 2011), Cross-K functions will be performed for comparing both accident distributions (NIS and SHAPES inquiry) at different scales, and for exploring the spatial characteristics associated with the accident locations. At the scale of the Brussels-Capital Region, bicycle accidents collected in the SHAPES survey are tend to locate near those reported by NIS, and vice versa (Figure 17). Both distributions are not randomly distributed and look alike; this seems to suggest that the same explanatory processes affect both data sets even if their definition is not exactly the same. Visually, the northern part of Brussels is underreported by SHAPES.

This descriptive research is one of the first steps before modelling the risk of having an accident since it helps to select explanatory variables (having a potential influence on the occurrence of accidents) and to detect the presence of spatial autocorrelation in the distribution of bicycle accidents. Concluding that SHAPES accidents (which are unreported, since we excluded these officially reported by NIS from the SHAPES database) are spatially located near these compiled by NIS is also an interesting result, since it means that the spatial distribution of these latter (NIS) could be considered as being a proper spatial sample of all bicycle accidents (i.e. accounting for the reported and unreported ones).

2.13.2. Differences in exposure between sub trajectories – based on the SHAPES field study

2.13.2.1. Introduction

Cyclists should be encouraged to take cycling lanes where cars are not admitted. In this study we only compared trajectories where cyclists and car drivers took exactly the same road. Thus we didn't look at differences between "car-free" areas and "heavy duty" roads.

Although the SHAPES study was not originally designed to look at chosen trajectories, we still want to take the opportunity to divide trajectories in sub-trajectories in order to compare the exposure on those sub trajectories. In this paragraph we describe the results of the Brussels trajectory.

Note that this material is not published in an article but is nevertheless interesting to look at, especially from a policy makers point of view.

2.13.2.2. Materials & Methods

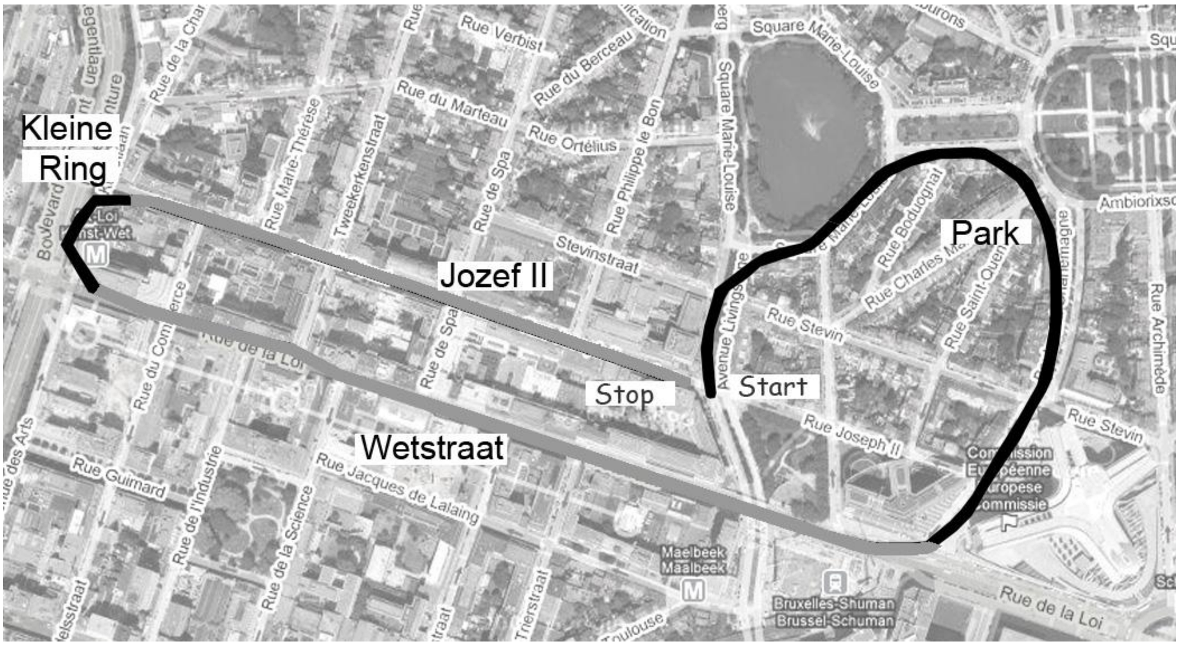
The data used are coming from the field study (thoroughly described in the previous topic) where fifty-five test persons cycled and were driven by car in three locations (Brussels, Louvain-La Neuve, Mol).

Based on the average traffic load and on the physical location of the biker relative to the road, we divide the trajectories in different sub trajectories (Table 30).

Table 30: Definition of sub trajectories in Brussels

Brussels Sub trajectories	Distance	Explanation
Quiet – on road cycling	0-875m	This is called "Park". This is quiet cycling in the city.
Very Busy - on road cycling	875-1675m	This is called "Wetstraat". This is a very busy 5 lane road (one direction) with no cycling path. This is an example of a street canyon.
Very Busy - cycling path	1675-1825m	This is called "Kleine Ring". This is a very busy 4 lane road, with two extra separate lanes on the side. It is planned in such a way that the cyclist is relatively far away from the car traffic.
Less Busy – on road cycling	1825-2400m	This is called "Jozef II". Compared to Wetstraat, this is a more quite road. This is an example of a street canyon.

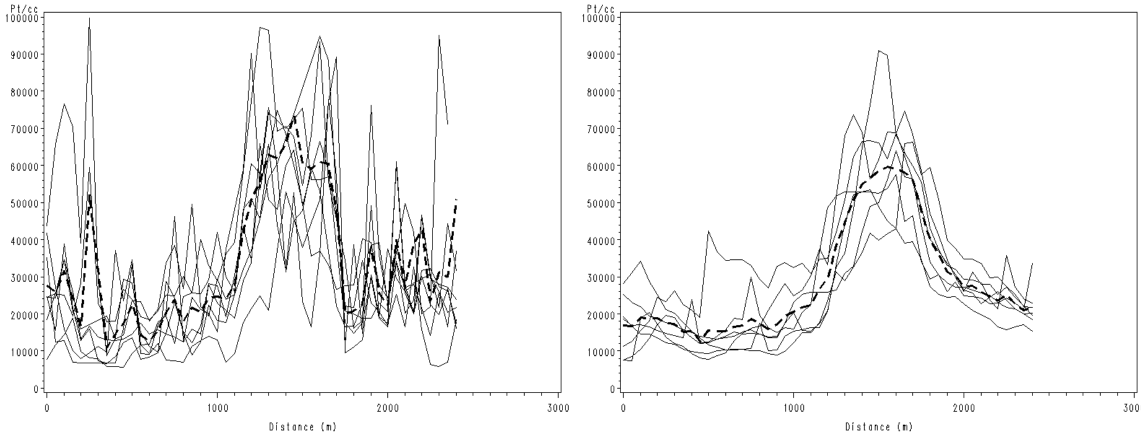
Figure 18: Trajectory in Brussels with start and stop and sub trajectories indicated



2.13.2.3. *Results*

We look at the pollutants concentrations on different parts of the trajectory. When looking at the individual pollutants measurements of the trips, we can see trends in those data. As an example we have plotted all individual measurements taken in Brussels on 4th of June 2009 in Figure 19.

Figure 19: PNC measurement for individual trajectories in Brussels on 4th of June 2009 (left: bicycle, right: car, daily average; dashed line)



In Figure 20, the day average and week average are shown and in Figure 21 all the daily averages are presented. Both Figure 20 and Figure 21 have the different sub-trajectories indicated. We clearly see that there are trends in those measurements. Therefore we analyse the sub-trajectories to test for significant differences.

Figure 20: PNC measurement in Brussels, daily average on 4th of June 2009 (full line) and average of the whole 5 day sampling period (dashed line)

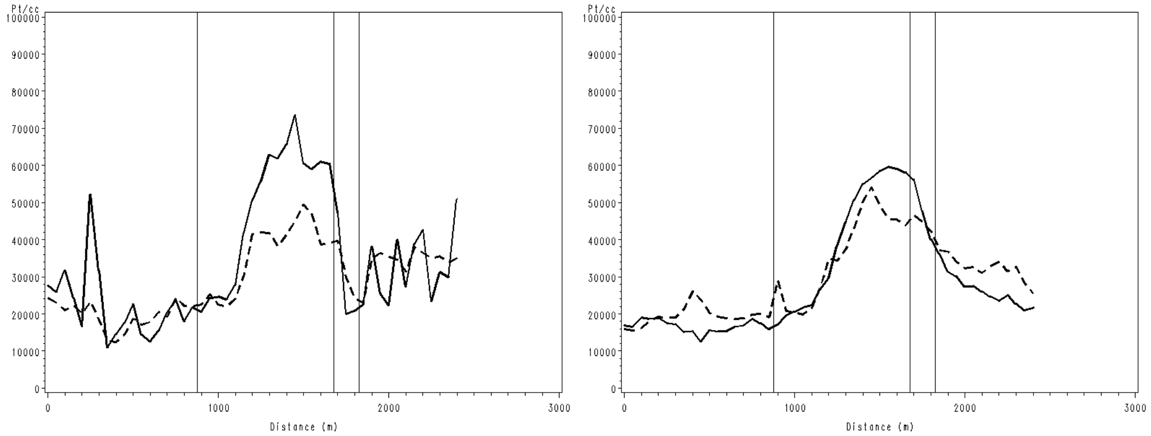


Figure 21: PNC measurement in Brussels, daily averages on from 4th till 9th of June 2009

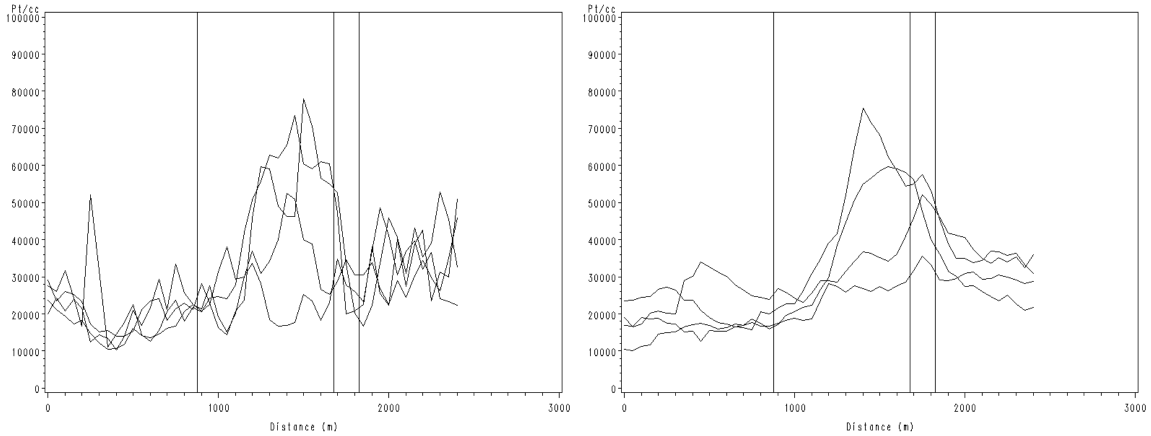
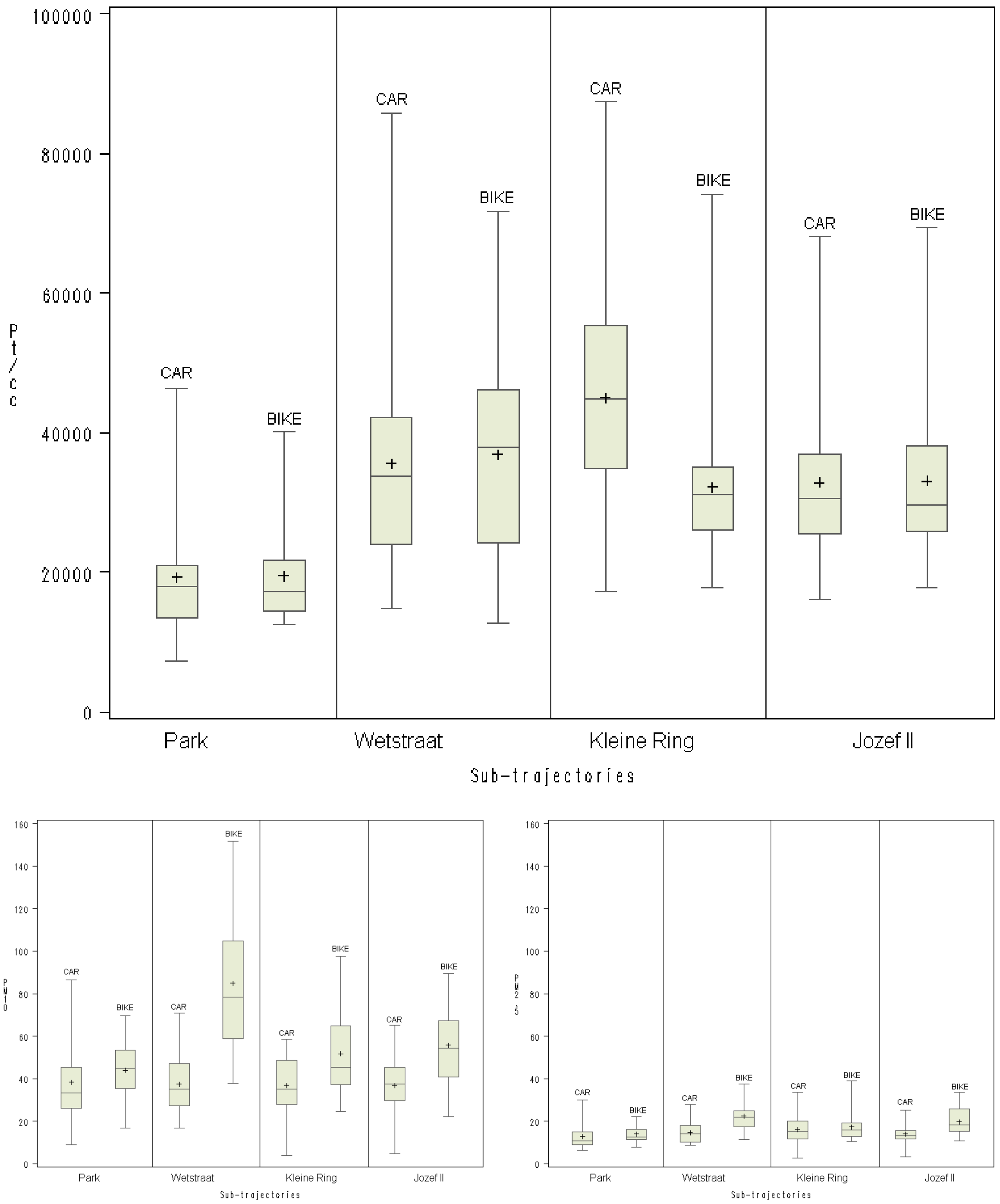


Figure 22: Boxplot per sub trajectory per vehicle type (Car, Bike) for the three different pollutants measured



first graph: PNC, second graph: PM_{10}, third graph: $PM_{2.5}$

Within a certain region, the level of PNC is significantly different in case the biker is on a quiet road compared to a busy road (compare for example Wetstraat and Park).
The level of PNC on “Kleine ring” is lower for the bicycle because the location of the cycling path is further away from the traffic. On other sub trajectories PNC is not significantly different for car and cyclist, but the levels are significantly different (lower for Park).

For $PM_{2.5}$ measured on Jozef II and Park, we see that the levels are significantly lower for the car than they are for the bike. For PM_{10}, the levels are also lower for the car (than bike) for all sub trajectories. This can be linked with the ventilation filter in the car.

2.13.2.4. Conclusion

We conclude that the exposure difference between Park and Wetstraat is almost half for all pollutants tested. This means that it is very important to deviate cyclists to roads with low traffic volumes or to car-free roads / areas, or at least build the cycling lanes as far away as possible from busy roads.

2.13.3. Effect of cycling speed and physical condition on exposure to fine particles in traffic

2.13.3.1. Introduction

In paragraph 2.8, we concluded that cyclists are much higher exposed to air pollution compared to car passengers, due to higher ventilation. The minute ventilation (VE) while riding a bicycle was found to be 4.3 times higher. We dig further into this high ratio, wondering if this is due to the speed at which the cyclists were cycling. We define optimal speed as the cycling speed that minimizes inhalation of pollution. Moreover, we investigate if there is a more "optimal" speed at which those cyclists could have cycled to reduce their ventilation and hence their exposure. Further we investigate the difference between well trained and poorly trained cyclists

2.13.3.2. Materials & Methods

For this analysis, we use the same group of cyclists as in Int Panis et al. (2010). Those cyclists cycled trajectories in three Belgian locations (Brussels, Louvain-la-Neuve and Mol). During the experiment, each test person cycled the trajectory at his/her freely chosen speed. We measured heart rate, cycling speed, minute ventilation and PNC and PM concentrations. Next to this field test, those cyclists also underwent a maximal exercise test (65 persons). During this test we measured heart rate and minute ventilation simultaneously at increasing cycling intensity. We focus on the cyclists who cycled the trajectory in Mol, because this was the only trajectory that was flat and that allows straightforward conversion between power and speed.

We start the analysis looking at the maxtest data. We convert this power into cycling speed using the method of Martin (1998), and define an optimal interval. Next to this we divide the cyclists in three groups according to their VO_2max, which is a measure used for condition. This allows us to check if we see differences depending on the physical condition of the test persons.

2.13.3.3. Results

1. Calculating an optimal speed interval

We start from the maxtest data. In order to make the results more visual, we lift out one person, called cyclist X, for which we show the results of the maxtest in detail (see Figure 23).

We convert the power into speed for all cyclists using the method of Martin et al. (1998). This conversion is shown for the same cyclist X in Figure 23. Using the maxtest with the calculated speeds attached to it, we can calculate for each cyclist the inhaled volume per km for each different level of power. For cyclist X, we find that the optimal speed is 20.1 km/h (which corresponds to 90 Watt). Note that this conversion into speed is only valid under specific road, weather and cycling conditions encountered during the field trips in Mol. Figure 23 shows the total inhaled volume for different cycling speeds for cyclist X.

Figure 23: Left: Maxtest results for cyclist X. The vertical line represents VT1, Middle: Speed vs. power for cyclist X, Right: Inhaled volume (L/km) per cycling speed for cyclist X

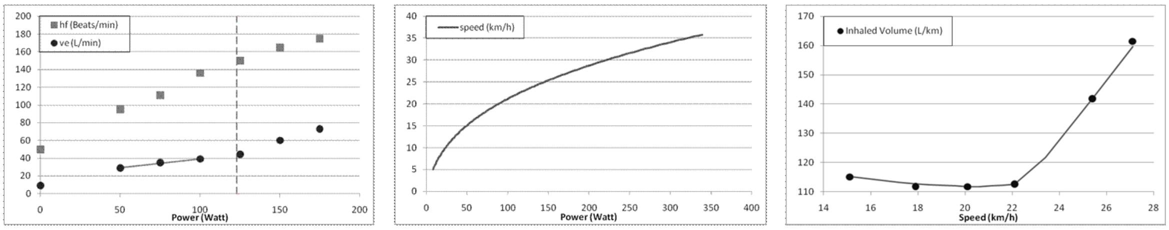


Table 31 shows the average "optimal interval" results for all cyclists, next to the field test results of Mol. When we compare for all cyclists the calculated optimal cycling speed with the field test speed in Mol, the bikers can win approximately 10.7% on inhaled litres. If they would have cycled on average 2.5 km/h slower, they would have gained on average 13.96 L/km of air intake.

Unfortunately this small reduction in air intake is not going to bring down the shocking ratio of 4.3 times as much inhaled pollution between cyclists and car passengers.
From Table 31, we can see that the optimal cycling power is about 81 - 114 Watt for men and 53 - 87 Watt for women. Which for flat road conditions, bicycle and weather like we encountered in Mol, corresponds to cycling speeds of 18.5 - 21.8 km/h for men and 15.3 - 19.2 km/h for women.

Table 31: Optimal interval descriptive statistics for the 65 cyclists

	Optimal interval derived from the maxtest data		Field test Mol results	
	men	women	men (N=7)	women (N=6)
External Power (Watt)	80.61 (114.29)	52.81 (86.56)		
VE(L/min)	33.46 (40.51)	27.27 (34.79)	47.73	38.74
Speed (km/h)	18.55 (21.83)	15.25 (19.22)	22.07	19.71
HR (Beats/min)	104.82 (116.81)	106.48 (125.48)	128.26	133.05
VE (L/km)	107.16 (111.20)	105.64 (108.89)	127.86	110.73

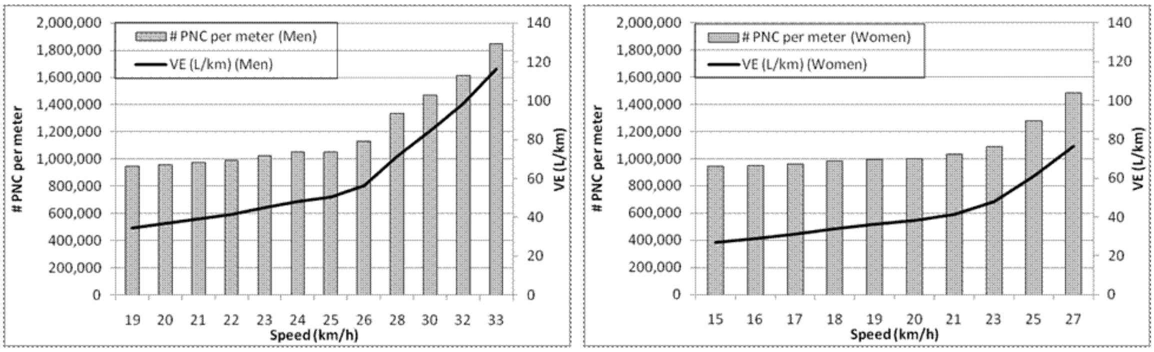
Values are mean (SD)
The two right columns show descriptive statistics from the field test in Mol

2. Heavy Physical training in polluted areas

The previous results can be set out in a graph displaying average #PNC intake per m for men and women.

Figure 24, shows that from a certain speed onwards, the total #PNC intake per meter increases greatly. So this means that it is very important not to train in highly polluted areas.

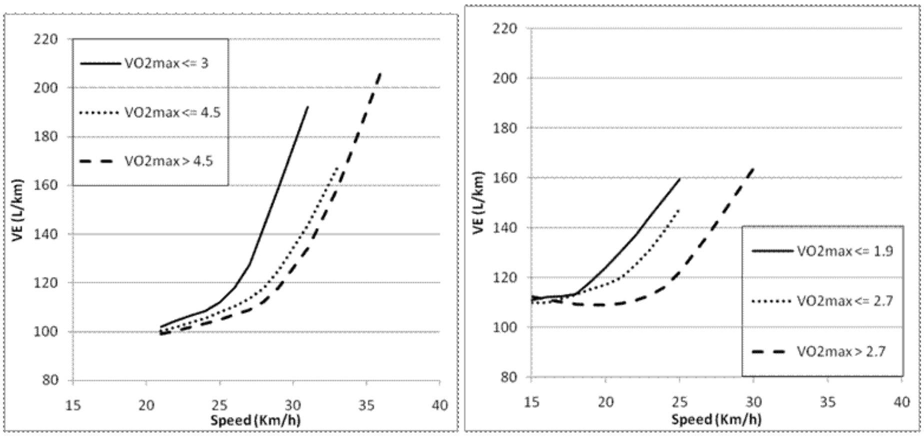
Figure 24: Men (left) and women (right) # PNC per meter profile per speed unit



3. Amelioration of condition to optimize exposure

We wonder if we can prove from our study that there is a way to optimize exposure by getting a better condition. We divide the cyclists in 3 groups based on condition (VO_2max). We do this separately for men and women. For each group we calculate an average profile of speed versus inhaled air (L/km). The results can be seen in Figure 25.

Figure 25: Men (left) and women (right) population divided in 3 VO_2max groups



A well trained biker can cycle at higher speeds while keeping the breathing rate optimal for exposure to pollution.

From Figure 25, we conclude that we don't see a significant difference in inhaled air per km between the different groups when the cycling speed is low. But the difference in physical condition between cyclists gets more significant when the cycling power or speed increases.

This means that cyclists with a good physical condition can cycle at a faster pace while using the same amount of inhaled air per km (L/km).

2.13.4. No exercise-induced increase in plasma BDNF after cycling near a major traffic road.

2.13.4.1. Introduction.

Commuting by bike has clear health enhancing effects, but regular exercise is also known to improve brain plasticity, which results in enhanced cognition and memory performance. Animal research has clearly shown that exercise upregulates Brain-Derived Neurotrophic Factor (BDNF – a neurotrophine) enhancing brain plasticity. Studies in humans found an increase in serum BDNF concentration in response to an acute exercise bout. Recently, more evidence is emerging suggesting that exposure to air pollution (such as particulate matter (PM)) is increased during commuting. Furthermore, it has been shown that enhanced exposure to PM is linked to negative neurological effects, such as neuroinflammation and cognitive decline.

Within the PM²TEN cooperation, SHAPES has carried-out an additional cross-over experiment to examine the acute effect of exercise on plasma BDNF, a marker of neurogenesis, and the potential effect-modification by exposure to traffic-related air pollution (Bos et al., 2011).

2.13.4.2. Materials and Methods

Thirty eight physically fit, non-asthmatic volunteers (mean age: 43, 26% women) performed two cycling trials, one near a major traffic road (Antwerp Ring, R1, up to 200000 vehicles/day) and one in an air-filtered room. The air-filtered room was created by omitting fine as well as ultrafine particles (Bionaire Mini Tower air purifier, MadicCleanAir, Genano 310). Particle matter was measured by GRIMM for PM10 and PM2.5 & P-TRAK for UFP.

The duration and intensity of cycling (20 minutes), as well as heart frequency and ventilation rate were kept the same for each volunteer for both cycling trials. Plasma BDNF concentrations were measured before and 30 minutes after each cycling trial.

2.13.4.3. Results and Discussion

Particle concentrations were substantially higher when cycling along the Antwerp Ring. Average concentrations of PM10 and PM2.5 were 64.9 μg/m^3 and 24.6 μg/m^3, in contrast to 7.7 μg/m^3 and 2.0 μg/m^3 in the air-filtered room. Average concentrations of UFP were 28180 particles/cm3 along the road in contrast to 496 particles/cm3 in the air-filtered room.

As expected, exercise significantly increased plasma BDNF concentration after cycling in the air-filtered room (18.30 vs. 20.93 ng/mL; p=0.036). In contrast, plasma BDNF concentrations did not increase after cycling near the major traffic route (22.14 vs. 22.25 ng/mL; p=0.94).

Although active commuting is considered to be beneficial for health, this health enhancing effect could be negatively influenced by exercising in an environment with high concentrations of PM. Whether this effect is also present with chronic exercise and chronic exposure must be further elucidated.

We derive the hypothesis that exercise-induced increase in BDNF is abolished while cycling near a busy road where the concentration of PM & UFP is much higher than in a controlled clean room. Although it is tempting to speculate that the inflammation caused by PM and the subsequent oxidative stress could be the primary explanation for these results, further research is necessary to detect the possible mechanism. This analysis will continue in 2011 and may eventually be submitted for publication.

3. POLICY SUPPORT[2]

3.1 General policy support

This section emphasizes two important general aspects to encourage commuters to shift from car to bicycle: (1) the combination of several measures, in order to achieve a comprehensive (and hence effective) package of measures; and (2) the implementation of a spatially differentiated strategy in order to opt for the best measures at a specific place.

First of all, such actions are generally not effective when implemented on their own. For instance, policies aiming at reducing the traffic volume in urbanized areas (e.g. urban toll) could have unexpected safety consequences for cyclists if they are done on their own (i.e. without traffic calming measures, traffic education, etc.), if this would case vehicles to travel faster. At worst, this may lead to adverse effects for the cyclists' safety and decrease bicycle use (Shefer and Rietveld, 1997; Noland and Quddus, 2004). Consequently, planners and policy makers should be aware that only a **combination of several measures** (promotional campaigns, improvement of cycling facilities, etc.) will really lead to an increase in cycle commuting (Pucher et al., 2010).

Second, our results also show that there are strong spatial differences in bicycle use and in its associated risks (i.e. accidents and the exposure to air pollution), which suggests that cycling policies should be **spatially differentiated**. In particular, a low casualty risk is observed in most of the large cities (i.e. in their city centres) while a higher risk is observed in their peripheries or in rural areas (which is explained by the lower number of hurdles that reduce the speed of traffic). Moreover, our findings show that commuters cycling in urban areas (e.g. in Brussels) are exposed to higher concentrations of traffic related air pollutants, compared to these cycling in rural areas or smallest towns (e.g. Louvain-la-Neuve or Mol). Variations of exposure are also very high within the same route, depending on its specific features that vary in space (e.g. traffic volume, street canyon, residential area, volume of heavy duty vehicles, street hilliness, etc.). In this case, alternatives to busy streets should be preferred in order to reduce the exposure to air traffic pollutants. Apparently many cyclists already choose routes that reduce their exposure to traffic related air pollution especially for leisure related trips (Dons et al., 2011). More importantly, a significant reduction of the motorised traffic volume in urban areas – combined with traffic calming measures - is highly recommended in order to reduce the exposure of cyclists (and also of the urban population as a whole) to air pollution and accidents. This would favour a safe mix of road users (without increasing the health risks associated to cycling), as well as it would improve the public health of urban population owing to a better air quality and a higher share of cyclists in the traffic (higher volume of physical activity). In rural areas and in the town peripheries, a continuous network of dedicated bicycle infrastructures should be implemented in order to decrease the casualty risk as well as the exposure to traffic related pollutants (especially along high-speed routes), while paying attention to the visibility of cyclists

---

[2] This section is a summary of discussions and interactions between the SHAPES team and the follow-up committee of policy makers and advocacy groups. The discussion is limited to those aspects that are related to the scientific work done in the SHAPES project. Not all points are endorsed by everyone.

(e.g. through road signs or by designing the infrastructure to improve the visibility of cyclists). Finally, the design and the continuity of bicycle networks need to be ensured at junctions / intersections with the motorised traffic (i.e. where the motorised traffic interferes with other road users, like cyclists), in order to reduce the risk of bicycle crashes. Spatially differentiated measures (urban-rural, national-local roads, junctions-sections) hence matter in the decisions.

If properly implemented (combination and spatial differentiation of measures), policies resulting in an increase in bicycle use could in turn address some of the environmental, mobility and health problems (and their associated costs) with which society is faced nowadays. Additionally, they may have sustainability and economic consequences. The lion's share of trips are currently made by car, and our society and its economic activity is becoming more and more car- and fuel-dependent. Increasing the number of commuter cyclists will mean lowering the number of drivers and reducing the dependence of the economy on fuel, which in turn will help to decrease society's vulnerability to an energy crisis.

3.2 Specific policy support

This section identifies a package of specific / targeted actions, derived from SHAPES (indicated in *italic*) and from an exhaustive review of the scientific literature (which corresponds to the 'common international knowledge'). Such actions include the 5 E's (Engineering, Education, Encouragement, Enforcement, Evaluation) and help policy makers and planners to make clear and science-based choices related to commuter cycling and transport modal shift in cities. Such choices / actions are essential to encourage bicycle use and improve its safety.

(a) Policy recommendations for increasing the modal share of cycling in commuter practices

- *Implementing land-use and urban design policies that **reduce the peri-urbanisation** in rural and peripheral areas (i.e. urban sprawl).* It is well-known that peri-urbanisation leads to more and longer commuting trips and make the commuters more car-dependent (which hence discourages walking or cycling);
- *Promoting **dense** and **mixed-use development** to reduce commuting distances and make these bikeable*, through e.g.:
    - Redevelopment of urban areas (i.e. urban regeneration);
    - Financial measures encouraging people to live in cities (e.g. through incentives in private and public companies, instead of providing company cars);
- *Making bicycle use safer through **better development, design and maintenance of cycling infrastructures** (especially in Wallonia and Brussels, where it is currently lacking compared to Flanders):*
    - *Providing safe and well-designed cycleways* (e.g. continuous, equipped with traffic lights, well maintained, directional signs). Please refer to subsection (c) for further details;
    - Providing traffic-calming areas or safe crossings for cyclists, as well as implementing routes that reduce exposure to pollutants;
    - Developing secure cycle parking facilities at transport stops (e.g. cycle lockers or guarded parking at stations);

  - *Making new cycleways/bridges as flat/gentle as possible (so that the physical effort is reduced), especially in municipalities with important slopes variations on the road network (e.g. in the provinces of Liège and Luxembourg, or in the southern part of the Brussels-Capital Region);*
  - Providing off-street short-cuts (e.g. passages through car dead-ends) and opening contraflow cycling streets in urban areas (especially in the Walloon cities, where they are currently lacking);
  - Encouraging the implementation of public bicycle sharing system in large urban areas and close to public transport (e.g. at railway and metro stations, bus and tram stops, Cambio stations, etc.);
  - Implementing car-free city centres in the main urban areas.

- **Promoting alternatives to the (company) car in private and public companies**, and trying to make these alternatives more competitive (e.g. by providing showers at workplace and (increasing) financial incentives such as a mileage allowance or a company bicycle). The regular physical activity carried out during commuting trips should be (financially) encouraged and rewarded, while the use of a company car should be discouraged or not financed if not essential for the professional activity (e.g. in the sense that bulk goods have to be carried / delivered);
- Implementing strict parking policies and ***regulating the motorised traffic*** *(especially in urban areas)* by implementing parking and road capacity limitations (through e.g. restriction of car use, increase of the parking fares, etc.), traffic calming measures, speed limitations;
- Encouraging the **integration with public transport**;
- *Including **information about the topography** on cycling maps, especially in municipalities with important slopes variations on the road network (e.g. in the provinces of Liège and Luxembourg, or in the Brussels-Capital Region);*
- Promoting the use of **electric bicycles** (especially for large distances, hilly environments and/or people over 45 years of age).

(b) Policy recommendations to reduce exposure of cyclists to air pollution

- ***Providing 'optimal paths'*** *for cyclists (i.e. alternatives to congested, polluted, sloping and/or hazardous roads)*. These paths could either be existing streets (e.g. quiet residential streets, without parking facilities) or new cycling infrastructure (e.g. constructed along the road);
- ***Reducing emissions (flows) of motorised transport / motor vehicles***
  - Banning 2-stroke mopeds from cycling lanes;
- ***Increasing distance between cyclists and motorised traffic*****, while paying attention to the visibility** (especially at the junctions between the respective networks)
  - Establish car free zones
  - Indicating back streets cycling routes;
  - Building separated cycling lanes as far from the road as possible, without blocking the visibility (between cyclists and motorists);
  - Creating advanced stop lines at intersections.

(c) Policy recommendations to reduce accident risks and costs

- **For roads with high speeds** and traffic volumes (ensuring the link between towns / urban areas), designing cycling infrastructures so that they are separate from road traffic but still allow cyclists and motorists to see each other. At junctions / intersections with such routes, paying attention to make the crossing safe for cyclists (using e.g. continuous infrastructures and dedicated traffic lights for cyclists) and reducing the speed of the motorised vehicles (using e.g. speed limits or speed bumps);
- **In urban areas** like Brussels, special attention should be paid to the bicyclist's safety when designing on-road tram railways, bridges and 'major' intersections since their presence is significantly associated with a higher risk of cycling accident
    - Making major/complex intersections more easily legible for all road users, e.g. by using the simplest possible signing or by decreasing the number of traffic lanes;
    - Whenever possible, preferring crossable reserved tram lanes – or even physically segregated lanes – to on-road railways so far as possible. It could be profitable not only to cyclists (increased safety) but also to public transport companies (increased commercial speed of vehicles);
    - Building adjacent cycling facilities on bridges – separated with physical hurdles (e.g. barriers) – in order to offset the increased accident risk caused by the reduced number and/or width of the road lanes.
- **Designing cycling facilities with great care, especially at intersections** where the risk of having an accident is quite high for cyclists
    - In the case where investments devoted to the cycling facilities are limited, planners and policy makers should primarily give priority to the provision of **high-quality infrastructure** (i.e. continuous, visible, well-kept, etc.) rather than investing in an extensive network built in haste and carelessly;
    - Designing separated cycling facilities so that motorists get some time to see the cyclists before arriving at the intersection: while approaching the intersection, the distance between the separated cycling facility and the adjacent road should be first reduced in order to favour a **visual contact** between the cyclist and the motorist, and then increased just some meters before the intersection in order to give more time for both road users to see each other and to avoid the accident. As a complement, a **sharp turning radius** (90°) combined with an **advanced green light** could also be implemented so that right-turning motorists are forced to slow down and cyclists get some advance over these latter to cross the intersection;
    - **Making (on-road) marked and suggested cycle lanes more visible** to motorists (e.g. using coloured pavements) to reduce the risk of cycling accident;
    - Installing **mirrors** at (dangerous) signalized intersections to help lorry drivers to spot cyclists riding on cycle lanes and positioned in the blind spot of the vehicle, as well as to remind them to check their mirrors.
    - Keep implementing **advanced stop zones** for cyclists to reduce the risk of accident associated with blind spot (since such zones put cyclists into the view of motorists);
    - Avoiding building (separated) cycling facilities in the 'door zone' of parked vehicles (< 0.8m) as much as possible, since the cyclists are exposed to a higher

    risk of accident due to the opening of car doors. A greater **safety margin/distance** (> 0.8m, or even > 1.2m) is here strongly supported in order to improve the bicyclist's safety;
  - Keep implementing streets where **contraflow cycling** is permitted in urban areas, but using warning measures at their entrance (i.e. at the intersection) to inform motorists they could come face to face with cyclists.
- *Special attention should be paid to **traffic education**, particularly: (1) for specific age groups for which the accident risk is higher; (2) in Wallonia where the accident risk is generally higher than in the rest of the country mainly due to lower densities and higher speed habits*. Examples of measures:
  - disseminating information (e.g. through safety campaigns);
  - improving driver training for motorists, in order to make them more mindful / respectful of commuter cyclists;
  - teaching safe cycling practices to commuters and schoolchildren (= future commuters), in order to encourage them to cycle and to make them more aware of the risks associated to a bicycle crash (e.g. with a lorry);
- Promoting bikepooling in order to increase self-confidence of unexperienced cyclists who worry about their personal security;
- Encouraging more actions towards preventive and protective approaches. For instance, preventive measures (e.g. lights, reflectors, safety jackets, etc.) should be taken / encouraged to make the cyclists more conspicuous in the traffic and to decrease the risk of having an accidents. Protective measures (such as helmets) will decrease the severity of the (head) injuries if a collision occurs;
- Increasing the **police presence** (and hence making it more visible);
- **Increasing the perceived risk of being punished** (following an illegal/dangerous manoeuvres or violations of the traffic regulations);
- **Improving official registration of bicycle accidents** (and bicycle use) as demonstrated in the SHAPES project to permit better targeted actions;
- **Avoid overtaking behaviour of motorists in 30 km/h zones**;
- Improving **cleaning in general and de-icing of the bicycle network** during winter.

(d) Policy recommendations to improve / enhance / increase the health benefits of commuter cycling

- **Encouraging campaigns and mass events** organised by public authorities and advocacy groups, in order to underscore the health benefits as well as the improvements in the quality of life associated with bicycle use; This includes health improvements both for the people taking up cycling but also for the rest of the population (e.g. through reduction of noise and air pollution in the cities)
- **Encouraging people** (and more particularly commuters) **to cycle at least 3 times per week**, with a travel time equal or higher to 30 minutes per day (possibly separated in two 15-minutes bouts). This could improve the physical and mental health of the population, which in turn could increase the productivity at work
- Special attention should be paid at encouraging women to use the bicycle as a mode of transport. This can be done by mass events and by increasing the traffic safety, as women are more averse to risk than men.

4. DISSEMINATION AND VALORISATION

4.1. PUBLICATIONS

4.1.1. Published in International peer reviewed journals

Aertsens J, de Geus B, Vandenbulcke G, Degraeuwe B, Broekx S, De Nocker L, Liekens I, Mayeres I, Meeusen R, Thomas I, Torfs R, Willems H, Int Panis L, Commuting by bike in Belgium, the costs of minor accidents, Accident Analysis & Prevention, 42, 2010, 2149-2157

Int Panis L, de Geus B, Vandenbulcke G, Willems H, Degraeuwe B, Bleux B, Mishra V, Thomas I, Meeusen B, Exposure to particulate matter in traffic: A comparison of cyclists and car passengers, Atmospheric Environment, 44, 2010, 2263-2270

Int Panis L, 2011. Cycling: Health Benefits and Risks. Environ Health Perspect 119(3): doi:10.1289/ehp.1103227

Jacobs L, Nawrot TS, de Geus B, Meeusen R, Degraeuwe B, Bernard A, Sughis M, Nemery B, Int Panis L, Subclinical responses in healthy cyclists briefly exposed to traffic-related air pollution: an intervention study, Environmental Health 2010, 9:64; doi:10.1186/1476-069X-9-64

Vandenbulcke G, Thomas I, de Geus B, Degraeuwe B, Torfs R, Meeusen R, Int Panis L, Mapping bicycle use and the risk of accidents for commuters who cycle to work in Belgium, Transport Policy, 16 (2), 2009, 77-87.

Vandenbulcke G, Dujardin C, Thomas I, de Geus B, Degraeuwe B, Meeusen R, Int Panis L, Cycle commuting in Belgium: Spatial Determinants and 'Re-Cycling' Strategies, Transportation Research Part A: Policy and Practice, 45 (2), 2011, 118-137.

4.1.2. Articles in popular journals without peer-review (2008-2010 incomplete)

DAGBLADEN		
Brommers zijn grotere vervuilers dan trucks	Metro	29/02/2008
Dubbel zoveel fijn stof in auto op snelweg als fiets in Wetstraat	De Standaard	11/03/2008
Chauffeurs slikken dubbel zoveel fijn stof als fietsers	De Morgen	11/03/2008
Twee keer meer fijn stof in auto dan op fiets	BVL	11/03/2008
Dubbel zoveel fijn stof in auto als op fiets	GVA	11/03/2008
Troquer la voiture pour le vélo, prudent ?	Le Soir	11/3/2008
Dubbel zoveel fijn stof in auto op snelweg dan op fiets in Westraat	Nieuwsblad	11/03/2008
Meer last van fijn stof in auto	Het Laatste Nieuws	11/03/2008
Dubbel zoveel fijn stof in auto als op fiets	HLN.be	11/03/2008
Bromfiets stoot meeste ultrafijn stof uit	BVL	10/04/2008
Bromfietsen schaden fietsers het meest	Het Laatste Nieuws	10/04/2008
Tussen fietspad en rijweg hoort gracht of berm	Het Nieuwsblad	30/04/2008

Fietsen in de smog	De Standaard	30/04/2008
Fietsen door vervuilde lucht	De Standaard	30/04/2008
Marathonparcours Peking bevat tot 3x meer fijn stof dan Wetstraat	De Morgen	21/06/2008
Meettoestellen voor fijn stof	De Nieuwe Gazet	12/07/2008
Le vélo : une solution miracle aux problèmes de l'auto-maux-bilité ?	Le Soir	14/08/2008
Bruggelingen en Gentenaars fietsen het liefst naar het werk	De Morgen	8/10/2008
Il y a de la vie dans les bouchons	Le Soir	17/10/2008
Fietsers melden weinig ongelukken	De Standaard	15/05/2009
Vrouwen staan minder vaak in de file	GVA	27/05/2010
Toxic cities mock 'healthy' cycle riding Sunday Times, 30.05.2010	Sunday Times	31/05/2010
Fietsen in de stad is ongezond	Nieuwsblad	31/05/2010
Fietsers ademen massa's fijn stof in	Nieuwsblad/Standaard	31/05/2010
Les cyclistes respirent plus de particules fines que les autres	La Libre	31/05/2010
Fietsen is niet ongezond	Nieuwsblad	1/06/2010
Fietsen is (on)gezond	BVL	1/06/2010
Fietsers ademen meer fijn stof in dan chauffeurs	Laatste Nieuws	1/06/2010
Fietsers ademen tot 9 keer meer fijn stof in dan chauffeurs	De Morgen	1/06/2010
Les particules fines empoisonnent les cyclistes	Le Soir	1/06/2010
A vélo on inhale plus de polluants	La Capitale	1/06/2010
Fietsen in Limburg gezonder dan in rest van Vlaanderen	Nieuwsblad	1/06/2010
Fietsen blijft gezond ondanks fijn stof	Metro	1/06/2010
Rouler à vélo parmi les autos est-il bon pour la santé?	La Libre Belgique	2/06/2010
Veilig op de fiets?	Weekkrant	9/06/2010
Fiets meet slechte lucht	Standaard	13/07/2010
Fiets meet luchtkwaliteit	Laatste Nieuws	13/07/2010
Fiets meet fijn stof in Gentse lucht	Laatste Nieuws	13/07/2010
Fiets meet luchtkwaliteit	Streekkrant Leuven/Hasselt	4/08/2010
Minder schadelijke stoffen in de lucht	BVL	11/08/2010
De onstuitbare opmars van het stalen ros	De Morgen	21/08/2010

TIJDSCHRIFTEN		
Face aux particules fines : mieux vaut être sur son vélo que dans son auto !	Santé & Environnement, Inter Environnement Wallonie,	12/03/2008
On demande des cyclistes	Equilibre	1/05/2008
Le vélo au quotidien, c'est bon pour la santé. Oui, mais…	Ville à vélo n°137 juillet-août 2008	07/08/2008

Fietsers gezocht	Bodytalk	1/09/2008
Bon pour la santé le vélo?	Ma Santé	1/11/2009
Meer fijn stof voor fietsers	Brussel deze week	3/06/2010

WEBSITES		
Brommers vuiler dan vrachtwagens	Belga (NL/FR)	28/2/2008
Bromfiets stoot meeste ultrafijn stof uit	Nieuwsblad.be	10/04/2008
Bromfiets stoot meeste ultrafijn stof uit	standaard.be	10/04/2008
Bromfiets stoot meer fijn stof uit dan vrachtwagen	demorgen.be	10/04/2008
Bromfiets stoot meeste ultrafijn stof uit	hbvl.be	10/04/2008
Bromfiets stoot meeste ultrafijn stof uit	gva.be	10/04/2008
Bromfiets stoot meeste ultrafijn stof uit	Nieuwsblad.be	10/04/2008
Bromfiets stoot meer fijn stof uit dan vrachtwagen	hln.be	10/04/2008
Bromfiets stoot meeste ultrafijn stof uit	hetvolk.be	10/04/2008
Les vélomoteurs sont des pollueurs en particules ultrafines	actu24.be	10/04/2008
Les vélomoteurs sont des pollueurs en particules ultrafines	webmember.be	10/04/2008
Les vélomoteurs sont des pollueurs en particules ultrafines	advalvas.be	10/04/2008
Les vélomoteurs sont des pollueurs en particules ultrafines	levif.be	10/04/2008
Les vélomoteurs sont des pollueurs en particules ultrafines	7sur7.be	10/04/2008
Les vélomoteurs sont des pollueurs en particules ultrafines	rtl.be	10/04/2008
Les vélomoteurs sont des pollueurs en particules ultrafines	dhnet.be	10/04/2008
Les pistes cyclables devraient être plus éloignées des routes.	www.7sur7.be	02/05/2008
Concentratie aan fijn stof tien maal hoger in spitsuur	streekkrant.be	4/02/2009
Fietsen langs drukke wegen is ongezond	deredactie.be	31/05/2010
Fietsers ademen massa's fijn stof in	msn/knack/standaard/skynet.be	31/05/2010
Fietsers ademen tot 5 keer meer fijn stof in	gva/zita/hbvl/vandaag.be	31/05/2010
Fietsers ademen tot 9 keer meer fijn stof in dan chauffeurs	demorgen/hln.be	31/05/2010
Les cyclistes respirent plus de particules fines que les autres	lacapitale/lalibre/sudpresse/levif/dhnet/lameuse/rtbf	31/05/2010
Fietsers ademen massa's fijn stof in	wielertoerist.be	31/05/2010
Fiets niet aan de kant zetten vanwege fijn stof	knack.be	31/05/2010
Fietsen toch gezond ondanks fijn stof	standaard/nieuwsblad	31/05/2010
Fietsersbond over fijn stof: en toch is fietsen gezond	hln.be	31/05/2010
Fietsen toch gezond, ondanks fijn stof	De Standaard.be	31/05/2010
Fietsen langs drukke wegen is ongezond	De Redactie	31/05/2010

Fietsers slikken veel meer fijn stof	Brussel Nieuws	31/05/2010
Cyclister inhalerer mest i den partikelfyldte storbyluft	e-pages.dk	6/06/2010
Viajar en bicicleta es sano	BBC MUNDO	1/06/2010
Fietsen is (on)gezond	mojawyspa.co.uk	1/06/2010
Cyclists inhale high levels of traffic pollution	ec.europa.eu/environment	1/06/2010
Meetfiets brengt Gentse luchtkwaliteit in kaart	nieuwsblad/standaard/knack/skynet /mns	12/07/2010
Gent gebruikt meetfiets om de luchtkwaliteit in kaart te brengen	gent.be	12/07/2010
Meetfiets brengt Gentse luchtkwaliteit in kaart	vt4.be	12/07/2010
Meetfiets brengt Gentse luchtkwaliteit in kaart	tombalthazar	12/07/2010
Meetfiets brengt Gentse luchtkwaliteit in kaart	ademloos.be	13/07/2010

PERSBERICHTEN		
Brommers vuiler dan vrachtwagens	Belga (NL/FR)	28/02/2008
SHAPES	Federaal Wetenschapsbeleid	03/03/2008
Test meet dubbel zoveel fijn stof in auto als op fiets	Belga (NL/FR)	10/03/2008
Bromfiets stoot meeste ultrafijn stof uit	Belga	9/04/2008
Les vélomoteurs sont des pollueurs en particules ultrafines	Belga	9/04/2008
Gezondheidsrisico's van fijn stof en verkeerslawaai	VITO	18/11/2008
Fietsers gezond	Body Talk	1/09/2008
De la voiture au vélo, sans risque	Louvain 178	4/2009
Fietsers ademen massa's fijn stof in	Belga	31/05/2010
Fietsers ademen massa's fijn stof in: Fietsen toch gezond	Belga	31/05/2010
Particules fines : les cyclistes en première ligne ?	GRACQ, Communiqué de presse	2/06/2010
Meetfiets brengt Gentse luchtkwaliteit in kaart	Belga	12/07/2010
A chacun sa politique d'aménagement	Imagine 82	11/2010

RADIO & TV		
Fijn stof	VOLT	23/01/2008
Luc Int Panis SHAPES	Radio 1	10/03/2008
Luc Int Panis SHAPES	Het nieuws/Terzake	10/03/2008
Fijnstof metingen fiets/bromfiets (Luc Int Panis)	één/Radio 1	9/04/2008
Fijnstof uitstoot (Luc Int Panis)	Canvas (Terzake)	9/01/2009
Fijn stof (Luc Int Panis)	Radio 1	9/02/2010
Fijn stof bij fietsers (Luc Int Panis)	Radio 1/Q music/VTM	31/05/2010
Mondmaskers voor Fietsers (Luc Int Panis)	VRT Radio 1	9/5/2011

4.2. PRESENTATIONS

4.2.1. Presentations at International congresses

Vandenbulcke, G., Thomas, I., de Geus B, Int Panis L, Meeusen R.
Modelling the risk of having a bicycle accident in Brussels: a Bayesian approach
BIVEC-GIBET Transport Research Day 2011, 25/5/2011, Namur (Belgium).

Vandenbulcke, G., Thomas, I., de Geus B, Int Panis L, Meeusen R.
A Bayesian approach to modelling the risk of having a bicycle accident – The case of Brussels (Belgium)
NECTAR Conference, 18-20/6/2011, Antwerp (Belgium).

Thomas, I., Frankhauser, P., Vandenbulcke, G.
Road safety while cycling: do meso-scale built-up morphologies matter? Fractal evidences from Antwerp (Belgium)
NECTAR Conference, 18-20/6/2011, Antwerp (Belgium).

Thomas, I.
Navettes à vélo et santé : un peu de géographie
Mobility and Health Day, 17/9/2010, Brussels, Belgium

de Geus B, Vandenbulcke G, Int Panis L, Torfs R, Degraeuwe B, Thomas I, Meeusen R.
Measuring Air Pollution during Commuter Cycling
3rd ICPAPH, 5-8/05/2010, Toronto, Canada

Vandenbulcke G, Dujardin C, Thomas I, Int Panis L, Torfs R, Degraeuwe B, Meeusen R, de Geus B.
Cycling to work: modeling meso-scale spatial variations
16th ECQTG Conference, 4-8/9/2009, Maynooth, Ireland

Vandenbulcke G, Dujardin C, Thomas I, Int Panis L, Torfs R, Degraeuwe B, Meeusen R, de Geus B.
Cycling to work: modeling meso-scale spatial variations within Belgium
1st Transatlantic NECTAR Conference, 18-20/6/2009, Arlington, USA

Vandenbulcke G, Dujardin C, Thomas I, Int Panis L, Torfs R, Degraeuwe B, Meeusen R, de Geus B.
Determinants of bicycle use and accident risks for cyclists. A geo-statistical approach for Belgium.
BIVEC-GIBET Transport Research Day 2009 (3rd Edition), 27/5/2009, Brussels, Belgium

Bleux N, de Geus B, Degraeuwe B, Vandenbulcke G, Torfs R, Thomas I, Meeusen R, Int Panis L.
Exposure of cyclists to air pollution: a pilot study
EAC, 2009, Karlsruhe, Germany

de Geus B, Vandenbulcke G, Int Panis L, Torfs R, Degraeuwe B, Thomas I, Meeusen R.
A new survey on accident risks and injuries in commuter cyclists in Belgium
14th Annual Congress of the European College of Sport Science, 24-27/06/2009, Oslo, Norway

de Geus B, Vandenbulcke G, Int Panis L, Torfs R, Degraeuwe B, Thomas I, Meeusen R.
Commuter cycling and the influence of air pollution
2009 Annual Conference of the ISBNPA, 17-20/06/2009, Estoril, Portugal

de Geus B, Vandenbulcke G, Int Panis L, Torfs R, Degraeuwe B, Thomas I, Meeusen R.
A new survey on accident risks and injuries in commuter cyclists in Belgium
15th Velo-City conference, 12-15/08/2009, Brussels, Belgium

Vandenbulcke G, Dujardin C, Thomas I. et al.
Cycling to work: modelling spatial variations within Belgium

48th European Congress of the Regional Science Association International (ERSA 2008 Colloquium), 27-31/8/2008, Liverpool, United Kingdom

Int Panis, L., Bleux, N., Torfs, R., Mishra, V., de Geus, B., Meeusen, R., Vandenbulcke, G., Thomas, I.
Exposure of cyclists to ultra fine particles.
9th Highway and Urban Environment Symposium, 9-11/6/2008, Madrid, Spain

de Geus B, Vandenbulcke G, Thomas I, Torfs R, Int Panis L, Meeusen R.
Cycling to work: impact on health. SHAPES project
2nd International Congress on Physical Activity and Public Health, 13-16/4/2008, Amsterdam, the Netherlands

Vandenbulcke G, Thomas I. et al.
Spatial analysis of bicycle use and risk when commuting in Belgium
34th Colloquium Vervoersplanologisch Speurwerk (CVS 2007), 22-23/11/2007, Antwerpen, Belgium

16th Velo-City conference, 22-25/006/2010, Copenhagen, Denmark

5. ACKNOWLEDGEMENT

The work reported in this final report was financed by the Belgian Science Policy under the Science for Sustainable Development program (project n°: SD/HE/03). VITO provided additional financial resources from its strategic research budget (N9792).
The authors wish to thank Emmanuèle Bourgeois gestionnaire de programme at Belspo en the entire follow-up committee of the SHAPES project for their advices. They are also grateful to dr Ir Nico Smets for creating the online registration system and to Didier Antoine (Walloon Ministery for Equipment and Transports), Marjan Beelen (UA), Roger Bivand (NHH), Isabelle Chalanton (Belgian Institute for Road Safety), David Dabin (Federal Police), Claude Hannecart (BRIC), Alison Kelly, Sylvain Lassarre (INRETS), Vincent Lorant (UCL), Patrick Meyfroidt (UCL), Roland Nardi (National Institute for Statistics), Atsu Okabe (University of Tokyo), Dominique Peeters (UCL), Marie Poupé (Brussels Institute for Environment Management), Isabelle Reginster (IWEPS), Chantal Roland (Brussels-Capital Region Ministery), Nicolas Sougnez (UCL) and Ann Verhetsel (UA) for the data as well as for their advices. Special thanks goes to the colleagues from the BLITS laboratory who helping with the maximal exercise tests: Dr. Luk Buyse, Dr. Guido Van Gent, Lieve De Hauvere, Bart Roelands, Kevin De Pauw, Kristel Knaepen, Vinciane Fontenelle, Inne Aerts, Elke Cumps and Maaike Goekint. Rob Babers and Nico Bleux are thanked for their help with the development of the instruments for mobile air quality measurements, organisation of the field measurements and analysis of the fine particle data. Inge Bos contributed to the analysis of BDNF. The authors acknowledge inspiring discussions on the health impacts of cycling with Yves De Weerdt, Moniek Zuurbier and Ari Rabl.

Last but not least, we thank all the participants who filled out the diaries, questionnaires and participated in the field measurements.

6. REFERENCES

Aertsens J, de Geus B, Vandenbulcke G, Degraeuwe B, Broekx S, De Nocker L, Liekens I, Mayeres I, Meeusen R, Thomas I, Torfs R, Willems H, Int Panis L, 2010. Commuting by bike in Belgium, the costs of minor accidents, Accident Analysis & Prevention, 42, 2149-2157

Ainsworth BE, Haskell WL, Whitt MC, Irwin ML, Swartz AM, Strath SJ, O'Brien WL, Bassett DR Jr., Schmitz KH, Emplaincourt PO, Jacobs DR Jr., Leon AS, 2000. Compendium of physical activities: an update of activity codes and MET intensities. Med Sci Sports Exerc 32(9 Suppl), S498-S504.

Aultman-Hall, L., Hall, F. , 1998. Ottawa-Carleton commuter cyclist on- and off-road incident rates. *Accident Analysis and Prevention* 30 (1), 29-43.

Aultman-Hall, L., Kaltenecker, M.G. , 1999. Toronto bicycle commuter safety rates. *Accident Analysis and Prevention* 31 (6), 675-686.

Batty M. , 2005 , *Cities and Complexity: Understanding Cities with Cellular Automata, Agent-Based Models, and Fractals*. Cambridge, Massachusetts, The MIT Press.

Beusen B., Broekx S., Denys T., Beckx C., Degraeuwe B., Torfs R., Int Panis L., 2009. Using on-board logging devices to study the long-term impact of an eco-driving course. Transportation Research D 14, 514-520.

Bickel, P., Friedrich, R., Burgess, A., Fagiani, P., Hunt, A., De Jong, G., Laird, J., Lieb, C., Lindberg, G., Mackie, P., Navrud, S., Odgaard, T., Ricci, A., Shires, J., Tavasszy, L., 2006. Proposal for Harmonised Guidelines; HEATCO, deliverable 5; February 2006; p. 193.

Bolstad, W.M. , 2007. *Introduction to Bayesian Statistics* (2nd Edition). New Jersey: Wiley.

Bos I., Jacobs, L., Nawrot TS., de Geus B., Torfs R., Int Panis L., Degraeuwe, B., Meeusen R., 2011. No exercise-induced increase in serum BDNF after cycling near a major traffic road. Neuroscience Letters Accepted Manuscript Number: NSL-11-720. available online: 17-JUN-2011 DOI information: 10.1016/j.neulet.2011.06.019

BRSI (Belgian Road Safety Institute) , 2006. Cycling accidents in an urban context: three years (1998–2000) of casualties along the regional roads of the Brussels capital region; available online at: http:/www.ibsr.be (in French/Dutch)

BRSI (Belgian Road Safety Institute, Observatory for road safety) , 2008. *Evolution de la sécurité routière en Belgique (2000-2006)*. IBSR/BIVV, Brussels.

BRSI (Belgian Road Safety Institute, Observatory for road safety) , 2009. *Rapport thématique Cyclistes: Accidents de la route impliquant des cyclistes (2000-2007)*. IBSR/BIVV, Brussels.

CBS (Statistics Netherlands). 2008. Available: http://www.cbs.nl/en-GB/menu/themas/verkeer-vervoer/cijfers/default.htm.

Chalupa D., Morrow, P., Oberdörster G., Utell M., Frampton M., 2004. Ultrafine Particle deposition in subjects with asthma. Environmental Health perspectives 112(8), 879-882.

Chapman, L. , 2007. Transport and climate change: a review. Journal of Transport Geography 15, 354-367.

Christie, N., Cairns, S., Towner, E., Ward, H., 2007. How exposure information can enhance our understanding of child traffic ‘‘death leagues’’. Injury Prevention 13, 125–129.

Cho G., Rodriguez D., Khattak A. , 2009 The role of the built environment in explaining relationships between perceived and actual pedestrian and bicyclist safety. Accident Analysis and Prevention, 41, 692-702.

Cryer C, Langley JD, 2006. Developing valid indicators of injury incidence for “all injury”. Inj Prev 12, 202–207

Daigle C., Chalupa D., Gibb F., Morrow P., Oberdörster G., Utell M., Frampton M., 2003. Ultrafine particle deposition in humans during rest and exercise. Inhalation Toxicology 15, 539-552.

de Geus, B., Van Hoof, E., Aerts, I., Meeusen, R. , 2008. Cycling to work: influence on indexes of health in untrained men and women in Flanders. Coronary heart disease and Quality of life. Scan J Med Sci Sports 18, 498-510.

de Geus, B., Joncheere, J., Meeusen R. , 2009. Commuter cycling: effect on physical performance in untrained men and women in Flanders. Minimum dose to improve indexes of fitness.Scan J Med Sci Sports 19, 179-187.

de Hartog J, Boogaerd H, Nijland H, Hoek G, Do the health benefits of cycling outweight the risks?, Environmental Health perspectives, 2010

de la Bruhèze, A., 1999. Bicycle use in practice and policy during the twentieth century: similarities and differences of bicycle use in Amsterdam, Eindhoven, Enschede, Southeast-Limburg, Antwerp, Manchester, Copenhagen, Hanover en Basel. Dutch Ministry of Transport, Public Works and Water Management. [in Dutch]

de Nazelle A, Nieuwenhuijsen M, 2010. Integrated health impact assessment of cycling, Occup Environ Med 2010;67:76-77 doi:10.1136/oem.2009.050054

De Nocker, L., Int Panis, L., Mayeres, I., 2006. De externe kosten van personenvervoer. Mobiliteit en (groot)steden beleid. Vlaams Wetenschappelijk Economisch Congres - VWEC - 2006 - Editor: Macharis Cathy VWEC, (Belgium), (5)381-415. (in Dutch)

De Mol, J., Lammar, P., 2006. Half the road victims are not reported in the statistics. Verkeersspecialist 130, 15–18. Available online at: http://www.isaweb.be/bestanden/Artvsp130.pdf (in Dutch).

Dhillon PK, Lightstone AS, Peek-Asa C, Kraus JF., 2001. Assessment of hospital and police ascertainment of automobile versus childhood pedestrian and bicyclist collisions. Accid Anal Prev. 33 (4), 529–37.

Dons, E., Int Panis, L., Van Poppel, M., Theunis, J., Willems, H., Torfs, R., Wets, G., 2011. Impact of time-activity patterns on personal exposure to black carbon. Atmospheric Environment, 45, 3594-3602.
Doom, R., Derweduwen, P., 2005. Optimalisatie van de verkeersongevallenstatistieken. Onderzoekscontracten CP/02/392, CP/F1/391 (eindrapport) voor BIVV, CDO en het Federaal Wetenschapsbeleid (in Dutch).

Dumbaugh, E., Rae, R. , 2009. Safe Urban Form: Revisiting the Relationship Between Community Design and Traffic Safety. Journal of the American Planning Association 75 (3), 309-329.

Elvik, R., 2009. The non-linearity of risk and the promotion of environmentally sustainable transport. Accident Analysis and Prevention 41, 849–855

Elvik, R.,Vaa,T. (Eds.), 2004. The Handbook of Road Safety Measures. Elsevier, Amsterdam. ISBN: 0 08 044091 6; 1078 pp.

EPA, Environmental Protection Agency; 2006; The Cost of Illness Handbook; prepared for the Office of Pollution Prevention and Toxics, under the direction of Nicolaas Bouwes, by Abt Associates, Cambridge, Massachusetts

EU (European Union), 2003. Energy and transport in figures. European Commission, Directorate-General for Energy and Transport, Brussels. Available online at: < http://gasunie.eldoc.ub.rug.nl/root/2004/2999175/>

ERSO (European Road Safety Observatory) , 2006. *Pedestrians & Cyclists*. Retrieved 4-17-2011 from www.erso.eu.

Frankhauser P., 1998. The fractal approach: a new tool for the spatial analysis of urban agglomerations, *Population* 4, 205–240.

Frankhauser P., 2008. Fractal geometry for measuring and modelling urban patterns. Springer, The Dynamics of Complex Urban Systems, 241-243.

Gatersleben, B., Appleton, K.M. , 2007. Contemplating cycling to work: Attitudes and perceptions in different stages of change. Transportation Research Part A 41, 302-312.

Geertman, S.C.M., Ritsema van Eck, J.R. , 1995. GIS and models of accessibility potential: an application in planning. *International Journal of Geographical Information Systems* 9 (1), 67-80.

Geurs, K.T., Ritsema van Eck, J.R. , 2001. *Accessibility measures: review and applications*. RIVM Report 408505 006. National Institute of Public Health and the Environment, Bilthoven. Available from: http://www.rivm.nl/bibliotheek/rapporten/408505006.html

Geurs, K.T., van Wee, B. , 2004. Accessibility of land-use and transport strategies: review and research directions. *Journal of Transport Geography* 12, 127-140.

Giles-Corti B, Timperio A, Bull F, Pikora T, 2005. Understanding physical activity environmental correlates: increased specify for ecological models. *Exercise and Sports Sciences Reviews* 33 (4), 175-181.

Goldberg AS, Moroz L, Smith A,Ganley T, Injury Surveillance in Young Athletes. A Clinician's Guide to Sports Injury Literature, Sports Med 2007; 37 (3): 265-278

Hague Consulting Group, 1990. The Netherlands' 'Value of Time' Study: Final Report, The Hague.

Hendriksen IJM, Zuiderveld B, Kemper HCG, Bezemer PD. Effect of commuter cycling on physical performance of male and female employees. Med Sci Sports Exerc 2000: 32: 504-510

Hubert, J-P., Toint, P. , 2002. La mobilité quotidienne des belges. Namur: Presses universitaires de Namur

Int Panis L., Broekx S., Liu R., 2006. Modelling instantaneous traffic emission and the influence of traffic speed limits. Science of the Total environment 371, 270–85.

Int Panis, L., De Nocker, L., Cornelis, E., Torfs, R. , 2004. An uncertainty analysis of air pollution externalities from road transport in Belgium in 2010. *Science of the Total Environment* 334-335, 287-298.

Int Panis L, de Geus B, Vandenbulcke G, Willems H, Degraeuwe B, Bleux B, Mishra V, Thomas I, Meeusen B, Exposure to particulate matter in traffic: A comparison of cyclists and car passengers, Atmospheric Environment, 44, 2010, 2263-2270

Int Panis L, 2011. Cycling: Health Benefits and Risks. Environ Health Perspect 119(3): doi:10.1289/ehp.1103227

Jacobs L, Nawrot TS, de Geus B, Meeusen R, Degraeuwe B, Bernard A, Sughis M, Nemery B, Int Panis L, Subclinical responses in healthy cyclists briefly exposed to traffic-related air pollution: an intervention study, Environmental Health 2010, 9:64; doi:10.1186/1476-069X-9-64

Jacobsen, P.L. , 2003. Safety in numbers: more walkers and bicyclists, safer walking and bicycling. Injury Prevention 9, 205-209.

Jensen, M. , 1999. Passion and heart in transport – a sociological analysis on transport behaviour. Transport Policy 6, 19-33.

Kéry, M. , 2010. *Introduction to WinBUGS for ecologists. A Bayesian approach to regression, ANOVA, mixed models and related analyses*. Amsterdam: Academic Press.

Kim, J.K., Kim, S., Ulfarsson, G.U., Porrellon, L.A., 2007. Bicyclist injury severities in bicycle–motor vehicle accidents. Accident Analysis and Prevention 39, 238–251.

Koop, G. , 2003. *Bayesian Econometrics*. West Sussex: Wiley Publishers.

Li, L., Zhu, L., Sui, D.Z. , 2007. A GIS-based Bayesian approach for analyzing spatial-temporal patterns of intra-city motor vehicle crashes. *Journal of Transport Geography* 15 (4), 274-285.

Luyten, S., Van Hecke, E., 2007. De Belgische stadsgewesten 2001. Statistics Belgium – Working Paper n°14. FPS Economy (Direction for Statistics and Economic Information), Brussels.

Martens, K. , 2004. The bicycle as a feedering mode: experiences from three European countries. Transportation Research Part D 9, 281-294.

Martens, K. , 2007. Promoting bike-and-ride: The Dutch experience. Transportation Research Part A 41, 326-338.McClintock and Cleary, 1996

McClintock, H., Cleary, J. , 1996. Cycle facilities and cyclists' safety – experience from Greater Nottingham and lessons for future cycling provision. *Transport Policy* 3, 67-77.

Mérenne-Schoumaker, B.,Van der Haegen, H., Van Hecke, E., 1999. General socio-economic survey of the Belgian population and for the housing (1991): Work and school migrations. National Institute for Statistics (NIS) and Belgian Federal Science Policy Office, Brussels. [in French]

MF (Mobile Flanders), 2002. Flemish Cycling Plan. Department Mobility and Public Transport. Available online at: < http://www.mobielvlaanderen.be/vtf/vtf01.php?a=14> [in Dutch]

Miaou, S-P., Song, J.J., Mallick, B.K. , 2003. Roadway traffic crash mapping: A space-time modeling approach. *Journal of Transportation and Statistics* 6 (1), 33-57.

Nawrot T., Torfs R., Fierens F., De Henauw S., Hoet P., Van Kersschaever G., De Backer G., Nemery B., 2007. Stronger associations between daily mortality and fine particulate air pollution in summer than in winter: evidence from a heavily polluted region in western Europe. J Epidemiol Community Health 61, 146-149.

NIS (National Institute for Statistics), 2001a. National house hold survey on mobility. Realization and results. Research contract MD/13/036, FUNDP-GRT-LV-UIA-IW-INS. Belgian Federal Science Policy Office, Brussels. Available online at: /http://www.belspo.be/belspo/fedra/proj.asp?l=en&COD=MD/DD/18S (in French).

NIS (National Institute for Statistics), 2001b. Downloadable files. Available online at: /http://statbel.fgov.be/figures/download_fr.aspS (in French/Dutch).

NIS (National Institute for Statistics), 2009. FOD Economie, Algemene directie Statistiek en Economische Informatie, Publicatiecode: S220.A1N/2007,. Available online at: http://statbel.fgov.be/nl/binaries/Totale%20en%20belgische%20bevolking%20op%201-1-2007%20NL_tcm325-75739.pdf.

Noland, R.B., Quddus, M.A. , 2004. A spatially disaggregate analysis of road casualties in England. *Accident Analysis and Prevention* 36, 973-984.

O'Donoghue R., Gill L., McKevitt R., Broderick B., 2007. Exposure to hydrocarbon concentrations while commuting or exercising in Dublin. Environment International 33, 1–8.

OECD, 2010. http://stats.oecd.org/Index.aspx?DataSetCode=CSP2010

Oja P, Mänttäri A, Heinomen A, Kukkonen-Harjula K, Laukkanen R, Pasanen M, Vuori I. Physiological effects of walking and cycling to work. Scan J Med Sci Sports 1991: 1: 151-157

Okabe, A., Satoh, T. and Sugihara, K. , 2009. A kernel density estimation method for networks, its computational method and a GIS-based tool. *International Journal of Geographical Information Science*, 23(1), 7-32.

Osler T, Rutledge R, Deis J, et al. ICISS: An international classification of disease-9 based injury severity score. J Trauma 41:380 –388; 1996

Parkin, J., Wardman, M., Page, M. , 2007. Models of perceived cycling risk and route acceptability. Accident Analysis and Prevention 39 (2), 364-371.

Parkin, J., Wardman, M., Page, M. , 2008. Estimation of the determinants of bicycle mode share for the journey to work using census data. Transportation 35 (1), 93-109.

Pei, X., Wong, S.C., Sze, N.N. , 2010. A joint-probability approach to crash prediction models. *Accident Analysis and Prevention* 43 (3), 1160-1166.

Pope C., Ezzati M., Dockery D., 2009. Fine-Particulate Air Pollution and Life Expectancy in the United States. N Engl J Med 360(4), 376–386.

Pucher J, Dijkstra L, Making walking and cycling safer: Lessons from Europe, Transportation Quarterly, 54(3), 2000, 25-50

Pucher, J., Dijkstra, L. , 2003. Promoting safe walking and cycling to improve public health: Lessons from the Netherlands and Germany. Public health matters 93 (9), 1509-1516.

Pucher, J., Dill, J., Handy, S. , 2010. Infrastructure, programs, and policies to increase bicycling: An international review. *Preventive Medicine* 50, 106-125.

Pucher, J., Komanoff, C., Schimek, P. , 1999. Bicycling renaissance in North America? Recent trends and alternatives policies to promote bicycling. Transportation Research Part A 33, 625-654.

Rank J., Folke J., Jespersen P., 2001. Differences in cyclists and car drivers exposure to air pollution from traffic in the city of Copenhagen. Sci Total Environment 279, 131–6.

Räsänen, M., Summala, H. , 1998. Attention and expectation problems in bicycle-car collisions: an in-depth study. *Accident Analysis and Prevention* 30 (5), 657-666.

Rietveld, P. , 2001. Biking and walking: The position of non-motorized transport modes in transport systems. Tinbergen Institute Discussion Paper TI 2001-111/3.

Rietveld, P., Daniel, V. , 2004. Determinants of bicycle use: do municipal policies matter? Transportation Research Part A 38, 531-550.

Robinson RL, Safety in numbers in Australia: more walkers and bicyclists, safer walking and bicycling, Health Promotion Journal of Australia 2005;16(1):47-51

Rodgers, G.B. , 1997. Factors associated with the crash risk of adult bicyclists. *Journal of Safety Research* 28 (4), 233-241.

Rodríguez, D.A., Joo, J. , 2004. The relationship between non-motorized mode choice and the local physical environment. Transportation Research Part D 9, 151-173.

Rowe, R.D, Schulze, W.D., Breffle, W.S, 1996. A Test for Payment Card Biases. Journal of environmental Economics and Management 31, 178-185.
Rutledge R, Osler T, Emery S, et al. The end of the Injury Severity Score (ISS) and the Trauma and Injury Severity Score (TRISS): ICISS, an International Classification of diseases, Ninth Revision based prediction tool, outperforms both ISS and TRISS as predictors of trauma patient survival, hospital charges, and hospital length of stay. J Trauma 44:41– 49; 1998

Service Public de Wallonie , 2008. La CeMathèque : le plan Escargot – un soutien financier aux communes pour favoriser les modes alternatifs de déplacement. Namur.SSTC, 2001

Shefer, D., Rietveld, P. , 1997. Congestion and safety on highways: towards an analytical model. *Urban Studies* 34 (4), 679-692.

Stone, M., Broughton, J., 2003. Getting off your bike: cycling accidents in Great Britain in 1990–1999. Accident Analysis and Prevention 35 (4), 549–556.

Thomas, I., Frankhauser, P., De Keersmaecker, M.-L. , 2007). Fractal dimension versus density of the built-up surfaces in the periphery of Brussels. *Papers in Regional Science*, 86 :2, 287-307.

Van Hecke, E. , 1998. Actualisering van de stedelijke hiërarchie in België. Tijdschrift van het Gemeentekrediet van België, No. 205, 45–76.

van Wijnen J., Verhoeff A., Jans H., van Bruggen M., 1995. The exposure of cyclists, car drivers and pedestrians to traffic-related air pollutants. Int Arch Occup Environ Health 67, 187–93.

Vandenbulcke, G., Steenberghen, T., Thomas, I. , 2007. *Accessibility indicators to places and transports*. Belgian Science Policy and FPS Mobility & Transports, Brussels. Available from: http://www.mobilit.fgov.be/data/mobil/accessibilityfe.pdf

Vandenbulcke G., Thomas I., de Geus B., Degraeuwe B., Torfs R., Meeusen R., Int Panis L., 2009. Mapping bicycle use and the risk of accidents for commuters who cycle to work in Belgium, Transport Policy, Volume 16, Issue 2, 77-87, DOI: 10.1016/j.tranpol.2009.03.004.

Vandenbulcke G., Dujardin C., Thomas I., de Geus B., Degraeuwe B., Meeusen B., Int Panis L., 2011. Cycle commuting in Belgium: Spatial determinants and `re-cycling' strategies, Transportation Research Part A: Policy and Practice, Volume 45, Issue 2, 118-137, DOI: 10.1016/j.tra.2010.11.004.

Veisten K, Saelensminde K, Alvaer K, Bjørnskau T, Elvik R, Schistad T, Ytterstad B, Total costs of bicycle injuries in Norway: correcting injury figures and indicating data needs, Accid Anal Prev, 2007; 39(6): 1162-9

Verhetsel, A., Thomas, I., Van Hecke, E., Beelen, M. , 2007. Monografie van het woonwerkverkeer in Belgïe. Belgian Science Policy and FPS Mobility and Transports, Brussels.

Ware JE, Kosinski M, Kelle SD, SF-36 physical and mental health summary scales: a user's manual. Boston MA: The Health Institute, 1994

Witlox, F., Tindemans, H. , 2004. Evaluating bicycle-car transport mode competitiveness in an urban environment. An activity-based approach. World Transport Policy and Practice 10 (4), 32-42.

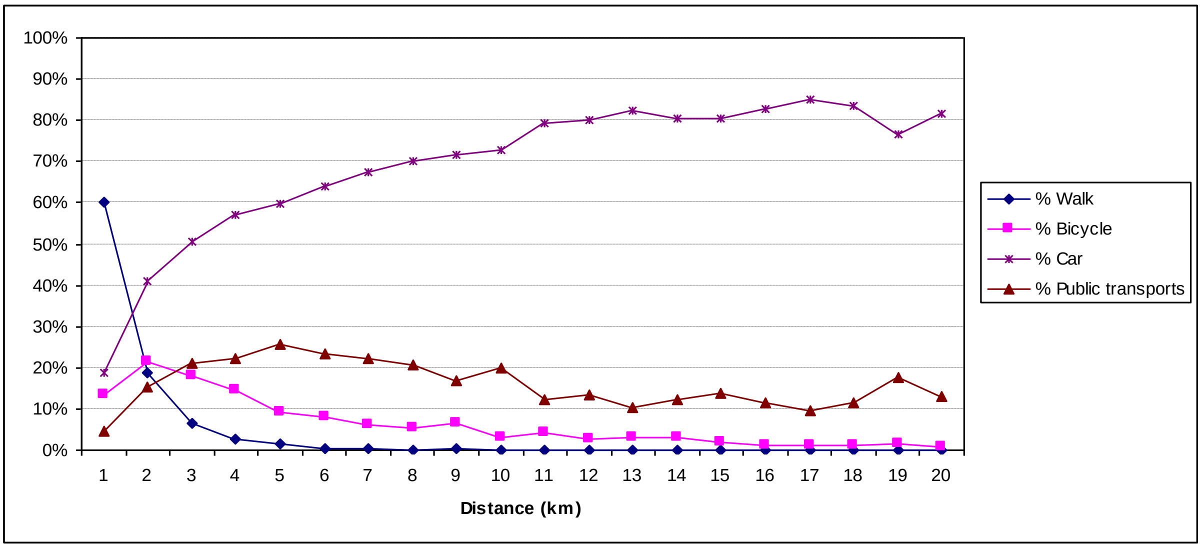
World Health Organization (WHO) , 2002. 30 minutes for a healthy life span. Press release EURO/07/02, Copenhagen and Rome.

Zuurbier M., Hoek G., van den Hazel P., Brunekreef B., 2009. Minute ventilation of cyclists, car and bus passengers: an experimental study. Environmental Health 8:48.

ANNEX 3: ADDITIONAL TABLES AND FIGURES

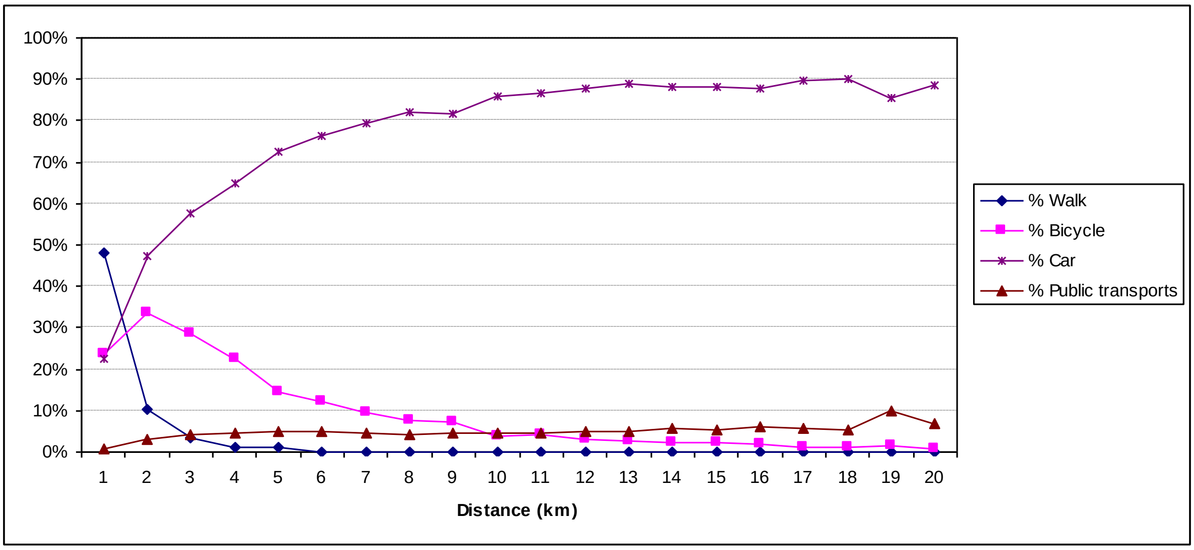
1.1. Mapping bicycle use and the risk of accidents for commuters who cycle to work in Belgium

Figure 26: Large cities as destinations (*H₁*) – Shares of transport modes as a function of the commuting distance (2001)



Source: Vandenbulcke et al., 2009

Figure 27: Regional cities as destinations (*H₂*) – Shares of transport modes as a function of the commuting distance (2001)



Source: Vandenbulcke et al., 2009

Table 32: The means of variables in communes with different ranks in the urban hierarchy

Description	Source	H_1	H_2	H_3	H_4	H_5	H_6	H_7	H_8
% of commuter who cycle	2001 Census	4.65	8.89	7.11	5.22	5.59	4.83	4.73	2.16
Median income (in euro)	NIS (2001)	17010	18733	19135	19247	18855	19282	19789	19287
Population density (inhabitants/km²)	NIS (2001)	2460	912	945	399	556	1545	342	160
Jobs density (jobs/km²)	NIS (2001)	1877.25	374.16	367.58	115.43	146.29	484.53	62.38	31.86
% of economically active people below 25 years of age	2001 Census	10.57	10.90	10.54	10.74	10.22	10.10	9.89	9.39
% of economically active people above 54 years of age	2001 Census	7.71	6.96	7.34	6.91	7.08	7.13	6.84	6.73
% of economically active people having only primary schooling	2001 Census	7.38	6.06	6.12	5.95	6.04	6.17	5.92	5.63
% of economically active people having a school leaving certificate as their highest qualification	2001 Census	52.51	54.22	56.01	58.64	58.56	56.83	57.86	58.11
% of economically active people having a university degree	2001 Census	40.11	39.72	37.87	35.41	35.40	37.00	36.22	36.26
% of households without children	2001 Census	77.64	73.94	73.08	70.69	70.27	70.75	68.43	67.28
% of households that do not own any bicycles	NIS (2001)	57.65	35.82	32.95	35.00	33.93	35.60	27.76	33.48
% of households that do not own a car	NIS (2001)	37.78	25.99	22.34	21.09	20.26	21.06	15.56	15.14
% of households estimating they have low-quality cycling facilities in their	2001 Census	68.89	59.59	59.46	66.87	63.68	63.32	63.73	73.82

neighbourhood									
Average daily commuting distance (kilometres)	2001 Census	17.31	19.40	19.26	22.86	22.05	20.56	22.86	27.02
Annual number of bicycle thefts per 100 cyclists	Federal Police (2000-2002)	15.82	13.78	13.91	13.64	12.16	11.08	6.89	5.31
Average number of casualties (cyclists) per 100,000 bicycle minutes (i.e. total minutes spent commuting by bicycle)	NIS (2002-2005) and 2001 Census	0.02	0.03	0.04	0.07	0.04	0.05	0.06	0.13
% of surface area dedicated to public services (e.g. council offices, schools)	NIS (2004)	4.52	2.09	1.77	0.87	1.12	1.78	0.53	0.21
% of surface area which is built up	NIS (2004)	78.00	45.45	36.67	26.45	30.66	39.95	24.04	14.38
Number of vehicles (million) by kilometre of regional road	FPS Mobility and Transports (NIS, 2000)	5.69	4.12	3.87	2.56	3.26	3.79	2.94	1.99
Number of vehicles (million) by kilometre of municipal road	FPS Mobility and Transports (NIS, 2000)	0.90	0.46	0.30	0.20	0.23	0.27	0.13	0.08
% of inhabitants declaring they are in a bad state of health	2001 Census	29.44	25.01	24.31	23.60	25.22	24.77	23.29	24.74

H_1: large cities; H_2: regional cities; H_3: small cities, well equipped; H_4: small cities, moderately equipped; H_5: small cities, poorly equipped; H_6: non-urban communes, well-equipped; H_7: non-urban communes, moderately equipped; H_8: non-urban communes, poorly equipped.

1.2. Cycle commuting in Belgium: Spatial determinants and 're-cycling' strategies

Table 33: Variable used: description, units of measurement and data sources

Group	Variable	Description	Units	Source
DEPENDENT VARIABLE				
	Share of commuter cyclists (y)	Share of commuter cyclists	Percent	2001 Census
INDEPENDENT VARIABLES				

Demographic data	Active men	Percentage of active people that are men	Percent	NIS (2001b)
	Age 1 (< 25 years)	Percentage of active people being less than 25 years of age	Percent	2001 Census
	Age 2 (45-54 years)	Percentage of active people being between 45 and 54 years of age	Percent	2001 Census
	Age 3 (> 54 years)	Percentage of active people being more than 54 years of age	Percent	2001 Census
	Young children	Percentage of active households (i.e. with one or more active parents) having one or more young children (i.e. being between 0 and 5 years of age)	Percent	Own computation from 2001 Census
Socio-economic data	Education 1 (primary degree)	Percentage of active people having a primary degree as highest qualification	Percent	2001 Census
	Education 2 (secondary degree)	Percentage of active people having a secondary degree as highest qualification	Percent	2001 Census
	Education 3 (higher/university degree)	Percentage of active people having a higher/university degree as highest qualification	Percent	2001 Census
	Income	Median income	Euro (.10^3)	NIS (2001b)
	Bad health	Percentage of inhabitants feeling they have a bad state of health	Percent	2001 Census
	Car availability	Percentage of households that do not own any car	Percent	NIS (2001b)
Environmental and policy-related data	Population density	Population density	Inhabitants/km²	NIS (2001b)
	Jobs density	Jobs density	Jobs/km²	NIS (2001b)
	Commuting distance	Average commuting distance of active people, by day	Kilometre	2001 Census
	Minimum distance to the closest town	Minimum network distance to the closest town. Town = large town, regional town, and small town which is well-equipped (see Vandenbulcke et al. (2009) for more details)	Kilometre	Vandenbulcke et al. (2007)
	Share of commuters, d < 10 km	Percentage of commuters that live no further than 10 km from their workplace	Percent	2001 Census
	City size	Urban hierarchy of Belgian communes (largest towns = 1; regional towns = 2; …; smallest towns = 8)	0-8	Van Hecke (1998)
	Urbanisation	Percentage of urban area in the commune	Percent	NIS (2004)
	Forests	Percentage of forest area in the commune	Percent	NIS (2004)
	Agriculture	Percentage of agricultural area in the commune	Percent	NIS (2004)
	Public services	Percentage of surface dedicated to public services (e.g. administrations, schools) in the commune	Percent	NIS (2004)
	Recreational areas	Percentage of surface dedicated	Percent	NIS (2004)

		to recreational activities (e.g. parks, sport terrains) in the commune		
	Slopes	Mean slope along the municipal road network (excepted motorways and main express roads)	Degree	Own computation from EROS data (2002)
	Cycling facilities unsatisfaction	Percentage of households estimating they have low-quality cycling facilities located in their neighbourhood	Percent	2001 Census
	Bicycle theft	Average annual number of bicycle thefts	Bicycle thefts	Federal Police (2000-2002)
	Risk of bicycle theft	Average annual number of bicycle thefts, divided by the total number of cyclists in the commune	Number of bicycle thefts per cyclist	Own computation from Federal Police data (2000-2002) and 2001 Census
	Accident risk	Average number of victims (cyclists) of accidents per 100,000 bicycle minutes (i.e. travelled on a bicycle)	Victims (cyclists) per 100,000 minutes	Own computation from NIS data (2002-2005) and 2001 Census
	Air quality	Mean concentration of particulate matter (PM10)	Microgram/m³	Based on IRCEL-CELINE data (2000-2005)
	Traffic volume 1 (regional network)	Number of vehicles-km (.10^6) by kilometre of regional road	10^6 vehicles-km by kilometre of network	FPS Mobility and Transports, 2000
	Traffic volume 2 (municipal network)	Number of vehicles-km (.10^6) by kilometre of municipal road	10^6 vehicles-km by kilometre of network	FPS Mobility and Transports, 2000

Table 34: Regression coefficients for the spatial regime specification (ML estimation)

	ML with spatial regimes and heteroskedasticity correction	
	North (Flanders)	*South (Wallonia & Brussels)*
Intercept	2.3084*	4.3095***
	[0.0000]	[0.0000]
Lag coefficient (r)	0.5362***	
	[0,5097]	
DEMOGRAPHIC VARIABLES		
Working men	0.0296**	0.0008
	[1.0246]	[0.0288]
Age 2 (45-54)	-0.0417**	-0.0205***
	[-0.5854]	[-0.3007]
Age 3 (> 54)†	-0.1074	-0.0680
	[-0.1317]	[-0.0867]
Young children	-0.0365***	-0.0247***
	[-0.4372]	[-0.3306]
Socio-economic variables		
Education 3 (degree)†	-0.0968	-0.3132***
	[-0.2104]	[-0.6862]
Income	0.0311*	-0.0027
	[0.3824]	[-0.0307]
Bad health	-0.0098	-0.0146**
	[-0.1274]	[-0.2481]
ENVIRONMENTAL AND POLICY-RELATED VARIABLES		
Commuting distance	-0.0165***	-0.0047*
	[-0.2061]	[-0.0765]
Town size	-0.1146***	-0.0361***
	[-0.4539]	[-0.1483]
Slope†	-0.1931**	-0.1972***
	[-0.1145]	[-0.1966]
Dissatisfaction with cycling facilities	-0.0052***	-0.0045***
	[-0.1666]	[-0.2227]
Accident risk†	-0.7632***	-0.1489***
	[-0.1047]	[-0.0493]
Air pollution	0.0138***	-0.0054
	[0.2551]	[-0.0956]
Traffic volume 2 (municipal/local roads)†	-0.2357	-0.4521**
	[-0.0306]	[-0.0700]
N	589 (N_{North} = 308; N_{South} = 281)	
Log likelihood	93.923	
Akaike information criterion (*AIC*)	-123.846	
Schwarz information criterion (*SIC*)	16.264	

* Significant at the 90% level
** Significant at the 95% level
*** Significant at the 99% level
Standardized regression coefficients in brackets
† variables logarithmically transformed
ML: Maximum Likelihood

1.3. SHAPES online registration system

1.3.1. General questionnaire

Table 35: Flow chart for the in- and exclusion of the participants

left e-mail on the server	1849				
did not respond to the first e-mail	377				
in- and exclusion criteria participants					
age? <18 and > 65	23				
paid job outside home? yes	116				
commuter cycling <2x/week?	101				
living in Belgium? no	29				
included participants filling out **GQ**	**1203**				
filled out > 1 TD	**1187**				
in- and exclusion criteria questionnaires	**RQ**	**PQ**			
reported an accident? yes	933	293			
correctly reported? yes	924	286			
accident? yes	227	286			
recreational cycling? no	190	234			**CQ**
acute injury? yes	185	**223**	→	filled out CQ? yes	**118**
corporal and/or material damage?					
material (NO_INJ)	45	49			13
corporal + material	73	60			
corporal	67	114			
only bruise or cramp? yes (LIGHT_I)	71	104			57
only bruise or cramp? no	**69**	**70**			
1 injury	54	62			
2 injuries	3	6			
3 injuries	12	1			
short term (<9 months consequences; ABI_ST)					41
long term (>9 months consequences; ABI_LT)					7

numbers in Bold indicate the number of participants that were enrolled in the respective studies
GQ: General Questionnaire; PQ: Prospective Questionnaire; CQ: Cost Questionnaire ; TD: travel diary

1.4. Minor bicycle accidents in commuter cyclists in Belgium: a prospective study

Table 36: Comparison between the total study population and those who were involved in an accident (PQ)

	total study population (N = 935)			injured participants (PQ) (N = 62)		
	men + women	**men (68%)**	**women (32%)**	**men + women**	**men (73%)**	**women (27%)**
age (year)	39.7 (10.2)	40.7 (10.3)	37.7 (9.7)	37.7 (9.43)	38.2 (9.0)	36.5 (10.6)
length (cm)	175.7 (10.3)	179.8 (6.6)	167.3 (6.1)	177.0 (9.5)	181.5 (7.1)	166.8 (5.8)
weight (kilograms)	72.1 (12.3)	76.9 (10.2)	61.8 (8.4)	72.0 (12.5)	78.0 (9.3)	58.1 (5.9)
BMI (km/m^2)	23.2 (3.1)	23.8 (2.9)	22.1 (2.8)	22.8 (2.6)	23.6 (2.2)	20.9 (2.3)
education						
lower	11.6	13.0	5.8	7.7	7.9	7.1
higher	88.4	87.0	94.2	92.3	92.1	92.9
job status						
students (with paid job)	1.8	0.9	3.7	3.8	0.0	14.3
employee	49.5	48.5	53.2	40.4	28.9	71.4
functionary	25.7	25.7	26.4	28.8	36.8	7.1
freelance	5.5	5.8	5.1	3.8	0.0	7.1
executive	9.1	11.0	5.4	17.3	23.7	0.0
workman (blue collar)	2.4	3.1	1.0	1.9	2.6	0.0
other	4.9	4.9	5.1	3.8	5.3	0.0
perceived health						
very good	42.6	42.5	44.1	44.2	36.8	64.3
good	49.2	50.2	48.5	46.2	55.3	21.4
average	6.9	6.9	7.1	9.6	7.9	14.3
poor	0.3	0.3	0.3	0.0	0.0	0.0
living situation						
with partner	71.8	77.6	61.7	63.5	76.3	71.4
without partner	27.2	22.4	38.3	36.5	23.7	28.6

values are mean (SD) or a % of total
lower education: primary/secondary; higher education: high-school/college/university

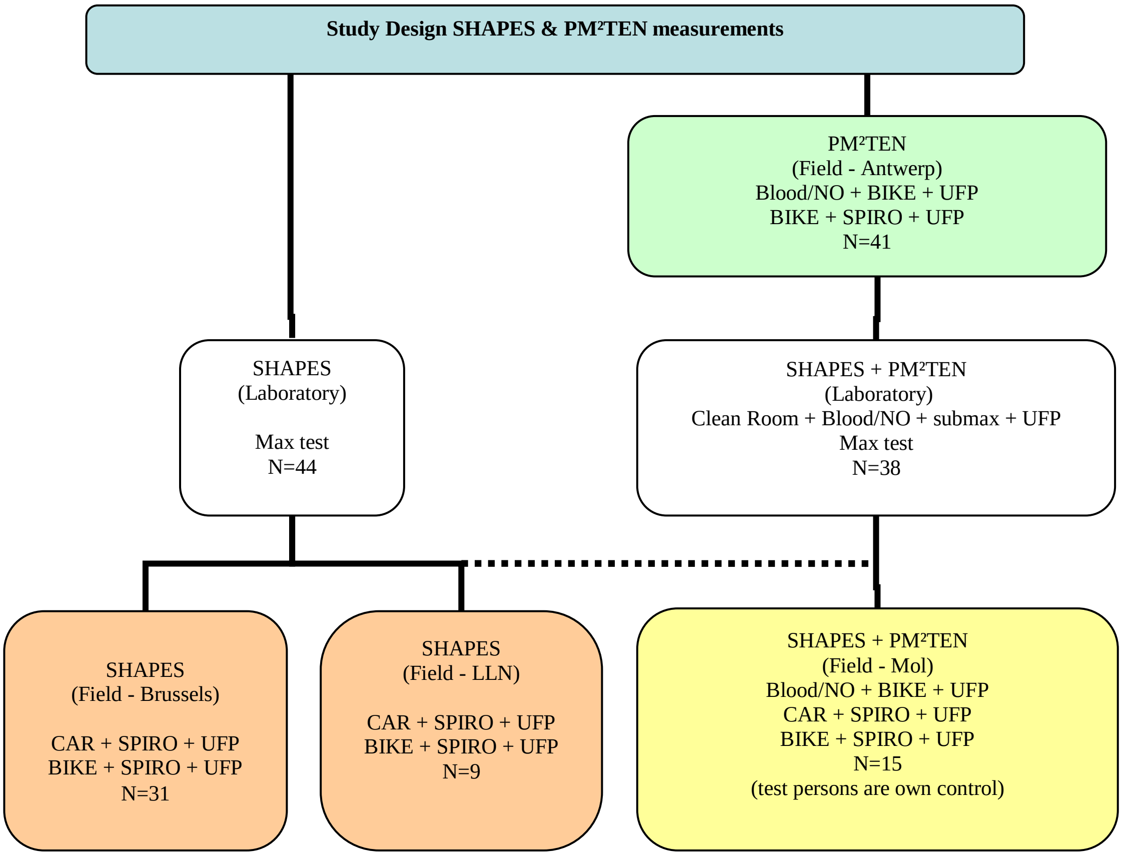
1.5. Commuting by bike in Belgium, the costs of minor accidents

Table 37: Accident related costs (in euro) – average cost per respondent (Aertsens et al, 2010)

Type of accident	**ABI_LT**	**ABI_ST**	**LIGHT_I**	**NO_I**
Direct Costs	**696**	**132**	**78**	**64**
Medical Costs	**369**	**43**	**13**	**0**
Doctor visits	53	11	5	-
Specialist visits	60	12	1	-
Physio-therapist visits	159	4	4	-
Ambulance intervention	9	2	0	-
Medication and bandages	87	15	3	-
Non medical costs	**327**	**89**	**65**	**64**
Bike repair	30	16	38	61
Value of old bike if replaced	54	0	0	3
Damaged clothes	71	20	21	0
Damaged helmet	25	7	3	0
Other material damage	129	32	3	1
Police intervention	18	14	0	0
Indirect costs	**4760**	**555**	**122**	**46**
Productivity loss	**4616**	**537**	**104**	**37**
Late arrival at work	69	12	16	19
Period unable to work	3923	450	58	0
Lower productivity	624	76	29	19
Leisure time loss	**144**	**18**	**18**	**9**
Repairing and replacing	34	5	12	8
Personal medical care	31	9	8	0
Actions for refund	54	4	6	2
Lower efficiency householding	19	3	1	0
Late at home (day of accident)	5	3	3	7
Intangible costs	**3761**	**122**	**84**	**135**
Permanent invalidity	1018	-	-	-
WTP to avoid pain	1885	19	60	0
WTP to avoid psych. conseq.	858	103	24	135
Other costs	**131**	**11**	**39**	**49**
costs for 3rd parties	131	11	39	49
Total costs	**9348**	**820**	**322**	**295**
Confidence intervals (95%)	3764-17425	588-1089	244-411	157-476

1.6. Exposure to particulate matter in traffic: A comparison of cyclists and car passengers

Figure 28: Study design of the SHAPES and PM^{2}TEN field measurements



1.7. Modelling the risk of having a bicycle accident in Brussels

Table 38: Risk factors used – description, units of measurement and data sources

Variable	Definition	*X* values	Units	Data source
Infrastructure				
Bridge[a]	1 if the accident/control occurred on a bridge (with safeguards on both sides), 0 otherwise	-	-	Own digitalization and computation, from CCBR (UrbIS 2007-2008, GeoLoc) & Google Earth (2004, 2007, 2009)
Funnel[a]	1 if the accident/control occurred in a funnel or below an elevated infrastructure, 0 otherwise	-	-	Own digitalization and computation, from CCBR (UrbIS 2007-2008, GeoLoc) & Google Earth (2004, 2007, 2009)
Traffic-calming area *X*[a]	1 if the accident/control occurred in a type *X* traffic-calming area, 0 otherwise	*X* = 1 (30 km/h area), 2 (pedestrian area), 3 (residential area), 4 (all types of traffic-calming areas, i.e. 1-3)	-	Own digitalization and computation, from CCBR (UrbIS 2007-2008, cycling map BCR 2006 & 2008), Ministry of the Brussels-Capital Region (IRIS 2), City of Brussels (Map of the "comfort area")
Crossroad *X*[a]	1 if the accident/control occurred in a type *X* crossroad, 0 otherwise	*X* = 0 (no crossroad), 1 (yield/stop signal), 2 (right-of-way), 3 (traffic light), 4 (roundabout), 5 (crossroad with right-turn), 6 (pedestrian light)	-	Own digitalization and computation, from CCBR (UrbIS 2007-2008, GeoLoc), Google Earth (2004, 2007, 2009)
Complexity index *X*	Complexity index at the place of the accident/control, with *X* bandwidth (m)	*X* = 10, 20, 30, 40, 50, 75 or 100 m	Meters	Own computation, from CCBR (UrbIS)
Tram railways *X*[a,b]	1 if the accident/control occurred on or close to a type *X* tram railway infrastructure, 0 otherwise	*X* = 0 (no tram railway), 1 (tram railways crossing, e.g. in a crossroad), 2 (tram railways in crossable reserved lanes), 3 (on-road tram railways)	-	Own digitalization and computation, from CCBR (UrbIS 2007-2008, GeoLoc), Google Earth (2004, 2007, 2009), STIB-MIVB / BRSI
Cycling facility *X*[a,b]	1 if the accident/control occurred on a type *X* cycling facility, 0 otherwise	*X* = 0 (no cycling facility), 1 (unidirectional separated cycle lane), 2 (bidirectional separated cycle lane), 3 (marked cycle lane), 4 (suggested cycle lane) or 5 (bus and bicycle lane)	-	Own digitalization and computation, from FPS Economy (2006-2008), CCBR (UrbIS 2007-2008, GeoLoc, cycling map BCR 2006 & 2008), Google Earth (2004, 2007, 2009)
Parking area *X*[a,b]	1 if the accident/control occurred close to a type *X* parking area, 0 otherwise	*X* = 0 (no parking area), 1 (longitudinal parking), 2 (angle parking, in the direction of traffic), 3 (angle parking, in the opposite direction of traffic), 4 (parking perpendicular to the road) or 5 (other type of parking area)	-	Own digitalization and computation, from FPS Economy (2006-2008), CCBR (UrbIS 2007-2008, GeoLoc), Google Earth (2004, 2007, 2009)
Proximity parking-cycling facility *X*[a,b]	1 if the accident/control occurred on a type *X* cycling facility, very close to a parking area (d ≤ 0.8 m, and outside a crossroad), 0 otherwise	*X* = 1 (unidirectional separated cycle lane), 2 (bidirectional separated cycle lane), 3 (marked cycle lane), 4 (suggested cycle lane) or 5 (bus and bicycle lane), 6 (all types of cycling facilities, i.e. 1-5)	-	Own digitalization and computation, from NIS-FPS Economy (2006-2008), CCBR (UrbIS 2007-2008, GeoLoc, cycling map BCR 2006 & 2008), Google Earth (2004, 2007, 2009)
Contraflow cycling[a,b]	1 if the accident/control occurred in a contraflow cycling and in the opposite direction of motorised vehicles (i.e. in the direction of the contraflow), 0 otherwise	-	-	Own digitalization and computation, from CCBR (UrbIS 2007-2008, GeoLoc, cycling map BCR 2006 & 2008, OneWayMap application), Google Earth (2004, 2007, 2009)
Major road	1 if the accident/control occurred on a major road, 0 otherwise	-	-	Own computation, from CCBR (UrbIS 2007-2008)
Number of garages *X* (≤ 100m)	Number of garages (in a range *X*) over a network distance ≤ 100m from the place of the accident/control	*X* = 0, 0-10, 11-20, 21-30, 31-40, 41-50, 51-60, 61-70, > 70 garage(s)	-	Own computation, from CCBR (UrbIS 2007-2008)
Garage length	Sum of all the garage lengths over a network distance ≤ 100m from the place of the accident/control	-	Meters	Own computation, from CCBR (UrbIS 2007-2008)
Garage ≤ *X* (m)	1 if the accident/control occurred over a network distance d ≤ *X* (m) from a garage, 0 otherwise	*X* = 10, 50 or 100 m	-	Own computation, from CCBR (UrbIS 2007-2008)
Distance garage	Network distance to the closest garage	-	Meters	Own computation, from CCBR (UrbIS 2007-2008)
Distance crossroad	Network distance to the closest crossroad, whatever the type of crossroad	-	Meters	Own computation, from CCBR (UrbIS 2007-2008)
Distance discontinuity[a,b]	Network distance to the closest discontinuity (on cycling facilities)	-	Meters	Own digitalization and computation, from CCBR (UrbIS 2007-2008, GeoLoc, cycling map

				BCC 2006 & 2008), Google Earth (2004, 2007, 2009)
Distance city centre	Network distance to the Brussels' town hall (city centre)	-	Meters	Own digitalization and computation, from Google Map/Earth 2009
Distance major road	Network distance to the closest crossroad of a major road	-	Meters	Own computation, from CCBR (UrbIS 2007-2008)
Distance parking area *X*	Network distance to the closest type *X* parking area	*X* = 1 (park-and-ride, public or private parking area), 2 (delivery parking), 3 (diplomatic corps parking), 4 (disabled parking), 5 (taxi parking), 6 (all types of parkings, i.e. 1-5)	Meters	Own computation, from CCBR (UrbIS 2007-2008)
Distance public transport *X*	Network distance to the closest type *X* public transport stop	*X* = 1 (bus stop), 2 (tram stop), 3 (all types of public transport stops, i.e. 1-2)	Meters	Own computation, from CCBR (UrbIS 2007-2008)
Distance public administration *X*	Network distance to the closest type *X* administrative building	*X* = 1 (european administrative building), 2 (regional administrative building), 3 (all types of administrative buildings, i.e. 1-2)	Meters	Own computation, from CCBR (UrbIS 2007-2008)
Distance school *X*	Network distance to the closest type *X* school	*X* = 1 (primary or secondary school), 2 (international primary or secondary school), 3 (superior school), 4 (all types of schools, i.e. 1-3)	Meters	Own computation, from CCBR (UrbIS 2007-2008)
Distance industrial estate	Network distance to the closest industrial estate	-	Meters	Own computation, from CCBR (UrbIS 2007-2008)
Distance shopping center	Network distance to the closest shopping center / mall	-	Meters	Own computation, from CCBR (UrbIS 2007-2008)
Distance supermarket	Network distance to the closest supermarket	-	Meters	Own computation, from CCBR (UrbIS 2007-2008)
Distance service station	Network distance to the closest service station / petrol pump	-	Meters	Own computation, from CCBR (UrbIS 2007-2008)
Distance cultural building	Network distance to the closest cultural building / center	-	Meters	Own computation, from CCBR (UrbIS 2007-2008)
Distance sports complex	Network distance to the closest sports complex	-	Meters	Own computation, from CCBR (UrbIS 2007-2008)
Distance playground	Network distance to the closest playground	-	Meters	Own computation, from CCBR (UrbIS 2007-2008)
Distance religious building *X*	Network distance to the closest type *X* religious building	*X* = 1 (synagogue), 2 (protestant church), 3 (orthodox church), 4 (mosque), 5 (catholic buildings), 6 (all types of religious buildings, i.e. 1-5)	Meters	Own computation, from CCBR (UrbIS 2007-2008)
Distance police building	Network distance to the closest police building	-	Meters	Own computation, from CCBR (UrbIS 2007-2008)
Distance hospital	Network distance to the closest hospital	-	Meters	Own computation, from CCBR (UrbIS 2007-2008)
Distance embassy	Network distance to the closest embassy	-	Meters	Own computation, from CCBR (UrbIS 2007-2008)
Traffic				
Car traffic $X^{a,b}$ (06:00 a.m. - 10:59 p.m.)	1 if the accident/control occurred on a road with intensity *X* car traffic between 06:00 a.m. and 10:59 p.m., 0 otherwise	*X* = 1, 2, 3, 4, 5 (class 1 = very low car traffic ; class 5 = very high car traffic)	-	Own computation, from STRATEC/IBGE-BIM (2006), CCBR (UrbIS 2007-2008)
Car traffic $X^{a,b}$ (08:00 a.m. - 08:59 a.m.)	1 if the accident/control occurred on a road with intensity *X* car traffic between 08:00 a.m. and 08:59 a.m., 0 otherwise	*X* = 1, 2, 3, 4, 5 (class 1 = very low car traffic ; class 5 = very high car traffic)	-	Own computation, from STRATEC/IBGE-BIM (2006), CCBR (UrbIS 2007-2008)
Car traffic $X^{a,b}$ (17:00 p.m. - 17:59 p.m.)	1 if the accident/control occurred on a road with intensity *X* car traffic between 17:00 p.m. and 17:59 p.m., 0 otherwise	*X* = 1, 2, 3, 4, 5 (class 1 = very low car traffic ; class 5 = very high car traffic)	-	Own computation, from STRATEC/IBGE-BIM (2006), CCBR (UrbIS 2007-2008)
Van traffic $X^{a,b}$ (06:00 a.m. - 10:59 p.m.)	1 if the accident/control occurred on a road with intensity *X* van traffic between 06:00 a.m. and 10:59 p.m., 0 otherwise	*X* = 1, 2, 3, 4, 5 (class 1 = very low van traffic ; class 5 = very high van traffic)	-	Own computation, from STRATEC/IBGE-BIM (2006), CCBR (UrbIS 2007-2008)

Van traffic $X^{a,b}$ (08:00 a.m. - 08:59 a.m.)	1 if the accident/control occurred on a road with intensity *X* van traffic between 08:00 a.m. and 08:59 a.m., 0 otherwise	*X* = 1, 2, 3, 4, 5 (class 1 = very low van traffic ; class 5 = very high van traffic)	-	Own computation, from STRATEC/IBGE-BIM (2006), CCBR (UrbIS 2007-2008)
Van traffic $X^{a,b}$ (17:00 p.m.- 17:59 p.m.)	1 if the accident/control occurred on a road with intensity *X* van traffic between 17:00 p.m. and 17:59 p.m., 0 otherwise	*X* = 1, 2, 3, 4, 5 (class 1 = very low van traffic ; class 5 = very high van traffic)	-	Own computation, from STRATEC/IBGE-BIM (2006), CCBR (UrbIS 2007-2008)
Lorry/truck traffic $X^{a,b}$ (06:00 a.m.- 10:59 p.m.)	1 if the accident/control occurred on a road with intensity *X* truck traffic between 06:00 a.m. and 10:59 p.m., 0 otherwise	*X* = 1, 2, 3, 4, 5 (class 1 = very low truck traffic ; class 5 = very high truck traffic)	-	Own computation, from STRATEC/IBGE-BIM (2006), CCBR (UrbIS 2007-2008)
Lorry/truck traffic $X^{a,b}$ (08:00 a.m.- 08:59 a.m.)	1 if the accident/control occurred on a road with intensity *X* truck traffic between 08:00 a.m. and 08:59 a.m., 0 otherwise	*X* = 1, 2, 3, 4, 5 (class 1 = very low truck traffic ; class 5 = very high truck traffic)	-	Own computation, from STRATEC/IBGE-BIM (2006), CCBR (UrbIS 2007-2008)
Lorry/truck traffic $X^{a,b}$ (17:00 p.m.- 17:59 p.m.)	1 if the accident/control occurred on a road with intensity *X* truck traffic between 17:00 p.m. and 17:59 p.m., 0 otherwise	*X* = 1, 2, 3, 4, 5 (class 1 = very low truck traffic ; class 5 = very high truck traffic)	-	Own computation, from STRATEC/IBGE-BIM (2006), CCBR (UrbIS 2007-2008)
Environment				
Slope	Maximum slope (to neighbouring pixels) computed at the pixel where the accident/control took place	-	Degree	Own computation, from EROS (2002)
Green blocks ≤ *X* (m)	1 if the accident/control occurred over an euclidean distance d ≤ *X* (m) from a green block, 0 otherwise	*X* = 10, 20, 30, 40 or 50 m	-	Own computation, from CCBR (UrbIS, 2007-2008)

[a] Year is controlled

[b] Direction of travel is controlled

Table 39: Results of the logistic and auto-logistic model (Bayesian framework)

Variables	Logistic model						Autologistic model					
	Estimate			Credible Interval (95%)		OR	Estimate			Credible Interval (95%)		OR
	Mean	SD	MC error	2.50%	97.50%		Mean	SD	MC error	2.50%	97.50%	
Intercept[a]	-2.29***	0.09	0.001	-2.47	-2.12	0.10	-2.29***	0.09	0.001	-2.46	-2.12	0.10
Autocovariate variable	-	-	-	-	-		2.15***	0.14	0.001	1.89	2.42	8.61
Infrastructure												
Complexity index												
Bandwidth = 10m	0.15***	0.01	0.000	0.13	0.17	1.16	-	-	-	-	-	-
Bandwidth = 40m	-	-	-	-	-	-	0.02***	0.00	0.000	0.01	0.02	1.02
Bridge & no cycling facility	0.86	0.58	0.006	-0.29	2.00	2.37	0.88	0.59	0.005	-0.26	2.03	2.42
Contraflow cycling & no crossroad	-0.69*	0.35	0.003	-1.42	-0.05	0.50	-0.89**	0.36	0.003	-1.64	-0.23	0.41
Cycling facility & crossroad												
Fac. 1 (unidir.) & Crossr. 1 (yield/stop)	2.25**	0.92	0.009	0.63	4.27	9.53	2.02**	0.90	0.008	0.44	3.99	7.56
Fac. 2 (bidir.) & Crossr. 1 (yield/stop)	2.88**	1.38	0.013	0.66	6.02	17.78	3.36***	1.38	0.012	1.15	6.56	28.85
Fac. 3 (mark.) & Crossr. 3 (traff. light)	1.96**	0.94	0.009	0.32	4.01	7.10	1.85*	0.91	0.007	0.25	3.79	6.35
Fac. 3 (mark.) & Crossr. 4 (round.)	2.76*	1.52	0.013	0.18	6.13	15.83	2.83*	1.56	0.013	0.13	6.22	16.91
Fac. 4 (sugg.) & Crossr. 2 (right-of-w.)	3.13**	1.42	0.012	0.87	6.46	22.90	3.74***	1.37	0.011	1.60	7.05	42.22
Fac. 0 (no facility) & Crossr. 4 (round.)	1.02***	0.30	0.003	0.43	1.61	2.78	0.67*	0.32	0.002	0.03	1.30	1.96
Fac. 3 (mark.) & Crossr. 0 (no crossr.)	0.73*	0.33	0.003	0.06	1.35	2.07	-	-	-	-	-	-
Tram railways												
Class 1 (railways crossing)	0.86*	0.44	0.004	0.01	1.75	2.37	1.16**	0.46	0.004	0.29	2.09	3.20
Class 2 (crossable reserved lanes)	0.83**	0.33	0.003	0.17	1.47	2.30	-	-	-	-	-	-
Class 3 (on-road railways)	1.06***	0.23	0.002	0.60	1.51	2.87	0.82***	0.23	0.002	0.36	1.28	2.27
Number of garages (for d ≤100m)												
Range 0 (no garage)	-0.61*	0.28	0.003	-1.18	-0.07	0.54	-0.60*	0.28	0.002	-1.17	-0.07	0.55
Distance public administration[b]												
Public administration 2 (regional)	1.08***	0.22	0.002	0.65	1.52	2.95	-	-	-	-	-	-
Distance shopping center[b]	-	-	-	-	-	-	0.86***	0.24	0.002	0.38	1.33	2.36
Proximity parking-cycling facility												
Parking & Facility 1 (unidirectional)	1.28**	0.45	0.004	0.37	2.14	3.59	1.15*	0.48	0.004	0.18	2.08	3.16
Parking & Facility 2 (bidirectional)	2.07*	1.16	0.011	-0.22	4.40	7.95	1.76	1.30	0.011	-0.88	4.27	5.78
Traffic												
Van & truck traffic (6 a.m.-10:59 p.m.)												
Class 2 (low)	1.01***	0.15	0.001	0.71	1.30	2.73	0.92***	0.15	0.001	0.64	1.21	2.52
Class 3 (moderate)	1.32***	0.16	0.001	1.01	1.63	3.75	1.20***	0.16	0.001	0.89	1.51	3.32
Class 4 (high)	1.24***	0.22	0.002	0.80	1.68	3.46	1.26***	0.22	0.002	0.82	1.70	3.53
Class 5 (very high)	2.60***	0.35	0.003	1.93	3.29	13.46	2.13***	0.36	0.003	1.43	2.84	8.38
Deviance	2149***	6.92	0.060	2137	2164	-	2097***	6.70	0.052	2086	2112	-
MAPE	0.21***	0.00	0.000	0.20	0.22	-	0.21***	0.00	0.000	0.20	0.21	-
MSPE	0.11***	0.00	0.000	0.11	0.11	-	0.10***	0.00	0.000	0.10	0.11	-

*** Significant at 99.9%; ** Significant at 99%; * Significant at 95%

[a] Intercept value resulting from centering

[b] Exponentially transformed variables ($e^{-0.001.x}$)

Interaction variables:
Bridge & no cycling facility: Bridge = 1 and Cycling facility = 0
Contraflow cycling & no crossroad: Contraflow cycling = 1 and Crossroad = 0
Van & truck traffic (6 a.m.-10:59 p.m.): Maximum class value of van and truck traffic
Cycling facility & crossroad: Cycling facility = *X* and Crossroad = *Y* (*X* = 1, ..., 5; *Y* = 1, ..., 6)
Cycling facility 3 (marked) & no crossroad: Cycling facility = 3 and Crossroad = 0