Health impact model for modal shift from car use to cycling or walking in Flanders: application to two bicycle highways

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Abstract
In Flanders, a European hot spot for air pollution, alternatives to car transport are put in place to increase the daily level of physical activity (PA) among the population and reduce air pollution and global warming. To evaluate the economic impact of increased PA (cycling and walking), a health impact model was developed for a given volume of PA, relative to car use, within a defined population in Flanders. Flanders is an interesting region because of the combination of high air pollution, high cycling volumes and good data availability e.g. on crashes and PA. The model uses two health indicators: external costs and DALYs. Considered impacts in the model are: mortality and morbidity related to increased PA, air pollution exposure for society and active individuals and crash risks. In addition to health, external costs for CO2 emission, congestion and noise exposure can be considered. The model was applied to the new bicycle highways Antwerp-Mechelen and Leuven-Brussels, which were built near important traffic axes to provide the densely populated region with an alternative to car use. Different sensitivity analyses with a variable number of cyclists and travelled distances were elaborated to check the robustness of the results. Overall, the conclusion was that increased PA outweighed other impacts. The benefit:cost ratio for health impact and infrastructure construction costs was mainly positive, even with conservative assumptions and when the impacts of congestion, noise and reduced CO2 were not accounted for. When reduced congestion was added to the model, benefit:cost ratios largely exceeded one. The model can be used in a retrospective way to analyse previous investments or can be applied to new policy decisions. The presented model is tailored here to the Flemish context for crash risks and air pollution but parameters can easily be adapted to reflect conditions in other regions.

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1. Introduction

Lack of physical activity makes a major contribution to the burden of disease in modern societies in which sedentary behaviour is structural in everyday life. In the recent study of Lim et al. (2012) the health impact of physical inactivity and low physical activity was ranked 4th in Western Europe among >40 risk factors. Within the EU, the Eurobarometer reports high levels of physical inactivity (TNS Opinion & Social, 2010). In a Flemish analysis of the burden of disease (Buekers et al., 2014), physical inactivity was also ranked relatively high, similar to a recent study in the Netherlands (Hilderink, 2014). Correlated with this, some studies report an increased risk of obesity. They show that increasing obesity is associated with the number of trips by car (Davis et al., 2007). However, the association between overall physical activity levels and body weight is still a topic of controversy (Harris et al., 2009). Despite the high health burden of physical inactivity, a lot of money is still spent on health care, and only a fraction is spent on disease prevention.

While car transport tends to dominate in most cities, active transport (cycling, walking) is increasingly seen as a solution to a myriad of urban problems including congestion, noise, air pollution and health issues (De Nazelle et al., 2011). There is a clear causal association between increased physical activity and reduced mortality and to some extent reduced morbidity (Oja et al., 2011). Many car trips are

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short distance trips and could easily be replaced by cycling/walking. This would result in a win–win approach. Less air pollution is caused by forms of active mobility (AM) and there is a personal benefit of reduced mortality and morbidity on top.

The cost of health is seldom evaluated in urban-planning while this would help to create a better understanding of transportation investment costs. Conventional administrations tend to be reductionist i.e. transportation agencies are responsible for solving traffic problems without taking into account the health aspect, while health agencies are responsible for improving public health without much focussing on urban planning or transport (Litman, 2003). A better integration of policies is deemed necessary. The World Health Organisation WHO tries to invoke a “health in all policies” approach to systematically involve health implications in all public policies (Kahlmeier et al., 2010; McQueen et al., 2012). Integrating health objectives into transportation planning may be one of the most cost-effective ways to improve public health (Litman, 2003).

Some recent health impact assessments (HIAs) tried to quantify various ways in which travel policies affect health (Woodcock et al., 2007; De Hartog et al., 2010; Rojas-Rueda et al., 2011; Rabl and de Nazelle, 2012). Scenarios of mode shift to walking or cycling in terms of benefit of physical activity (PA) were worked out taking into account reductions in air pollution exposure for the general population and in terms of risk associated with increased air pollution inhalation during active mobility (AM). Some analyses even took into account the impact of crash risks, and in addition to health; noise, congestion and CO2 (Rabl and de Nazelle, 2012). Overall PA benefits largely outweighed the additional risk due to crashes and the increased air pollution dose while cycling/walking. Similar results were found in California (Maizlish et al., 2013). In cost-benefit analysis, taking into account infrastructure costs, there is evidence that building bike and pedestrian trails is cost-effective even when only a limited selection of benefits is considered (Cavill et al., 2009; Gotschi, 2011). Despite the consensus of recent studies, they use many different methodologies and approaches. Most are only based on mortality; incomplete with respect to morbidity or based on assumptions that are not necessarily valid for Flanders (e.g. with respect to crash risk, air pollution) (Int Panis, 2011; Mueller et al., 2015) which justifies the development of a model tailored to Flemish conditions. Crash risks and cycling/walking safety can vary significantly across and within countries (Vandenbulcke et al., 2009). In the UK, cyclists are three times more likely to die than cyclists in The Netherlands (Gill and Goldacre, 2009). Within Belgium, there are marked differences between the regions (De Geus et al., 2012). Because of such differences between countries and regions in crash risks, our model is (as far as possible) based on Flemish crash data to ensure a reliable analysis (Dhondt et al., 2013).

Our goal was to model the health impact in Disability Adjusted Life Years (DALYs) and in monetary terms of more cycling/walking. We build upon previous international work and make the model specific for the Flemish situation, a region with relatively a lot of air pollution (Buekers et al., 2011), and relatively high cycling rates (Vandenbulcke et al., 2009; De Geus et al., 2014). The model named CWICalc, Cycling and Walking Impact Calculator, is applied using real data on the recently built bicycle highways Antwerpen–Mechelen and Leuven–Brussels. The bicycle highways were built near important traffic axes at which congestion often takes place. They are generally separated from motorised traffic, only accessible by bike and with very few level crossings. They are a real alternative for commuting traffic. We tried to answer the question whether these bicycle highways have a positive or negative benefit:cost ratio, considering the health impact and infrastructure construction costs.

![Schedule of Flemish health impact model for modal shift from car use to cycling or walking](image)

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2. Model and methods

The health impact model takes a basic approach in which the impact of a shift from car use towards active mobility is quantified in terms of DALYs and external costs. DALYs are a measure for the Years of Life Lost (YLL) and Years Lived with Disability (YLD). The DALY is an indicator of the potential loss of “healthy life years” due to mortality and morbidity. Different health effects related to cycling, walking and driving a car are quantified and weighted in the DALY approach, so they can be compared. More info on DALYs can be found in the study of Lopez et al. (2006). External costs are costs that are not included in the market price of car driving, cycling or walking and are a monetary estimate of the damage they cause (health, environment). More info on these costs can be found in the study of Maibach et al. (2008). The model tries to quantify the health gain in terms of DALYs for a given volume of walking or cycling within a defined population and the economic value of this health benefit. The considered impacts are: reduced mortality rate due to increased physical activity, reduced morbidity incidence due to increased physical activity, reduced air pollution for society, increased individual exposure to air pollution during active mobility and crash risk during AM relatively to car use. Additionally external costs for reduced noise, reduced CO2 emission and reduced congestion can be calculated. Input in the model is the distance cycled/walked by a group of persons of a certain age category. The model uses the classic Value Of a Life Year lost (VOLY) approach, which was set at €43,801 (Rabl and de Nazelle, 2012). This number values the reduction of life expectancy with one year. All costs in the model are expressed in euros for the year 2010. Unit external costs for other calendar years are converted to the year 2010 based on the HICP (Harmonised Indices of Consumer Prices) (Eurostat, 2015). Output of the model are external costs and DALYs for the travelled distance taking into account the impact factors mentioned above. Additionally infrastructure construction costs for cycling/walking can be introduced resulting in a cost:benefit analysis. A schematic representation of the model is shown in Fig. 1. The model is currently available at Google Sites (Version 1.0; https://sites.google.com/site/cwicalc/input).

Table 1 presents an overview of the literature on which calculations in the health impact model are based. A short list of main assumptions in the model can be found in the Supplementary material (see Table S1).

2.1. Personal health gain from cycling/walking (external costs and DALYs)

2.1.1. Mortality

This calculation is based on avoided mortality (or mortality risk delayed in time). The relative risk (RR) for all-cause mortality for cycling is set at 0.89 (95% CI 0.83–0.96) corresponding with an energy expenditure of 11.3 METe/h/week ( = 100 min of cycling/week). This means that cycling for 100 min every week, reduces mortality risk by 11%. For all model calculations displayed in the result tables, central estimates were used. The energy expenditure of 11.3 METe/h/week equals global physical activity recommendations. For walking a RR of 0.90 (95% CI 0.87–0.94) per 11.3 METe/h/week ( = 168 min of walking/week) is used. These values are taken from the WHO HEAT (Health Economic Assessment Tool for cycling and walking) software package (Kelly et al., 2014; Kahlmeier et al., 2014). These dose response functions are linear without a threshold and valid for persons aged between 20–65 years for cycling and 20–74 years for walking. This means that there is a continuous health benefit even at small increases in cycling/walking. However, the dose-response curves are only valid for habitual cycling/walking and are corrected for non-transport related forms of physical activity. The default time needed to build up health benefits is set to 5 years, with an annual increment of 20% during the first 5 years. The upper end of the dose-response curves is capped (max. 45% benefit for cycling and 30% for walking). More detailed information on the methodology can be found in Kahlmeier et al. (2014). Avoided DALYs (in this case YLL) are calculated as avoided deaths multiplied by the difference between the average age of the person and the life expectancy at age of death. Costs are calculated by multiplying YLL by the VOLY.

2.1.2. Morbidity

The evidence for morbidity impacts of walking and cycling is weaker than for mortality (Andersen et al., 2000). A review by Woodcock et al. (2009) surveyed the literature on moderate-intensity physical activity as a surrogate for active commuting and concluded that the evidence was robust for a selected number of diseases. In our model health gain by avoided morbidity is based on the dose-response curves for the incidence of breast cancer in women, colon cancer, ischaemic heart disease, depression, diabetes and dementia as provided by Woodcock et al. (2013; Table 5 in publication of Woodcock). The lag time for avoided incidences of these diseases is described by a sigmoidal function by Jarrett et al. (2012; Table 3 in publication of Jarrett). Estimated times to achieve 50% and 100% of effect are given. Estimates of the damage they cause (health, environment). More info on these costs can be found in the study of Maibach et al. (2008). The considered impacts are: reduced mortality rate due to increased physical activity, reduced morbidity incidence due to increased physical activity, reduced air pollution for society, increased individual exposure to air pollution during active mobility and crash risk during AM relatively to car use. Additionally external costs for reduced noise, reduced CO2 emission and reduced congestion can be calculated. Input in the model is the distance cycled/walked by a group of persons of a certain age category. The model uses the classic Value Of a Life Year lost (VOLY) approach, which was set at €43,801 (Rabl and de Nazelle, 2012). This number values the reduction of life expectancy with one year. All costs in the model are expressed in euros for the year 2010. Unit external costs for other calendar years are converted to the year 2010 based on the HICP (Harmonised Indices of Consumer Prices) (Eurostat, 2015). Output of the model are external costs and DALYs for the travelled distance taking into account the impact factors mentioned above. Additionally infrastructure construction costs for cycling/walking can be introduced resulting in a cost:benefit analysis. A schematic representation of the model is shown in Fig. 1. The model is currently available at Google Sites (Version 1.0; https://sites.google.com/site/cwicalc/input).

Table 1
Overview of literature on which calculations in the health impact model are based

<table>
<thead>
<tr>
<th>Impact</th>
<th>DALY approach</th>
<th>External cost approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical activity (reduced mortality)</td>
<td>RR from HEAT (Kahlmeier et al., 2014)</td>
<td>RR from HEAT (Kahlmeier et al., 2014) and application VOLY</td>
</tr>
<tr>
<td>Physical activity (reduced morbidity)</td>
<td>RR from Woodcock et al. (2013); severity: Stouthard et al. (1997); duration: Jarrett et al. (2012) &amp; review of Flemish, Belgian literature (see Section 2.1.3)</td>
<td>RR from Woodcock et al. (2013); direct &amp; indirect costs (review of Flemish, Belgian literature, see Section 2.1.3)</td>
</tr>
<tr>
<td>Reduced air pollution</td>
<td>Impact function all-cause mortality &amp; PM2.5 exposure (Hurley et al., 2005)</td>
<td>Impact function all-cause mortality &amp; PM2.5 exposure (Hurley et al., 2005) and application VOLY</td>
</tr>
<tr>
<td>Increased individual exposure</td>
<td>RR all-cause mortality &amp; PM2.5 exposure (WHO, 2013)</td>
<td>RR all-cause mortality &amp; PM2.5 exposure (WHO, 2013) and application VOLY</td>
</tr>
<tr>
<td>air pollution during AM</td>
<td>Age and gender specific DALY/km (Dhondt et al., 2013)</td>
<td>Age and gender specific YLL &amp; YLD/km (Dhondt et al., 2013); cycling: cost fatal crashes/total costs (De Geus et al., 2014); walking: cost fatal crashes/total costs (Miller et al., 2004); application VOLY</td>
</tr>
<tr>
<td>Crash risk</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Reduced noise</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Reduced CO2</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Reduced congestion</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

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This is also con
disease occur, costs could go up to 5226 euro/year per patient (Williams et al., 2002; Diabetes liga, 2013). In the CODE-2 study 72% of the euro in case of macrovascular complications (coronary heart disease, cerebrovascular disease). When both micro- and macrovascular
2010, based on the change of the Harmonised Index of Consumer Prices HICP,
weighed according to the prevalence of the different complications, a cost of 2763 euro is obtained (euro 2002). Recalculated to the year
patients had at least one complication, 19% microvascular only, 10% macrovascular only and 24% micro- and macrovascular. When costs are
cancers colorectal cancer has the second highest productivity losses in the EU, followed by breast cancer (Luengo-Fernandez et al., 2013).
cancer costs. Few attempts exist in the EU that try to tackle the value per person of colorectal cancer related productivity losses. Among
cancer. Cost related to productivity losses are a key driver for total colon
costs are comparable with those found in an Irish study, 39,607 euro (Tilson et al., 2012). In our model, costs for productivity losses were
taken into account if the selected average age was below 65 years. These costs were estimated at 116,022 euro for a population in Ireland
(2010. A former review estimated that the annual costs of dementia in Europe varied between 6000
Dementia has a relatively large total cost of 16,000 euro/person/year (euro 2004; Fig. 3 in Schoenen et al., 2006) in or 18,300

### Table 2

Direct and indirect (productivity loss) costs in Flanders (Belgium) for selected diseases. Cost are valid for the total period of illness and are expressed in euro 2010, if enough information was available for correction based on HICP.

<table>
<thead>
<tr>
<th>Disease</th>
<th>Direct costs a in model</th>
<th>Indirect costs b (productivity loss) in model if selected age for physical activity is &lt; 65 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breast cancer</td>
<td>23,156</td>
<td>23,309</td>
</tr>
<tr>
<td>Colon cancer</td>
<td>33,930</td>
<td>116,022</td>
</tr>
<tr>
<td>Diabetes Type II</td>
<td>85,000</td>
<td>85,000</td>
</tr>
<tr>
<td>Depression</td>
<td>1984</td>
<td>5175</td>
</tr>
<tr>
<td>Dementia</td>
<td>183,000</td>
<td>–</td>
</tr>
<tr>
<td>Ischaemic heart disease</td>
<td>12,722</td>
<td>22,032</td>
</tr>
</tbody>
</table>

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2 Costs related to premature death are not considered here as they are already accounted for in the physical activity – premature mortality dose-response relationship.

Database. Intego has built a database containing about 3 million diagnoses, based on selected general practitioners in Flanders. For the calculation of DALYs, severity factors and duration of disease are necessary. In our model severity is based on the Dutch weights (Stouthard et al., 1997). Durations of disease are based on the publication of Jarrett et al. (2012) and data found in a review of disease costs for Flanders, Belgium (see next section).

### 2.1.3. Mortbidity costs in Flanders (Belgium)

For morbidity costs we tried to find as much Flemish (Belgian) data, publicly available and validated. We completed these with findings from neighbouring countries. This results in an estimate (order of magnitude) of the costs related to the studied diseases. Medical treatment costs for breast cancer (pre-diagnostic, acute, chronic phase; total period studied 27 months) in Flanders were set to 2194 euro (net personal contribution; Table 4.23 in Pacolet et al., 2011) plus 20,962 euro (social contribution; Table 4.24 in Pacolet et al., 2011), which equals 23,156 euro (see Table 2). In another Flemish study average medical costs were estimated at 23,768 euro (period studied 6 years; Table 26 in Den Hond et al., 2007). Depending on the age, costs for productivity loss were taken into account in our model, as these costs have a major contribution to the indirect costs of the disease. Productivity losses (without premature mortality) related to breast cancer in Flanders were estimated at 23,309 euro on average (Den Hond et al., 2007; Broeckx et al., 2011).

Medical treatment cost for colon cancer (pre-diagnostic, acute, chronic phase; total period studied 27 months) in Flanders were set to 3119 euro (net personal contribution; Table 4.23 in Pacolet et al., 2011) plus 30,811 euro (social contribution, Table 4.24 in Pacolet et al., 2011) which equals 33,930 euro. Colon cancer related medical costs are relatively high during the entire treatment period. The medical costs are comparable with those found in an Irish study, 39,607 euro (Tilson et al., 2012). In our model, costs for productivity losses were
taken into account if the selected average age was below 65 years. These costs were estimated at 116,022 euro for a population in Ireland
(study period 30 months; no costs for premature mortality included; Hanly et al., 2013). In 2010 the Gross Domestic Product (GDP) per hour worked was equal to 45.9 euro in Belgium and 48.2 euro in Ireland, which is comparable. The study of Hanly et al. (2013) stressed the considerable losses in productivity associated with colon cancer. Cost related to productivity losses are a key driver for total colon cancer costs. Few attempts exist in the EU that try to tackle the value per person of colorectal cancer related productivity losses. Among cancers colorectal cancer has the second highest productivity losses in the EU, followed by breast cancer (Luengo-Fernandez et al., 2013). This is also confirmed by a similar study in the US (Bradley et al., 2008).

For diabetes type II, the CODE-2 study (Cost of Diabetes in Europe-Type II) showed that for Belgium yearly direct treatment costs for patients were equal to 1505 euro when no complications are diagnosed, 2563 euro when microvascular complications take place, 3148 euro in case of macrovascular complications (coronary heart disease, cerebrovascular disease). When both micro- and macrovascular disease occur, costs could go up to 5226 euro/year per patient (Williams et al., 2002; Diabetes liga, 2013). In the CODE-2 study 72% of the patients had at least one complication, 19% microvascular only, 10% macrovascular only and 24% micro- and macrovascular. When costs are
weighed according to the prevalence of the different complications, a cost of 2763 euro is obtained (euro 2002). Recalculated to the year 2010, based on the change of the Harmonised Index of Consumer Prices HICP, this results in a cost of 3263 euro. The average and median age at which diabetes type II is diagnosed is around 54 years (CDC, 2014). In case there is a good treatment regime, life expectancy can
equal that of the general population (Lutgers et al., 2009). This would result in an average direct lifetime cost of around 85,000 euro per person. There is little known about the indirect costs of diabetes type II. Kanavos recently showed that for Germany, the UK and France, indirect costs (absenteeism, early retirement and expenditure on social benefits) are on par with direct costs (premature mortality not accounted for; Kanavos et al., 2012). Taking this into account the diabetes type II costs would be around 190,000 euro per case.

Depression medical treatment costs are relatively low compared to productivity losses. For affective disorders total costs per patient in Belgium are around 6000 euro/year (euro 2004; Fig. 3 in Schoenen et al., 2006). Recalculated to the year 2010, based on the change of the HICP, this results in 6900 euro. Around 25% of the costs are direct costs whereas 75% are related to indirect costs (Fig. 4 in Schoenen et al., 2006). This results in 1725 Euro for the direct costs and 5175 for the indirect costs. According to Spijker et al. (2002) 80% of people with depression recover within one year whereas 20% are still not cured after 2 years.

Dementia has a relatively large total cost of 16,000 euro/person/year (euro 2004; Fig. 3 in Schoenen et al., 2006) in or 18,300€ recalculated to the year 2010. A former review estimated that the annual costs of dementia in Europe varied between 6000–19,000 euro.
per patient, although methodological differences were present between cost evaluations in different countries. For Belgium this was 15,435 euro (euro 2004; Jonsson and Berr, 2005). The non-medical care of these patients is relatively expensive. In most cases dementia happens in relatively older people, not active on the labour market and thus without first order economic productivity loss. The average survival time for people who are diagnosed with dementia before the age of 70 years, is around a decade or longer (Ferri et al., 2005; Xie et al., 2008). Total costs per patient per lifetime were therefore set to 183,000 euro (10 × 18,300).

In a publication of 1998, Annemans et al. (1998) estimated the treatment costs of coronary heart disease in Belgium during the acute and follow-up phase. The acute cost of coronary heart disease was equal to 191,933 BEF (In 1999 the BEF was coupled to the euro, 1 euro=40.3 BEF) for acute myocardial infarction (MI), 175,959 BEF for coronary insufficiency, and 159,912 BEF for angina pectoris. Follow-up costs amounted to 47,000 BEF per year, of which 13,000 for drugs, statins not included. In euro-1999 this amounts 4763 euro for acute myocardial infarction, 4366 euro for coronary insufficiency, 3968 euro for angina pectoris and 1166 euro/year for the follow-up phase. The costs during the follow-up phase are thus one fourth of the initial costs. In Germany direct medical costs for myocardial infarction were estimated at 7522 euro (2004) for the acute phase, 2445 euro for the following 1-6 months, 1705 for the following 7–12 months and 981 for the year after the MI took place, or a total cost of 11,672 euro (Brüggenjürgen et al., 2005). In 2008 Vlayen et al. (2008) published a study on the costs of atherosclerotic cardiovascular diseases (ACD) in Belgium. The mean annual cost per patient with established ACD was 2678 euro. The total direct cost was set at 2678 plus 670 (one fourth) for fifteen years which equals 12,722 euro. Slebus et al. (2012) observed that people with an acute coronary syndrome were back to work after 3 months. In 2010 the Gross Domestic Product per hour worked was 45.9 euro in Belgium. For a period of 3 months, indirect costs due to productivity loss would equal 22,032 euro. Selected morbidity costs for use in the model are summarised in Table 2.

2.2. Societal health gain due to air pollution reduction (external costs andDALYs)

One of the model input parameters is the ambient PM2.5 concentration. In Flanders the spatial variability of PM2.5 concentrations is limited. One fourth of the concentration is due to local Flemish emissions while the rest comes from abroad. Seventeen percent of the Flemish contribution is associated with local transport emissions (Deutsch et al., 2010). This means that for the population weighted PM2.5 concentration of 17 µg/m³, max. 0.7 µg/m³ is associated with local transport. We took a pragmatic approach and assumed that people taking up cycling or walking were driving passenger cars before and that around 60% of the transport PM2.5 emissions is related to passenger cars and another 40% to trucks and lorries (based on Fig. 25 in De Geest et al., 2010). We know that the average distance travelled by car is 31 km per day (Declercq et al., 2014) and calculated how much of this distance would be replaced by walking or cycling and weighted this by the number of persons actively travelling within the Flemish population. There is thus a linear relationship between the reduction in PM2.5 concentration (ΔPM2.5) and the distance travelled by bike or walking. The avoided YLL per year were calculated based on the estimate of 6.50 × 10⁻⁴ (95% CI 1.27 × 10⁻⁴–1.19 × 10⁻³) YLL/person/year/µg PM2.5/m³ (Pope et al., 2002; Bickel and Fricke, 2005; Hurley et al., 2005). External costs were calculated by multiplying YLL with the VOLY. Morbidity was not taken into account here as mortality due to PM2.5 exposure explains the largest part of the health impact.

2.3. Personal health loss due to increased air pollution exposure (external costs & DALYs)

There is a lot of uncertainty on the direction (personal gain or loss) for the change in air pollution exposure due to the shift from car to bicycle use or walking (Reynolds et al., 2010). This factor is largely influenced by the time and place where the shift takes place. In a dense city centre with lot of traffic, the inhaled dose can be relatively higher in people cycling or walking compared to car driving as the ventilation rate is higher in active people and the trip duration longer (Int Panis et al., 2010). However the impact is entirely negligible compared to the overall gain that comes with increased physical activity (see results). We assumed in our model a negative impact of air pollution while shifting from car to bike or walking. The PM2.5 concentration to which car drivers (passengers) are exposed to was set a factor 1.5 higher than the reported PM2.5 concentration by monitoring stations (Rabl and de Nazelle, 2012). The PM2.5 concentration for car drivers relative to cyclists was set at 1.24 based on a meta-analysis (Rojas-Rueda, 2012) from studies in London (Adams et al., 2001a; Adams et al., 2001b; Kaur et al., 2005), Barcelona (De Nazelle et al., 2011), Arnhem (Zuurbier et al., 2010) and several Dutch cities (Boogaard et al., 2009). An identical approach was taken for walking. Ventilation rates were set at 0.27 m³/h for sleeping, 0.61 m³/h for resting and car driving, 2.22 m³/h for cycling (Rojas-Rueda, 2012). For walking the ventilation rate was set at 1.14 m³/h (US-EPA, 2011; Rabl and de Nazelle, 2012). An identical approach was taken for walking. Ventilation rates were set at 0.27 m³/h for sleeping, 0.61 m³/h for resting and car driving, 2.22 m³/h for cycling (Rojas-Rueda, 2012). For walking the ventilation rate was set at 1.14 m³/h (US-EPA, 2011; Table 6–29 in US-EPA document; walking at 3 miles per hour). The obtained inhaled PM2.5 dose is thus always a little bit higher during active travel compared to car driving (Dons et al., 2012). Based on the dose difference between active and passive transport, an equivalent change in PM2.5 was calculated. By knowing the equivalent PM2.5 dose change and the dose-response relationship between all-cause mortality and exposure to PM2.5 (1,062 per 10⁻³ g PM2.5/m³; 95% CI 1.04,–1.19; WHO, 2013; Holland, 2014a) the potential impact fraction (PIF) could be calculated (Vander Hoorn et al., 2004). Applying this fraction to the death rate for all-cause mortality results in the attributable mortality due to increased air pollution during active transport. More details on the calculation method can be found in De Hartog et al., (2010). Years of Life Lost YLL were calculated by multiplying the attributable deaths by the difference in age of death and life expectancy. External costs were calculated by multiplying with the VOLY.

2.4. Crash risk (external costs and DALYs)

Crash risk for cycling and walking, relatively to car driving, is based on data for Flanders and Brussels published in Dhondt et al. (2013). We started from age and gender specific DALY/km data for cycling, walking and car driving (Fig. 3 in Dhondt et al., 2013). Based on the input (amount of km cycled or walked; gender; average age) DALYs could be calculated. Next to DALY, also the YLD/km were provided by Dhondt et al. (2013). For each trip DALYS and YLD for crash risk could thus be calculated. External costs for fatal crashes were calculated as (DALY–YLD) × VOLY. External costs for crash related morbidity were calculated as the costs for fatal crashes multiplied by the ratio of the costs for morbidity/cost of fatal crashes. The latter was derived for cycling in a recent study by De Geus et al. (2014) who reported that in Flanders costs for fatal crashes were 31% of the total costs (mortality + morbidity) (see Table 7 in De Geus et al., 2014). Previous studies
have mostly ignored costs associated with non-fatal and minor crashes whereas it has been shown that these are not negligible in Flanders (Aertens et al., 2010).

For walking, no Flemish data were available. We therefore used a US study which reported external costs for walking (Miller et al., 2004). The study reported for cycling and walking fatal and non-fatal crash costs. For cycling, fatality costs represented 17% of the total costs. For walking, fatality costs represented 70% of total costs which means costs for cycling are mainly morbidity driven while costs for walking are mainly mortality driven. The value of 70% was taken forward in our calculation. Finally external costs for cycling and walking could be calculated taking into account mortality and morbidity effects.

2.5. Noise (external cost)

Two major impacts are usually considered when assessing noise impacts: annoyance and health impacts like hypertension and myocardial infarction (Miedema and Vos, 2007). Noise pollution may increase the level of stress hormones which have a direct effect on the heart. Cycling or walking instead of using a car diminishes noise exposure for residents living near the trip trajectory (not necessarily next to the cycling/walking track). The average damage cost per km due to noise of passenger cars in the EU was set at 0.88 eurocent/vehicle km for the year 2010 (Ricardo-AEA, 2014). The value is valid for the urban cluster with a dense traffic situation. Earlier studies reported a value of 0.76 eurocent/vehicle km (Maibach et al., 2008; Rabl and de Nazelle, 2012). The value is based on a hedonic price study and not on health endpoint specific estimates, the preferred valuation method for noise effects (Máca et al., 2008). In the model the impact of noise is optional and can be switched off when it should not be accounted for. The model is thus built in a modular way. Currently, no dose-response relationship are derived for noise exposures during travel.

2.6. CO₂ (external cost)

Global scientific consensus exists that climate change is occurring and that human activity, primarily greenhouse gas emissions, is the most probable cause (IPCC, 2007). Avoided CO₂ emissions can be accounted for in the model. Passenger car emissions were set at 278.3 g/km for EURO4/EURO5 vehicles as calculated by COPERT4. This default value is valid for a fleet with equal percentages of gasoline and diesel engine cars but can be adjusted to better reflect national or local fleet characteristics. The cost per emitted tonne of CO₂ was set at €25 albeit that this value is highly uncertain (Rabl and de Nazelle, 2012). This results in an external cost for CO₂ of 0.7 eurocent/vehicle km. The value is comparable with the value of 0.85 eurocent/km derived by Meschik (2012) who started from an average CO₂ emission of 170 g/km, priced at €50/tonne (FSV, 2010). In the model the impact of CO₂ can be switched off when it should not be accounted for.

2.7. Congestion (external cost)

A user of a road network affects, by his/her decision to use the network for driving from A to B, the utility of all other users who want to use the same network capacity. Utility losses are monetised, resulting in a congestion cost. Avoided congestion was accounted for in the model at a cost of 76 eurocent/km for the year 2010. The value is an average estimate and valid for large urban areas in the EU (Ricardo-AEA, 2014). Earlier studies reported a value of 75 eurocent/km (Maibach et al., 2008; Rabl and de Nazelle, 2012). In the model the impact of congestion is optional.

2.8. Incidence/prevalence data

Mortality rates (deaths/year) for Flanders per 100,000 persons per age category are available from the Flemish Agency for Care and Health (Vlaams Agentschap Zorg en Gezondheid 4). The rate varies from 39/100,000 at the age of 20 to 1903/100,000 at the age of 74. Morbidity data are available from the Intego database. 5

2.9. Case studies: 2 bicycle highways

The CWICalc model was applied to two recent case studies for which detailed data was available: the 25 kilometre long bicycle highway Antwerp-Mechelen (See Fig. 2) and the 30 km long bicycle highway from Leuven to Brussels (See Fig. 3). The bicycle highways offer commuters a convenient, high quality and safe connection between cities. We focus on a completed section of each highway of ± 20 km long. Different scenarios with varying numbers of cyclists and distances cycled are presented. Numbers were extracted from reports with data on bicycle highway usage (Antwerp-Mechelen: Goossens, 2014; Leuven-Brussels: Fagard, 2012). Costs for installing the highways were estimated to be between 3 x 10^5 and 8 x 10^5 euro/km (personal communication Tina Caers, Province of Antwerp). Lowest costs correspond to a simple but wide dedicated cycle track whereas the largest cost reflects sections which include complex civil engineering structures such as dedicated fly-overs and/or tunnels. Benefit: cost ratios were calculated for different scenarios of the Antwerp-Mechelen and Leuven-Brussels bicycle highways for an evaluation period of 20 years. Also several hypothetical (but plausible) examples were worked out to find out the break-even point, i.e. how many new cyclists are necessary for a trajectory cycled of 10 or 20 km, to obtain a benefit:cost ratio of 1?

5 http://intego.be/en/Welcome

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Fig. 2. Bicycle highway Antwerp–Mechelen (25 km) with indication of traffic counters (AM1-AM14).
Source: Goossens, 2014
3. Results

Results of the application of the CWICalc model to the 2 bicycle highways are discussed. Different scenarios were worked out, varying in estimated number of cyclists and travelled distances, based on data extracted from reports analysing the use of these highways. Benefit: cost ratios taking into account the health effects and infrastructure construction costs were calculated. In Table 3 results of the scenario analyses are given. The approach is conservative as reduced congestion, noise and CO₂ were not accounted for. Almost all benefit: cost ratios were positive, except for two (scenarios 1 of the Antwerp–Mechelen & the Leuven–Brussels highway assuming an average construction cost of 8 × 10⁵ euro/km). For scenario 1 of the Antwerp–Mechelen highway the number of cyclists was set to the minimum observed at one recording point of the highway (AM13) resulting in a ratio of 0.7. At this recording point the highway is still under construction and currently there is a deterrent (see Fig. 2). For the Leuven–Brussels highway the number of cyclists were set to a daily average at one point (T1) in scenario 1 resulting in a ratio of 0.6 when the largest estimate of infrastructure construction costs was applied. It seems that the Antwerpen–Mechelen highway is more popular than the Leuven–Brussels one. Overall, most benefit: cost ratios were above one which means that construction investments were well considered. The period for depreciation was set to 20 years in this conservative example. For a period of 30 years, which is a realistic value for infrastructure including complex civil engineering structures, all benefit: cost ratios would be above one. When congestion reduction would be taken into account, in case of a 20 year evaluation period, the ratios clearly exceed one. For the Leuven–Brussels highway the benefit: cost ratio would increase from 0.6 to 4.2 (increase with a factor of 7). For the Antwerpen–Mechelen highway the ratio would increase from 0.7 to 3.9 (increase with a factor of 5). In the hypothetical case (see Table 3) of 10 km cycled/day at least 650 to 1700 cyclists a day (depending on construction costs) are necessary on a highway of 20 km long. For 20 km cycled per day 350–950 cyclists are necessary to achieve break-even result. The results presented in the lower half of Table 3 demonstrate, that based on the current set of parameters in the model, overall health benefits alone equal construction costs even for levels of bicycle traffic that are lower than currently estimated volumes.

Fig. 4 represents the results of the impact model in benefits and external costs/year for the bicycle highway Antwerp–Mechelen (scenario 1). The impact due to the gain in physical activity related to avoided mortality and morbidity is more than a factor 100 larger than the gain due to avoided air pollution from car usage for society. Crash risk and increased air pollution exposure during physical activity have a negative impact, but are, in absolute values, more than a factor 10 lower than the benefit of avoided mortality from increased physical activity. An identical graph with DALYS as output is provided in Fig. 5. Also here the gain due to avoided mortality is 5 to 20 times larger than other considered impacts. Physical activity benefits thus largely outweigh additional risks. Already more than 20 years ago a thorough effort for quantifying the trade-offs between risks and benefits of cycling was done for the British Medical Association. Hillman (1992) reported in accordance to our study that “in spite of the hostile environment in which most cyclists currently ride, the benefits in terms of health promotion and longevity far outweigh the loss of life years in injury on the roads”.

Table 4 represents detailed information on the total external costs for scenario 1 of the Antwerp–Mechelen highway with an evaluation period of 20 years. Gains due to decreased CO₂ emissions, avoided noise pollution and avoided congestion were not considered in the scenario. This is a conservative approach. In the Supplementary material results are given with inclusion of CO₂, noise and congestion (see Table S2). In Table 5 results are expressed in eurocent/km cycled. The health impact due to increased PA dominates. The crash risk in eurocent/km is largely dependent on the age of the cyclists. The average age in this example was set to 45 years. In this case, the gain for society by reduced air pollution is more than a factor 10 lower than the impact of increased individual air pollution exposure during active transportation. A factor that contributes to this, is the typical Flemish situation in which three quarters of the PM2.5 concentration is caused by emissions from abroad. Overall the contribution of Flemish traffic to the total PM2.5 concentration, is thus relatively small, which results in a small beneficial effect for society. However, this does not mean that the toxicity of the PM2.5 constituents, largely explained by black carbon coming from combustion, is less for the transport sector (Hoek et al., 2013; Grahame et al., 2014). Also in a recent study of Rojas-Rueda et al. (2013) in Barcelona, the absolute amount of DALYS lost due to air pollution during active transport by the travellers, was larger than the gain by the society due to the reduced air pollution by active transport (see Table 7 in Rojas-Rueda et al., 2013). In the Supplementary material CO₂, noise and congestion expressed in eurocent/km are included (see Table S3).

4. Discussion

We have built a model to comprehensively assess the health impacts of a shift from motorized transportation modes to active modes such as cycling and walking. Our model includes many beneficial morbidity effects from increased physical activity that are usually not included in a HIA. These additional benefits however remain small relative to the benefits of reduced mortality risk whether they are
<table>
<thead>
<tr>
<th>Scenario</th>
<th># cyclists (per day)</th>
<th>Travelled distance (km/day)</th>
<th>Benefit:cost ratio model for different building costsa</th>
<th>Scenario remarksb</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Antwerp–Mechelen</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario1</td>
<td>600</td>
<td>27</td>
<td>2.0</td>
<td>Average trip distance from a survey; minimum number of cyclists at one point (AM13; See Fig. 2)</td>
</tr>
<tr>
<td>Scenario2</td>
<td>2600</td>
<td>12</td>
<td>4.7</td>
<td>For the 7 first counting points (AM1-AM7; See Fig. 2) there are 2600 cyclists</td>
</tr>
<tr>
<td>Scenario3</td>
<td>4400</td>
<td>16</td>
<td>10.2</td>
<td>Own estimate of weighted average distance; maximum number of cyclists at AM1 (See Fig. 2)</td>
</tr>
<tr>
<td>Scenario4</td>
<td>4400</td>
<td>27</td>
<td>14.5</td>
<td>Average trip distance survey; maximum number of cyclists at AM1 (See Fig. 2)</td>
</tr>
<tr>
<td><strong>Leuven–Brussels</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario1</td>
<td>500</td>
<td>37</td>
<td>1.5</td>
<td>Average trip distance from a survey; average number of cyclists at one point (T1; See Fig. 3)</td>
</tr>
<tr>
<td>Scenario2</td>
<td>1100</td>
<td>37</td>
<td>3.4</td>
<td>Average trip distance from a survey; number of cyclists during an event</td>
</tr>
<tr>
<td>Scenario3</td>
<td>1624</td>
<td>32</td>
<td>5.2</td>
<td>Own estimate of weighted average distance &amp; number of cyclists</td>
</tr>
<tr>
<td><strong>Hypothetical</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario1</td>
<td>650</td>
<td>10</td>
<td>1.0</td>
<td>Number of cyclists changed until Benefit/Cost ratio equals one for smallest building costs of highway; Travelled distance fixed at 10 km</td>
</tr>
<tr>
<td>Scenario2</td>
<td>1700</td>
<td>10</td>
<td>1.0</td>
<td>Number of cyclists changed until Benefit/Cost ratio equals one for largest building costs of highway; Travelled distance fixed at 10 km</td>
</tr>
<tr>
<td>Scenario3</td>
<td>350</td>
<td>20</td>
<td>1.0</td>
<td>Number of cyclists changed until Benefit/Cost ratio equals one for smallest building costs of highway; Travelled distance fixed at 20 km</td>
</tr>
<tr>
<td>Scenario4</td>
<td>950</td>
<td>20</td>
<td>1.0</td>
<td>Number of cyclists changed until Benefit/Cost ratio equals one for largest building costs of highway; Travelled distance fixed at 20 km</td>
</tr>
</tbody>
</table>

a: A: building costs of highway equals $3 \times 10^5$ €/km; B: building costs of highway equals $8 \times 10^5$ €/km. For the calculation of building costs of the bicycle highways a distance of 20 km was used. Other input parameters for the model were: 50% of cyclists are males, distance is travelled 4 times/week, evaluation period is 20 years, mean age of the cyclists is 45 years. The impact of noise, congestion, CO₂ was not considered here to calculate the benefit:cost ratios which is a conservative approach.

b: Scenario data extracted from reports with statistical data on highway usage. All scenarios assume that if the trips were not made by bicycle, they would have been made by car.
expressed as DALY’s or as external costs. Despite our conservative assumptions, the cost:benefit ratio for any section of both bicycle highways was almost always favourable.

The major risk factor is crash risk. Previous studies have often been conducted for regions with lower crash risks (e.g. Copenhagen, The Netherlands) than Belgium. Within Belgium, crash risks in Flanders are very different from those in Wallonia (Vandenbulcke et al., 2009). However even when taking the local crash risks into account, they are still much smaller than the health benefits.

Our study has some strengths and weaknesses. An important restriction of our model is that the dose-response curves behind the health effects are based on population statistics and habitual cycling/walking and should not be used to estimate benefits for individuals,
small groups, one-off sporting events or irregular bouts of exercise. We have therefore tried to prevent improper use by restricting the model input for the distance travelled by cyclists (< 60 km/day) or walked by pedestrians (< 30 km/day). The number of cyclists or pedestrians studied should be larger than one hundred. The evaluation period was limited between > 1 and < 100 years. These restrictions were set to avoid unrealistic estimates.

The model for walking is built in a similar way as the cycling model. In our model, cyclists and pedestrians are seen as separate individuals. If an estimate should be made for people who cycle and walk, the model should be run separately for cycling and walking. Results should be interpreted with caution for groups of people that shift to levels of habitual walking and cycling that are close to the maximum.

Another weakness is that we have only included first order impacts. For noise, for example we have not included the possible health impacts of noise exposure during travel and ignored the possibility that if noise deters cycling or walking, the impact on physical activity may result in an indirect effect of noise on health Van Lenthe et al., (2005).

A final weakness is that discounting (time preference) over the considered period in our model was not taken into account. However we believe this is justified seeing the ethical discussion and controversy associated with it (Severens and Milne, 2004). Also we did take into account that there is a build-up time needed to achieve the health benefits associated with habitual physical activity.

A strength of our approach is the fact that we have chosen to consistently use VOLY. The value of a prevented fatality was not applied. One reason is that this value is based on a Willingness to Pay (WTP) of a middle-aged person to avoid sudden death (US EPA, 1999; Cavill et al., 2007). Whereas this could have been applied for crashes (on average a traffic fatality causes the loss of about half a life span, or ~40 years), air pollution deaths occur rather among frail individuals (older or in poor health) (Rabl and de Nazelle, 2012). The VOLY approach takes into account the age of death. Nevertheless we think that our model takes a very conservative approach by using average crash risks for all bicycle trips in Flanders. Because it is the explicit goal of the cycling highways to separate bicycles from motorized traffic and to eliminate level crossings, the real health cost of crashes occurring on the new infrastructure will likely be much lower than assumed here. If some of the bicycle traffic is displaced from other nearby routes, there may even be an additional safety benefit. Woodcock et al. (2009) also found that the road traffic injury burden in London is likely to increase only marginally with large increases in active transportation. Especially when new infrastructure is built, the safety-in-numbers-hypothesis may be valid ( Jacobsen, 2003).

Another strength in our analysis is the detailed knowledge we have on air pollution in Flanders, one of the European air pollution hot spots. It is known how much of the measured PM2.5 concentration is coming in from abroad and how much is due to local transport emissions (mainly from passenger cars and lorries). Based on comparable PM2.5 measurements in cars and near bicycles, different ventilation rates and distances covered, PM2.5 doses could be estimated to calculate the health impact.

Some model input parameters that have a substantial effect on the output need more study in the future. A peculiar effect in de model is seen when the input parameter “average age” of the cyclists increases e.g. from 20 to 65 years, the total benefit also increases as the impact of physical activity on reduced mortality becomes larger. This is because at higher age, the mortality rate is higher and the percentage of avoided premature deaths as well. The crash risk is also age (and gender) dependent and the eurocent/km for crashes is larger at the age of 65 compared to 20 or 40 years (Dhondt et al., 2013) although in absolute numbers it is still minor compared to the gain related to physical activity.

When infrastructure is evaluated over longer time periods (higher values for the input parameter “evaluation period”), the crash risk expressed in eurocent/km remains the same while the gain in physical activity expressed in eurocent/km increases. There is an annual build-up of health benefits (for avoided mortality set at 20% annually during first 5 years) in the model. When more kms/year are cycled (increase of distance, number of times/week) the crash risk in eurocent/km remains identical. The gain due to increased physical activity may increase until the maximum benefit is reached. If more km are cycled above the maximum health gain, the amount of eurocents/km gained will decrease. There is a maximum benefit for cycling on the number of avoided (extended) fatalities of 45%. In external costs this maximum is around 60 eurocent/km that can maximally be gained. When the evaluation period increases this also has an effect on the benefit:cost ratio. In our examples infrastructures were assumed to last for at least 20 years. In a sensitivity analysis we changed this value to 30 years resulting in all positive benefit:cost ratios. Brief or transient changes in behaviour (change in amount cycled or walked over time) were not considered. As mentioned above, there is a build-up of health effects for the first 5 years after which a level is reached which remains constant. Subsequent behavioural changes could be modelled by running the model several times for different time periods.

A final variable which has a large influences on the absolute value for health gain and crash risk is the VOLY. Currently it is set at € 43,801 in our model but other, higher estimates are possible (Desaigues et al., 2011). Using other values will affect the outcome of the model, but not the major conclusions of our case study on bicycle highways. Benefit:cost ratios of relative health gain versus infrastructure construction costs would increase. The value of € 43,801 is conservative and higher values around € 60,000 are also used in the EU (Holland, 2014b).
5. Conclusions

Physical inactivity is a major health burden in Western Europe. Strategies are worked out to increase the daily level of activity by regular cycling and walking. Health impact models try to estimate the increase in health of these activities and the related economic value. A health impact model for cycling and walking was built including both mortality and morbidity risks. Special attention was given to the specific situation in Flanders, a region high in air pollution (mainly coming from abroad), and made specific for local crash risks. The model was applied to data on the bicycle highways Antwerp-Mechelen and Leuven-Brussels. Overall physical activity outweighed other health impacts. Benefit:cost analysis was generally positive. The model can be applied retrospectively to other Flemish investments for which bicycle counts or walking data are known. In policy scenario analysis this model may facilitate the decision-making process, especially if a choice needs to be made between different scenarios e. g. a relative comparison. Even when major benefits such as the reduction of congestion, CO₂-emissions and noise are ignored, the construction costs of bicycle highways in Flanders are almost always lower than the health benefits. From a health perspective, further investment in bicycle highways seems warranted despite large uncertainties.

Abbreviations

AM active mobility
DALY Disability Adjusted Life Year
HIA health Impact Assessment
HICP Harmonised Index of Consumer Prices
MET Metabolic Equivalent, 1 MET is the typical expenditure of an individual at rest = 1 kcal/kg/h
PA physical activity
PM particulate matter
RR relative risk
VOLY Value Of Life Year
WTP Willingness To Pay
YLD Years Lived with Disability
YLL Years of Life Lost
WHO World Health Organisation

Symbols

# number of cyclists, pedestrians
♂ male
♀ female

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.jth.2015.08.003.

References


