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FACULTEIT SCHOOL VOOR MOBILITEITSWETENSCHAPPEN
master in de mobiliteitswetenschappen

Masterproef
Road charging effects on traffic safety

Promotor :
Prof.dr.ir Tom BELLEMANS

Copromotor :
Prof. dr. ir. Bruno KOCHAN

Jochen Roosen
Scriptie ingediend tot het behalen van de graad van master in de mobiliteitswetenschappen

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Preface

This is my Master thesis to attain a Master degree in Traffic Safety at the University of Hasselt. The thesis is about road charging and the traffic safety effects in Flanders.

I would like to thank my promotor Tom Bellemans, co-promotor Bruno Kochan and internal supervisor Ali Pirdavani. Their experience regarding the subject was more than welcome. Without their help and guidance, this work would not be what it is today.

I would also like to thank my family and especially girlfriend, Eileen, since I got on her nerves many times during the creation of this work.

Jochen Roosen
August 24th, 2015

Summary

When policy wants to influence congestion, there is a variety of travel demand management (TDM) measures that can be taken. As said, the primary goal is to improve traffic performance. A side effect of such a measure is the influence on traffic safety. This is also the main purpose of this study, to examine the effects of a road charging scheme on traffic safety in Flanders.

To accomplish this, a questionnaire was created. In the questionnaire, respondents were asked to state their preference in some hypothetical situations wherein variations were made through the cost of the charge, the distance, the time and the purpose of travel. The monthly price change was also indicated to present it more clear to the respondent. The sample group was a good representation of the entire population. After the questionnaire data was gathered and reviewed, it became clear that the results weren't as would be expected according to literature. The modal changes were insignificantly small and therefore not usable in the ZCPMs (zonal crashes prediction models). Since the thesis had advanced to such a far level, substitution data was searched and used to continue. Although the substitution, a fuel cost increase, has some advantages and disadvantages over a road charging scheme, it is from the same group of TDM measures. They both have the same goal, being changing the modal choice through a cost increase of driving a car. Literature also indicates that these types of TDM measures are very comparable concerning modal choice change. Data from a study about a fuel cost increase was used to continue with the creation of three scenarios: a null scenario, a 4 cent fuel cost increase and a 8 cent fuel cost increase. Car – car crashes and car – slow crashes were researched. Two ZCPMs were created using a selection of most suited variables, determined by using statistical program SPSS; one for car-car crashes and a second for car-slow crashes. Exposure data from the two scenarios, revealed through activity-based transportation model FEATHERS (Forecasting Evolutionary Activity-Travel of Households and their Environmental RepercussionS) was then applied in the ZCPMs. This yielded the necessary data on which conclusions are drawn.

Analysis showed that the amount of car – car crashes is predicted to drop for 91 % of TAZs (traffic analysis zones) in the 4 cent fuel cost increase scenario and for 98 % of TAZs in the 8 cent fuel cost increase scenario. Car – slow crashes are predicted to rise for 77 % and 90 % of TAZs in the respectively 4 and 8 cent fuel cost increase scenario. No exact numbers can be given since the data set wasn't robust enough after one run through an activity-based transportation model. It is expected however that the total amount of crashes will drop on the short term. On the long term, higher reductions are expected due to an initial shock effect where a modal shift occurs and leads to more use of slow modes of transport leading to higher exposure.

Table of contents

<u>Preface.....</u>	<u>1</u>
<u>Summary</u>	<u>2</u>
<u>List of tables</u>	<u>5</u>
<u>List of figures</u>	<u>6</u>
<u>Chapter I. Problem statement.....</u>	<u>7</u>
<u>1.1 The problem</u>	<u>7</u>
<u>1.2 Goal.....</u>	<u>7</u>
<u>1.3 Research questions.....</u>	<u>7</u>
<u>1.4 Plan of approach.....</u>	<u>8</u>
<u>Chapter II. Literature study</u>	<u>11</u>
<u>2.1 Road charging: what is it?.....</u>	<u>11</u>
<u>2.1.1 Road charging.....</u>	<u>13</u>
<u>2.1.2 Other incentives</u>	<u>16</u>
<u>2.2 Traffic safety</u>	<u>18</u>
<u>2.2.1 Safety on macroscopic vs microscopic scale.....</u>	<u>19</u>
<u>2.2.2 Safety effects of TDM measures</u>	<u>19</u>
<u>2.3 Study area: Flanders</u>	<u>21</u>
<u>Chapter III. Research design.....</u>	<u>25</u>
<u>3.1 General approach</u>	<u>25</u>
<u>3.1.1 FEATHERS</u>	<u>25</u>
<u>3.2 Questionnaire</u>	<u>27</u>
<u>3.2.1 Stated preference vs. revealed preference.....</u>	<u>27</u>
<u>3.2.2 Design and variables.....</u>	<u>27</u>
<u>3.2.3 Questionnaire.....</u>	<u>29</u>
<u>Chapter IV. Research execution</u>	<u>33</u>
<u>4.1 Questionnaire</u>	<u>33</u>
<u>4.1.1 Alternative data.....</u>	<u>41</u>
<u>4.2 Zonal crash prediction model (ZCPM)</u>	<u>43</u>
<u>Chapter V. Analysis of research results.....</u>	<u>47</u>
<u>5.1 Fuel cost increase results on car – slow modes crashes for the study area</u>	<u>47</u>
<u>5.2 Fuel cost increase results for car – car crashes for the study area</u>	<u>50</u>
<u>5.3 Total results</u>	<u>53</u>

<u>Chapter VI. Conclusion and discussion.....</u>	<u>55</u>
<u>6.1 Research questions.....</u>	<u>55</u>
<u>6.2 Conclusions and previous research</u>	<u>58</u>
<u>6.3 Recommendations.....</u>	<u>60</u>
<u>Bibliography.....</u>	<u>61</u>
<u>Appendix.....</u>	<u>66</u>
<u>Appendix 1: calculation company cars.....</u>	<u>66</u>
<u>Appendix 2: questionnaire</u>	<u>66</u>
<u>Appendix 3: mode choice for work and non-work related trips.....</u>	<u>67</u>

List of tables

TABLE 1 Typical TDM benefits (Litman, 2014a).....	12
TABLE 2 Road pricing types (Litman, 2013).....	13
TABLE 3 Expected road pricing benefits (Litman, 2013)	14
TABLE 4 World's most congested cities (“Top 10 Most Traffic Congested Cities in the World,” 2014).....	23
TABLE 5 Comparison of revealed and stated preference data (Nobuhiro, 2001)	27
TABLE 6 Variables subjected to randomisation	30
TABLE 7 Example 1	31
TABLE 8 Example 2	31
TABLE 9 Number of respondents	33
TABLE 10 Sex of respondents	33
TABLE 11 Work status	33
TABLE 12 Modal choice change results questionnaire	40
TABLE 13 Modal choice change results new data	41
TABLE 14 Descriptive statistics of selected variables to develop ZCPMs	43
TABLE 15 model estimates for the chosen ZCPMs.....	45
TABLE 16 Share for each category for car – slow mode crashes	47
TABLE 17 Maximum increase and decrease of car – slow modes crashes in percentage for both scenarios.....	49
TABLE 18 Share for each category for car – car crashes	50
TABLE 19 Maximum increase and decrease of car – car crashes in percentage for both scenarios	52
TABLE 20 Overview table predicted amounts of crashes	53

List of figures

<u>FIGURE 1 Flanders in Europe (“Vlaanderen,” 2014).</u>	<u>22</u>
<u>FIGURE 2 Motorway network and urban centres of Flanders (“Centrumstad,” 2014, “Google Maps,” 2014, “Lijst van E-wegen door België,” 2014).</u>	<u>22</u>
<u>FIGURE 3 Number of respondents per age category compared to population of Flanders (ADSEI, 2015).</u>	<u>34</u>
<u>FIGURE 4 Modal choice share according to charge and distance for work related trips.</u>	<u>35</u>
<u>FIGURE 5 Modal choice share according to charge and distance for non-work related trips.</u>	<u>36</u>
<u>FIGURE 6 Modal choice shares for respondents and Flanders according to work and non-work related trips (Janssens et al., 2012).</u>	<u>37</u>
<u>FIGURE 7 Modal choice share for base scenario and per distance category for work related trips (Janssens et al., 2012).</u>	<u>38</u>
<u>FIGURE 8 Modal choice share for base scenario and per distance category for non-work related trips (Janssens et al., 2012).</u>	<u>39</u>
<u>FIGURE 9 Percentages of change in predicted number of crashes for slow modes with the 4 cent fuel cost increase.</u>	<u>48</u>
<u>FIGURE 10 Percentages of change in predicted number of crashes for slow modes with the 8 cent fuel cost increase.</u>	<u>49</u>
<u>FIGURE 11 Percentages of change in predicted number of crashes for cars with the 4 cent fuel cost increase.</u>	<u>51</u>
<u>FIGURE 12 Percentages of change in predicted number of crashes for cars with the 8 cent fuel cost increase.</u>	<u>51</u>
<u>FIGURE 13 Mode choice for work and non-work related trips.</u>	<u>67</u>

Chapter I. Problem statement

1.1 The problem

Flanders has to deal with traffic congestion on a daily basis. There are a variety of measures in order to reduce the congestion in Flanders. One of these measures currently under consideration on a political level, is road charging. This congestion charge would foremost depend upon the amount of kilometres driven, the time at which they are driven and the degree of pollution of the vehicle (Van Besien, 2013). The goal of introducing a road charging scheme would be to encourage a behavioural adjustment. A pricing of € 0,07 per kilometre or more, seems to be enough incentive for drivers to adjust their behaviour (“Kostenneutraal rekeningrijden is onmogelijk,” 2012). In November 2012, the government considered a pricing of € 0,14 in peak hours and € 0,02 in off-peak hours (“Rekeningrijden dure zaak voor helft spitspendelaars,” 2012). Taking into account the € 0,07 necessary to encourage a behavioural change, the peak hour rate seems more than appropriate. The off-peak hour rate is very low and probably wouldn't lead to any behavioural change. This, however, shouldn't mean that there won't be any behavioural change noticeable, specifically due to the high peak hour rate. An aspect that comes into play when there is behavioural change concerning travelling habits, is the traffic safety. A peak hour rate upward of € 0,07 (“Kostenneutraal rekeningrijden is onmogelijk,” 2012) will most likely ensure there are less vehicles on the road during these times. In return, there will most likely be more vehicles on the road during the off-peak hours (compared to the current situation without road charging). This will lead to a change in traffic flows, resulting in a different traffic safety.

1.2 Goal

The goal of this study is to investigate the effects on traffic safety when a road charging scheme is to be implemented in Flanders. Within this thesis, emphasis will be on passenger cars.

In order to investigate the effects of road charging schemes, a stated preference questionnaire is to be carried out. Through this questionnaire, mode choice can be revealed. Using the FEATHERS model (Forecasting Evolutionary Activity-Travel of Households and their Environmental RepercussionS (Bellemans et al., 2010)), which simulates the impact of travel behaviour, the resulting traffic flows can be determined. These results are to be implemented in a ZCPM (zonal crash prediction model (Pirdavani, 2012)) to predict the possible effects on traffic safety.

1.3 Research questions

The central research question that will have to be answered at the end is the following:

What are the effects of a road charging scheme on traffic safety in Flanders?

There are several research questions that have to be addressed before the actual central research question can be solved.

- What defines a road charging scheme?
- What would be the impact of a road charging scheme on travel behaviour decisions?
- How do the changes in travel behaviour decisions influence the traffic performance?
- How do the changed traffic flows influence the traffic safety?

In a further stage, road charging schemes might even influence spatial planning, which in turn will affect traffic safety. This aspect however, isn't a direct part of this thesis and there will be no attempt to determine the influence on traffic safety. Primarily this is because the models that are to be used, are based on existing road networks. In order to determine the traffic safety in a different road network, an entirely new network has to be created in order to determine traffic safety. Even then, the issue of validation would arise: is the created new road network realistic and are the predicted traffic flows correct.

1.4 Plan of approach

In order to bring this study to a successful ending, a plan of approach has to be drafted. This outlines the steps that are to be undertaken, the time at which they most likely will be undertaken etc.

Literature study

The first step to be carried out is a literature study. Different road charging schemes in the past may have used different variables, through literature study these variables may be revealed and listed. Starting from this list of variables, a selection can be made to use in this thesis. There might be for example different solutions concerning pricing and timing of the charge. This might also lead to ideas for different scenarios.

Through literature study, the representative amount of respondents for the questionnaire in comparison to the entire population in the research area (Flanders) will be indicated at the appropriate time.

Variables

The result of the literature review will yield variables that can be utilized in the creation of a stated preference questionnaire.

Questionnaire (creation)

The questionnaire will be a stated preference questionnaire. The reason is that in this type of questionnaire, the starting point is a hypothetical situation. Since road charging isn't being used at this moment, people can only state their preference. There is no guarantee that they will behave as stated if the hypothetical situation becomes reality. The amount of respondents necessary with a stated preference questionnaire isn't very high. This in turn ensures that the results can be gathered and analysed on a short time period. The questionnaire will be based on the findings of the literature study.

Questionnaire (execution)

The questionnaire will then be distributed to the selected respondents. Important in this study is that the respondents are a good reflection of the entire population (being all traffic participants in Flanders). This

in order to eliminate the risk that one or more groups of the population (based on criteria such as might be age, gender, occupation etc.) are overrepresented or underrepresented when analysing the gathered data.

Questionnaire analysis/creating a choice model/creating scenarios

Based on the response, scenarios will be created as input to the FEATHERS model. Before this is done, a choice model will be created. This choice model will be implemented first in FEATHERS. After this step, different scenarios can be created and run through FEATHERS. There will always be a null scenario, being the traffic safety scenario when no road charging is implemented. A comparison of alternative scenarios to a null-scenario will be carried out in a later stage, when all the data has been run through the models.

Models

The models are the last step in the study. Based on the analysis of the questionnaire, input data will be created.

The changed travel behaviour decisions, resulting from the effects of the road charging, will be determined through the FEATHERS-model. This activity-based transportation model describes which activities an individual wishes to carry out, at what time, with whom, where and with which mode of transport the journey will be made. By applying this model to all individuals of a population, a detailed estimation of the traffic demands can be determined.

The safety effects of the implementation of road charging can be measured by creating and utilizing a ZCPM.

As stated earlier, different scenarios will probably be created and then compared to the null scenario, or the scenario wherein no road charging is implemented for Flanders.

In the end, a conclusion will be reached which will form an answer on the central research question.

Chapter II. Literature study

2.1 Road charging: what is it?

Road charging is a measure of Transportation Demand Management (or TDM).

People make travel decisions on a daily basis. The travel decisions depend on several aspects. They make these trips because they want to perform a certain activity like working, shopping, recreational etc. In order to reach this destination, there are institutional restrictions like working hours of your company, opening hours of shops and so forth. It is also possible to do more than one activity in one trip. Based within that possible frame, a mode choice is made. This depends on availability of chosen transport, a person's set of abilities (riding a bicycle, in possession of driver's license etc.), infrastructural facilities of the possible modes, the safety. Based on the mode choice, there is a route choice bound to it. In combination with the time choice, this can and will result in traffic. Where the capacity of the chosen mode or infrastructural facilities is reached and surpassed, congestion will arise. TDM uses strategies to influence travel decisions in general, and this is achieved by influencing one or more of the aspects bound to travel decisions.

TDM encompasses a series of strategies which aim to alter travel behaviour and increase the efficiency of the transport system (Litman, 2014a). These strategies can be classified in four main groups:

- Improvement of transport options;
- Incentives;
- Land use management;
- Policies and programs.

Improvement of transport options is directed at the mode choice. In order to influence the mode choice, measures can be taken on an infrastructural level (HOV-lanes, bicycle parking), socio-economical level (telework, alternative work schedules) or mode level by improving existing efficient mode choices (non-motorized transport, public transport, car sharing and carpooling).

Incentives are measures that try to change people's behaviour by increasing costs for less efficient mode choices. Road pricing, parking pricing, fuel tax increases and so forth are examples.

Land use management aims at how the available space is used. By making changes in planning, people can be guided and encouraged to change their behaviour. Creating more diversity of activity (housing, working, shopping and recreation) in a small area (smart growth/new urbanism) to reduce the need for long-distance transport, managing parking spaces to increase efficiency of the available space, long-term car-free planning etc.

Policies and programs address remaining aspects that influence travel decisions/behaviour. It can also combine measures of the other strategy groups in a more comprehensive and complete manner to achieve better results than applying only one measure (parking management and parking pricing).

TDM measure can benefit a society in multiple ways, some obvious, some less obvious. TABLE 1 gives an overview of typical TDM benefits according to Litman (2014a).

TABLE 1 Typical TDM benefits (Litman, 2014a)

Benefits	Description
Congestion reduction	Reduce traffic congestion and associated costs
Road & parking savings	Reduce road and parking facility costs
Consumer savings	Help consumers reduce their need to own and operate vehicles
Transport choice	Improve travel options
Road safety	Reduce crash risk
Environmental protection	Reduced air, noise and water pollution, wildlife crashes etc.
Efficient land use	Support strategic land use (urban redevelopment, reduce habitat fragmentation)
Community liveability	Improve local environmental quality and community cohesion
Economic development	Support economic objectives (increased productivity, employment, wealth, property values, tax revenues)
Physical fitness and health	Improve public fitness and health due to more physical activity (increased cycling and walking)

TDM measures aren't only influencing aspects that are directly linked to traffic, but also influence aspects on a higher level. These aspects are overlooked easily but are important as well to take into account.

Road charging, also referred to as *congestion pricing* or *value pricing*, is a measure from the incentives-group. It belongs to the larger group of *Road pricing*. There are several types of road pricing, which are different both in use as in objective. TABLE 2 gives an overview of these different types.

TABLE 2 Road pricing types (Litman, 2013)

Type	Description	Objective
Road charging	Time-based charge, higher in peak than off-peak hours	Raise revenue and reduce congestion
Cordon fees	Location-based charge, charge for driving in specific area	Reduce congestion in major urban centres
Distance-based fees	Mileage-based charge, charge for each kilometre driven	Raise revenue and reduce various traffic problems
HOV lanes	High Occupant Vehicle lane that accommodates limited number of lower-occupant vehicles for a charge	Favour HOV's compared with general-purpose lane Raise revenue compared with HOV lane
Pay-As-You-Drive insurance	Make insurance a variable cost dependant on mileage	Reduce primarily crashes and other various traffic problems
Road space rationing	Revenue-neutral credits to ration peak-period roadway capacity	Reduce congestion on major roadways or urban centres
Road toll	Road-based charge, charge for driving on a specific road	Raise revenues

The road charging that is most likely going to be used in Flanders, is a combination of *congestion pricing* and *distance-based fees*. The road user is charged for each kilometre driven with the charge at a higher level in peak hours than in off-peak hours. The objective in Flanders would be primarily to reduce congestion. The revenues generated by the road charging scheme will then replace the annual road tax that is due on every subscribed vehicle in Flanders.

In these times, road charging isn't seen as a measure of TDM solemnly, but also as a means to reduce greenhouse gases. According to the European Environment Agency (EEA); "*road transport is responsible for 17.5% of overall greenhouse gas emissions in Europe*" ("Most carmakers must further improve carbon efficiency by 2015 — European Environment Agency (EEA)," 2012). Carmakers are obliged to reduce the amount of pollutants each vehicle produces through regulation such as the EURO-norms. Each country also has a different fiscal system that is based on a combination of factors regarding vehicles and pollution is very frequently used in these systems. The majority of those rules are applicable to company cars only however, so there is a large share of vehicles not influenced by the policy measures. By aiming to reduce the amount of kilometres driven by each vehicle, the amount of pollutants created by road transport can be reduced.

2.1.1 Road charging

Road charging can be performed either with fixed charges or dynamic charges. The difference between the two is that with a dynamic charge, the charge depends on the congestion level at that specific time. If congestion lowers, charges drop to lower levels and the route can become more interesting for drivers. This is a perfect example of TDM, since drivers can be encouraged or guided to a less congested route which saves them time and possibly money and optimizing roadway capacity. There are highways that

combine free lanes with priced lanes that leaves the decision to pay up to the driver (Litman, 2013). He has the choice to drive in a congested lane or in a congestion-free lane where he has to pay. This is a type of *Responsive Pricing*, of which the goal is to change consumption patterns (Vickrey, 1997). There is one condition however concerning road pricing: there have to be viable alternatives. With a dynamic charge, the traffic pressure on a certain route can be relieved by making an alternative more interesting through a lower charge. With fixed charges, alternatives are public transport, carpooling or car sharing, more flexible working schedules or even teleworking.

TABLE 3 shows three road pricing strategies: road charging with a fixed charge, road charging with a dynamic charge and distance-based fees. For each of these, it shows the expected result for revenue generation, congestion reduction, pollution reduction and safety effects. A higher value indicates larger expected effects.

TABLE 3 Expected road pricing benefits (Litman, 2013)

Strategy	Revenue generation	Congestion reduction	Pollution reduction	Safety effects
Fixed charge	+3	+2	+1	+1
Dynamic charge	+2	+3	+2	+1
Distance-based	+3	+2	+2	+2
Flanders	+3	+2	+2	+2

Litman (2013) indicates that concerning revenue generation, a fixed charge and distance-based fees are most profitable. A dynamic charge is less profitable, probably because it can act as a guiding hand and lower charges can be used to optimise network capacity. Drivers will not choose routes that are congested and expensive if less congested and cheaper routes are available.

Concerning congestion reduction, a dynamic charge is most efficient. Again, by guiding drivers to more preferable routes, network capacity is optimised and congestion relieved. A fixed charge will not influence driver's route choice as much, while a distance-based fee might mean that drivers opt for the shortest route possible and those shorter routes are clogged faster.

Reduction of pollution is important too, and both the dynamic charge and distance-based fees are most efficient. By keeping traffic flowing, the emission levels in a certain area can be lowered compared to a congested situation. It may also mean that more kilometres have to be driven by other drivers, which might offset the gains by keeping traffic flowing. A distance-based fee means that most drivers choose the shortest possible route and thus reducing congestion compared to a longer route, if there is congestion on that route however the emissions can be elevated. Since a fixed charge doesn't influence a driver's route choice as much, the reduction of pollution will be less than those of the other strategies.

Concerning safety, a distance-based fee is most efficient. By choosing the shortest possible route, exposure is lower and the amount of crashes is lower at same risk levels (see

Traffic safety for more information concerning exposure, risk and amount of crashes). If those routes become congested, exposure and risk might be higher though. Fixed and dynamic charges are less efficient in increasing traffic safety. While both decrease the exposure rate, risk remains fairly constant thus the amount of crashes aren't influenced as much as distance-based fees.

Since the proposed road charging in Flanders combines fixed charges with distance-based fees, they have an altogether different expected effect on these four elements. It isn't simply a matter of summing up or averaging the values, since they can produce similar effects. In TABLE 3, the last row indicates the expected values for each of these elements. Where the values are identical for each separate strategy, the value is retained. Where the values differ, the highest value is selected.

In general, it must be said that a dynamic charge means there is more need for information for all drivers at any given time, as to maximise the guiding process. If drivers would have access to the same information when a fixed charge is applied, it might already mean some drivers choose the alternative route out of time consideration. In a small study as this, where the goal is to research safety effects of a yet to be introduced road charging scheme, it would increase complexity at the questionnaire and analysis afterwards and thus is not researched.

As said before, the benefits (summed up in TABLE 1) of a fixed charge and distance-based fee will be discussed.

It is explained why fixed charges combined with distance-based fees are interesting to increase mobility, the manner in which all these vehicles will be tracked isn't explained yet. There are several possibilities regarding this aspect:

- Pass: in order to enter a cordoned area, motorists have to buy a pass or road vignette;
- Toll booths: in order to use a certain part of the road network, drivers stop and pay at a booth.
- Electronic tolling: similar to toll booths although more advanced using more technology.

Overhead gantries are positioned at entry and exit points of a chosen area while vehicles are equipped with On-Board Units or OBU's in short. Each time they pass the gantry, they are charged for entering or driving through the area (e.g. Area Licensing Scheme, Singapore) (Bussels & Roosen, 2012).

- Optical Vehicle Recognition: at the entrance and exit of the chosen area, cameras with Automatic Number Plate Recognition are placed. Number plates of vehicles entering are registered and charged. Depending on the system, drivers may pay in advance or are charged afterwards (e.g. London Congestion Charging Scheme, London; Stockholm Congestion Tax, Stockholm) (Bussels & Roosen, 2012).
- GPS: each vehicle is equipped with an OBU and tracked individually. Data related to the time and place of the trip are automatically transmitted to a central computer. Drivers may have an account where they charge money on where the road charge is levied automatically or the charge has to be paid afterwards.

The road network and size of the area subject to the road charging are the largest determinants of the way in which vehicles will be tracked.

The road network in Flanders is very elaborate (see 2.3). The proposed road charge for Flanders would encompass all roads, although pricing differences between different types of road are still under consideration (Maerivoet & Delhaye, 2012). In close relation to the road network, is the area size. The proposed road charge scheme would cover the whole of Belgium, or 30.000 square kilometres. Toll booths or gantries would be insufficient, since within the area there would have to be booths as well for all internal trips. If the charge was to be levied on a specific type of road, such as highways only, gantries or toll booths would become more interesting. The road charging scheme will be applied to the entire road network though, thus toll booths and gantries aren't viable options for Belgium.

There is another type of vehicle tracking possible besides the ones discussed. Described by the Intelligent Transportation Systems Institute at the University of Minnesota (Donath et al., 2009), it isn't a system that seems to be used as of yet. It uses an in-vehicle device that can be connected without any alterations to the vehicle nor existing infrastructure. The device has access to the vehicle data bus and power and electronically calculates distance driven, which is then relayed through cellular service to the relevant institution. A differentiation between rural and urban areas is possible. There is no need for a GPS device, although this would be recommendable in Belgium if different charges are levied on different road types for more accurate positioning.

2.1.2 Other incentives

In the group of incentives, there are still other measures that can have a similar effect to road charging. **Fuel tax increases** can have a similar though different effect on people's behaviour. According to Litman (2014b), there are various reasons to increase fuel taxes:

- As a road user fee;
- To finance transportation programs;
- To encourage energy conservation;
- As a TDM strategy;
- As a revenue-neutral tax shift;
- To fund vehicle insurance.

Levying a charge on fuel cost brings along some advantages over road charging:

- No need to set up a complex system that has initial installation costs and requires maintenance over time. All the required systems already exist and are being used;
- Less economical vehicles that create more pollution will automatically pay more;
- Reduction of pollution as a consequence of mode choice as people will explore alternatives;
- Possible stimulant for vehicle sales as people will want to buy a newer, more economical vehicle earlier. This might also increase revenue for the government through taxes on sales;
- Less fraud sensitive.

With a road charging scheme, a complex system needs to be installed and maintained. If a part of the system (the OBU for example) breaks down and the owner keeps driving, he might free-ride for a while.

There are downsides to this alternative too:

- No differentiation possible concerning the time-element. The charge is exactly the same 24/7;

- It has no solution for the social element. Low income families will experience more nuisance of this measure (low budget restricts them from buying new, more economical vehicle) thus requiring government intervention;
- It is an extra charge on top of the already existing taxes levied on fuels, therefore it is very difficult to determine what part of the fuel price per litre is considered as the charge (unless a set charge is used). If no set charge is used, there will be no transparency about the charge;
- Fuel prices have the tendency to fluctuate over time. This raises the question if a set charge is to be used or if a certain percentage of the market fuel prices is to be levied as charge (the possibility of a set price per litre is highly unlikely, since there is an array of fuel suppliers with differences in prices).

With a road charging scheme, the prices are far more transparent. There is also the possibility to vary the charge according to time of day (essentially peak and off-peak hours) and thus resulting in a congestion oriented charge.

A study concerning the road safety effects of a fuel price increase for the Flanders region has been performed recently (Pirdavani, Brijs, Bellemans, Kochan, & Wets, 2012). The conclusion of that study is that an increase of the fuel price by 20% would result in a considerable traffic safety benefit. The amount of kilometres driven annually would drop by 11.57%, which would reduce the number of injury crashes by 2.83%.

2.2 Traffic safety

Since the goal of this thesis is to analyse the consequences of a road charging scheme on traffic safety, it is important to define traffic safety and how it can be measured.

According to Evans (2004, p. 6), there is no precise nor quantitative definition of traffic safety. Although it is used both by specialists as well as the public, it rarely generates any misunderstanding concerning its meaning. It is a general concept that he described as follows: “the absence of unintended harm to living creatures or inanimate objects”.

It becomes clear that measuring traffic safety is very difficult. How can one measure the ‘absence of unintended harm’? Therefore, traffic safety is measured by the opposite, being traffic unsafety (Daniëls, 2011). In essence, we count the amount of situations where harm is done to either living creatures and/or inanimate objects. This can result in the following objective counts:

- Number of crashes over certain period of time or per distance;
- Number of lightly injured;
- Number of severely injured;
- Number of deaths.

In order to put these numbers in perspective, the amount of crashes can be recalculated to number of crashes per vehicle kilometre driven, number of severely injured per passenger kilometre driven, ... This offers us a better perspective and context regarding the amounts. Within this context, it becomes easier to determine traffic unsafety and deduce from this, the traffic safety.

When performing a study however, where no quantitative, objective numbers can be gathered or observed, one has to use other methods to calculate an approximation of crashes or the expected number of crashes. In this respect, literature has come up with a formula. Daenen (2012) uses two variables to measure the expected number of crashes. These variables are *exposure* and *risk*. By multiplying these two elements, the expected number of crashes is attained.

Exposure is defined as “being in a situation which has some risk of involvement in a road traffic accident” (Wolfe, 1982). This definition includes both the active and passive aspect of being involved in a traffic accident. The active aspect refers to actively participating in traffic and being involved in situations with a risk of an accident. The passive aspect refers to situations where one is not (actively) participating in traffic (e.g. waiting in a car for a passenger, sleeping in a ground floor bedroom). A person is exposed to an accident in both aspects, although the exposure is lower when sleeping in a ground floor bedroom than driving on a congested road.

Within exposure, risk was already mentioned. Risk factors are various and can be categorized in four large groups, with subdivisions (Daenen, 2012):

- Spatial context:
 - Morphology, built-up area;
 - Road function, place in network.
- Longitudinal profile:
 - Number of driveways.

- Cross direction profile:
 - Road composition;
 - Traffic regulation;
 - Road environment.
- Site characteristics.

The risk thus varies greatly, as does the exposure.

2.2.1 Safety on macroscopic vs microscopic scale

Safety evaluations can be performed on two scales; macroscopic and microscopic. They are very different in approach. Macroscopic scale is on a large, regional scale and thus deals with characteristics on a macro-level e.g. income level, trip production/attraction, ... Microscopic scale focuses on small parts of the network such as one intersection. It describes crashes in a much more detailed manner, by for instance, considering human factors contributing to crashes, the influence of age on crashes, ...

Furthermore, safety analysis will be performed by using crash prediction models. Crash prediction models can estimate the amount of crashes that can be expected in a certain TAZ. These can be performed on a stretch of road or an intersection (microscopic scale) or on a larger, regional scale (macroscopic) (Pirdavani, 2012). TDM measures such as the road charging in this work, are applied on larger areas. In order to analyse the traffic safety impact of the proposed road charging scheme, an analysis on the macroscopic scale has to be performed.

Macro-level characterized variables are used by crash prediction models as explanatory variables that predict the number of crashes in an area. In a study conducted by Pirdavani et al. (2012), it was indicated that there are many variables that are significant predictors of crashes at the zonal level.

Exposure, as mentioned earlier, is one of the most important predictors of crashes. The exposure can be represented by the number of trips, vehicle hours travelled or vehicle kilometres travelled. It was observed that as these variables increase, so do the number of injury crashes.

The average speed limit, number of intersections and population were also positively correlated with the number of injury crashes per TAZ. Higher speeds increase the likelihood of injury crashes, more intersections mean more conflicts between vehicles which lead to more injury crashes. Existence of more inhabitants in a TAZ lead to higher exposure rates and more unsafe situations compared to less inhabited TAZs.

A negative association was found for income level. Poverty does have an influence on the amount of crashes. It is, therefore, observed that more crashes occur in lower-level income TAZs compared to higher-level income TAZs.

Urban areas experience more crashes than rural areas too. Explanations might be a combination of previously discussed factors, such as the population level, the amount of intersections, vehicle hours travelled etc.

2.2.2 Safety effects of TDM measures

TDM measures have already been described earlier. There, solely the different methods and reasons for applying a TDM measure were described and discussed within the framework of this thesis. In this part, the safety aspects of TDM measure are discussed, also within the framework of the thesis. The focus will

thus be on traffic safety effects that have been reported when implementing a road charging TDM measure.

Litman (2014c) indicates two major approaches of traffic safety strategies; *engineering* and *behaviour*. The engineering approach focuses on vehicles and infrastructure, while the behaviour approach focuses on traffic participants through mobility management, occupant safety and cautious driving.

Worthwhile to mention is that Litman (2014c) says that strategies aimed at congestion reduction can reduce the amount of crashes occurring, but also can increase the severity of crashes that do occur. Thus, strategies that shift “automobile travel time, route or destination do little to increase road safety or public health, and may increase injuries and fatalities.” The important part is to reduce total vehicle travel. ZCPMs that predict the number of crashes, based on existing crash data, will be created later on. The data is limited to crashes with injuries and doesn’t have geo-located property damage, so the model can’t predict the total number of crashes. It will predict the total amount of injury crashes, where one or more persons are injured. When strategies are applied that shift automobile travel to no motorized modes, “the risk per kilometre to people who change mode may be increased but can be offset by reduced risk for other road users, reduced trip length and health benefits from the aerobic exercise.”

If a strategy is applied that reduces total personal travel, large safety benefits are to be gained. For each 1% reduction in motor vehicle travel, the total crashes and casualties are reduced by 1,4% to 1,8% (Litman, 2014c).

For the suggested road charge in this thesis, the goal is to reduce the total amount of kilometres travelled, and for some trips, attain a shift to other modes of transport. Both of these goals are necessary to reduce congestion. As Litman (2014c) indicates, solely a modal shift may lead to less crashes but a higher severity of remaining crashes. This can be addressed by reducing the total amount of kilometres travelled, since the amount of crashes is expected to drop too then. When a higher reduction than 1% of total kilometres travelled can be attained, higher reductions of the amount of crashes and casualties are to be expected too.

In order to improve safety, a reduction in personal travel is required. If the reduction of personal travel is low, the attained safety benefits will be low too. A modal shift accompanying the introduction of a road charge may as well increase the amount of crashes and casualties, depending on the specific modal shift.

A study performed by Schepers & Heinen (2012) shows that with a shift for short trips from car to cyclist (or by foot), fewer victims are to be reported. The number of serious road injuries would increase though. The majority of this increase is due to single-bicycle crashes and not to increased crashes with other traffic participants. There is a neutral effect to be noticed on the number of fatalities.

Age is an important factor in cyclist casualties. At ages of 65 and up, the amount of fatalities is expected to increase, for ages ranging from 18 to 64 the amount of fatalities is expected to decrease. Car drivers in the age group of 18 to 24 shifting to cycling, gain the highest decrease in amount of fatalities. Regarding crashes, if more young car drivers shift to cycle use, a reduction in number of crashes is to be expected. For elder car drivers, the opposite is true. If the average population shifts, neither a decrease nor an increase is to be expected. It is desirable for a modal shift from car to bicycle to be spread unequally over the population to increase the overall traffic safety.

2.3 Study area: Flanders

Flanders is the northern region of Belgium. The official language in Flanders is Dutch. It's size of 13.682 km² combined with near to 7.5 million inhabitants, results in Flanders being one of the most urbanized areas in the world ("Vlaanderen," 2014). Furthermore, Flanders is positioned centrally in Europe and has the 15th largest container port (Antwerp) (World Shipping Council, 2013) and 78th busiest airport (Zaventem) (Rogers, 2014) in the world. In order to connect all these city and logistical centres, roads are necessary. As a country, Belgium has the most dense road network in the world: 508 kilometres of road per 100 square kilometres (OECD, 2013). The average for Europe, as comparison, is 118 km per 100 km². The motorway network density in Belgium is 577 km per 100 km², trailing behind Netherlands (637 km per 100 km²). The European average stands at 146 km per 100 km².

FIGURE 2 shows Flanders and its 13 'centre cities' (in Dutch: *centrumsteden*) plus the Belgian capital, Brussels. These thirteen centre cities are considered as defining for their surrounding area. From left to right, the centre cities are Ostend, Roeselare, Bruges, Kortrijk, Ghent, Aalst, Sint-Niklaas, Antwerp, Mechelen, Leuven, Turnhout, Hasselt and Genk.

Besides these cities, the map also shows the most important E-roads that cross Flanders and connect to large cities of neighbouring countries, such as the French Calais and Lille and the Dutch cities of Breda, Eindhoven and Maastricht. The German city of Aachen is also connected through Maastricht.

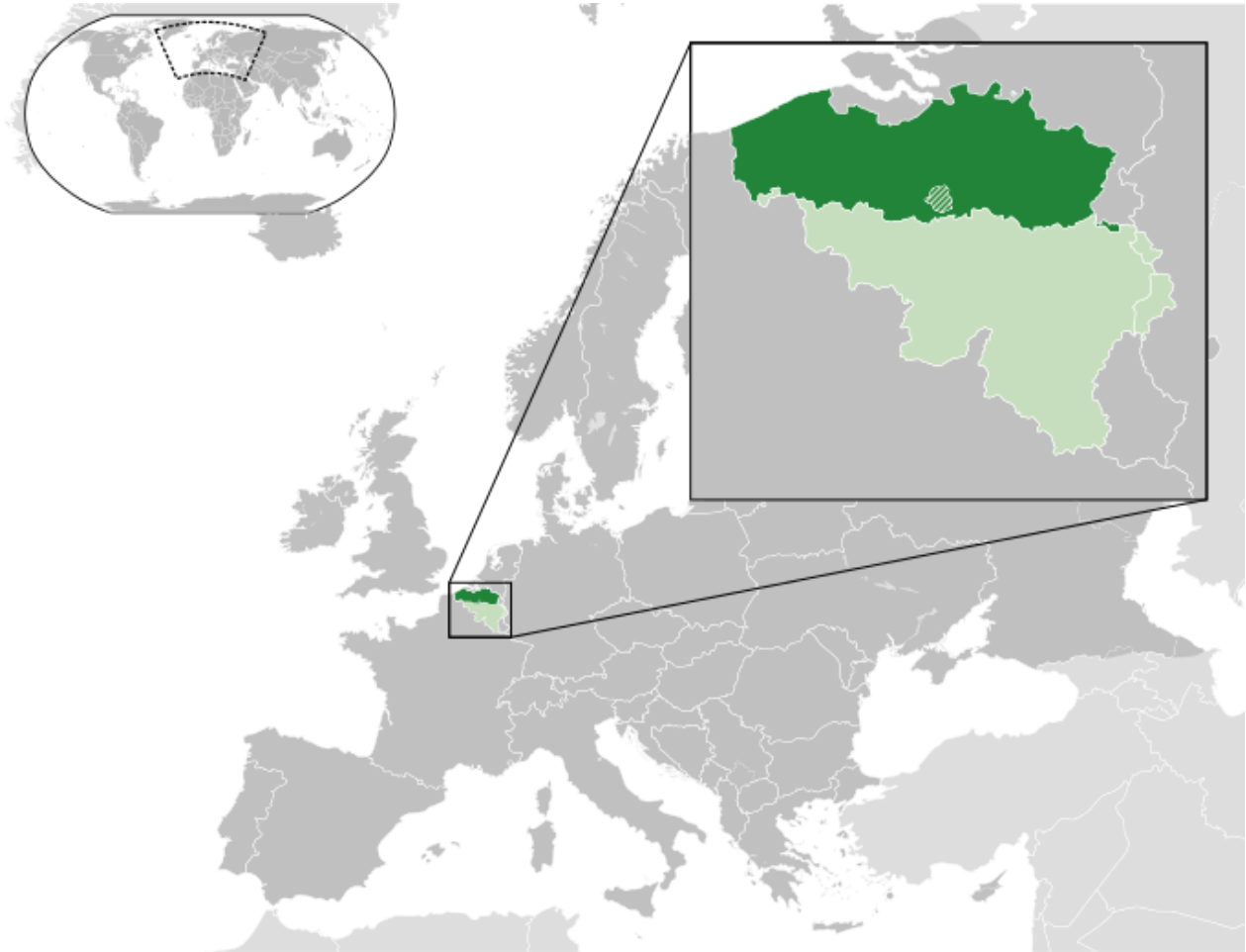


FIGURE 1 Flanders in Europe (“Vlaanderen,” 2014).



FIGURE 2 Motorway network and urban centres of Flanders (“Centrumstad,” 2014, “Google Maps,” 2014, “Lijst van E-wegen door België,” 2014).

As a result of the high road network density, Flanders has to deal with congestion on a daily basis. A dissimilarity between Flanders and other regions, are that in other regions congestion usually exists in the perimeter of large cities with a high population density. In Flanders, it can be said that the congestion is more spread out in comparison to other regions, following that Flanders is one of the most urbanized regions in the world.

Taking a look at the top ten of most traffic congested cities in the world, the top two places are covered by two cities in the Flanders region, first spot being taken by Brussels and second place going to Antwerp. When going further through the list, other large cities such as Milan (number four), London (number five) and Paris (number six) are featured too. When comparing the population densities however, something interesting can be noted.

TABLE 4 World's most congested cities ("Top 10 Most Traffic Congested Cities in the World," 2014)

Ranking	City	Population density per km²	Ranking	City	Population density per km²
1	Brussels	7 000	6	Paris	21 000
2	Antwerp	2 300	7	Honolulu	2 150
3	Los Angeles	3 200	8	Rotterdam	3 000
4	Milan	7 300	9	Manchester	4 350
5	London	5 350	10	San Francisco	6 900

TABLE 4 shows that in the case of Brussels, the density is equal or lower when compared to other congested cities. In the case of Antwerp, the density is much lower. Despite these lower densities, both cities still attain the top two spots of the list. The explanation for this problematically high levels of congestion can be due to several factors. It may be the result of poor spatial planning and execution in Flanders as a result of the lack of vision from the policy, it might also partially be explained by the culture in Flanders.

During the last century, a number of European routes (labelled as Exx or Exxx (where the x's stand for numbers)) have been constructed in Flanders, just as in other European countries. Because they provided a capacity that was much higher than the demand at the time of construction, for Flanders (and expansion Belgium) it might have led to people wanting to live in a quiet, rural area. On roads with a high capacity and low demand, the commute would have been very pleasant. Combined with the BREVER-law (the preservation of travel time and travel)¹, this lead to commuters moving away from their desired workplace further and further, resulting in the situation that Flanders faces today. The demand for infrastructure has outpaced the capacity of the infrastructure or road network.

The tendency to live in a rural area is still evident to this day, considering there are very few stretches of road in Flanders where there is almost no indication of human presence. The low density found in cities in Flanders reflects this too. Add to these that the road density in Belgium is one of the highest of any

¹ People have a tendency to restrict their travel time to a certain amount per day, which is situated around 80 minutes. Due to faster ways of transport (as a result of improvements on both vehicles and infrastructure), the distance that can be covered in that time has increased or decreased as society changed.

country in the world. Per 1 000 square kilometres, there is around 5 040 kilometre of road (Federaal Planbureau, 2014). This equates to a total of almost 155 000 kilometres of road in Belgium.

A second partial explanation could be the culture of Belgians. There is a saying in Dutch, which literally translates to: 'all Belgians are born with a brick in their stomach'. This refers to the fact that most Belgians consider building their own house as a life goal. Due to a changing market and reduced building space, an increasing number of Belgians buy a house (UPR, 2014). Nonetheless, they tend to live their whole life as long as possible in one house. As a consequence, the average daily distance travelled by a Belgian is 37 kilometres (Janssens, Declercq, & Wets, 2013). This includes all trips. When analysing work-related trips only, there are large differences attributable to educational level (Janssens et al., 2013). A person with a university degree on average has a commuting distance of 77 kilometres compared to 10 kilometres for a person that finished primary school. In general it can be said that persons with a higher educational level have higher commuting distances. This can also be linked to the third factor in the next paragraph.

A third factor could be the payroll charges in Belgium, that have led to companies offering company cars to their employees instead of a raise. Cars are an extra-legal benefit for employees, which most would gladly accept. According to a research performed by KPMG (Snoeys, 2012) the current national fleet consists of 20,66 % company cars. Compared to privately owned vehicles, these company cars on average drive 42 % more kilometres annually. This results in company cars representing 27,13 % of the total distance driven by the national vehicle fleet. Calculations for these numbers can be found under Appendix 1: calculation company cars.

Reliable estimates based on studies performed by the government and questionnaires performed by social organisations, indicate that about 1 in 3 cars during congested traffic are company cars (Van Gool, 2014). This is supported by the 27,13 % calculated earlier. There seems more to be gained by addressing private owned cars, although company cars can be more easily targeted through policy measures.

Chapter III. Research design

3.1 General approach

The goal of this thesis is to analyse the expected traffic safety if a road charging scheme is introduced in Flanders. In order to estimate this, several steps need to be taken.

A model to analyse the traffic safety is needed. ZCPMs can be created with the help of Ali Pirdavani, researcher at IMOB. The outcome of the ZCPMs will be validated by comparing it to observed crashes. The input for these ZCPMs needs to come from another model. This model will be FEATHERS, also developed at IMOB. Since it is an activity-based transportation model, it can simulate individuals' traveling behaviour in a realistic way. When introducing TDM measures in this model, the output will be reliable and can be used as input data for the ZCPMs. A questionnaire will provide data that will be used in FEATHERS to create a road charging sub model. This sub model can be implemented in FEATHERS.

The first step in the process, is to create a questionnaire that reveals the input data needed for FEATHERS. Of importance is to determine the expected behavioural change of individuals.

The second step is to create a sub model in FEATHERS, using data from the questionnaire. FEATHERS generates estimates of trips, based on the input data. These estimated trip data will then be used as input for the ZCPMs, the next step in the process.

The third step is to use the output data of FEATHERS as input to create the ZCPMs. Different outputs of scenarios from FEATHERS will yield different crash predictions in this last model.

3.1.1 FEATHERS

FEATHERS is an activity-based transportation model for transport demand and is short for Forecasting Evolutionary Activity-Travel of Households and their Environmental RepercussionS (Bellemans et al., 2010). It takes into account the activities an individual wants to carry out, at what time, with whom and the modal choice of the person. If applied to all individuals, a detailed estimation of traffic demand can be determined.

FEATHERS is a stochastic model. This entails that different runs of the model will yield slightly different results. When continuing with such data, this will mean that the results of reductions or increases in expected amount of crashes for each TAZ cannot be regarded as true. What can be deducted is if the amount of crashes is increasing or decreasing, and the approximate magnitude of this change. For best results, the FEATHERS model should be performed several times and an average of these results used as input for the ZCPMs.

FEATHERS is a framework made up of several modules that interact (Bellemans et al., 2010).

- Data module: two major data files: supply and demand. All other modules make use of the data stored in this module;
- Population module: data about individuals' characteristics and attributes are stored here.
- Schedule module: different scheduling algorithms can be implemented through this module. Using data about individuals from the population module and creating a schedule for each of these individuals, it stores the result back in the schedules in the population module;
- Statistics and visualisation models: constructs reports concerning the synthetic population and activity-schedules;
- Training module: calibrates the FEATHERS framework by using real-life data. It generates calibrated model parameters for the models used in other modules.

In Appendix 2: questionnaire, all questions posed in the questionnaire will be stated. The questions yield data that is needed to properly run FEATHERS.

As with all models, FEATHERS can't take all possibilities into account. The four modal choices are based on possibilities within the FEATHERS framework. Therefore, motorcycles aren't included since FEATHERS' ability to model these properly in congested situations is limited. This is somewhat unfortunate, since motorcycles have a positive impact on congestion. A study done in Flanders ("Rekeningrijden vermindert verkeer met 10%," 2012) shows that if 10% of all vehicles during peak hours would be motorcycles, both length and duration of congestion would decrease with as much as 40%. According to research of travel behaviour for Flanders (Janssens, Declercq, & Wets, 2012) the average occupancy rate of work related trips is 1,07 persons per vehicle thus in 95% of all work related trips made by car, the driver is the solemn occupant of the vehicle. A modal shift from car to motorcycle would therefore be very interesting as to reduce congestion levels in Flanders.

3.2 Questionnaire

3.2.1 Stated preference vs. revealed preference

The first step in this research, is to determine the behaviour of people when a road charging scheme is applied. Since there is no road charging scheme active, people’s behaviour can’t be revealed, thus eliminating a revealed preference questionnaire. A stated preference questionnaire is the questionnaire of choice here. It brings some advantages with it, but also some disadvantages, both of which are summed up in TABLE 5.

TABLE 5 Comparison of revealed and stated preference data (Nobuhiro, 2001)

	Revealed preference data	Stated preference data
Preference information	<ul style="list-style-type: none"> • Result of actual behaviour • Consistent with real-life behaviour • ‘Choice’ result 	<ul style="list-style-type: none"> • Expression under hypothetical situation • Possibility of inconsistency with real-life behaviour • ‘Ranking’, ‘rating’, ‘choice’, etc.
Alternatives	Only existing alternatives	Existing and non-existing alternatives
Attributes	<ul style="list-style-type: none"> • Measurement error • Limited range of attributes’ levels 	<ul style="list-style-type: none"> • No measurement error • Extensibility of range of attributes’ levels
Choice set	Non-clear	Clear
Number of respondents	One response per respondent (large amount of respondents needed)	Multiple responses per respondent (smaller amount of respondents needed)

A major downside of stated preference research is the reliability. The stated behaviour may not correspond to real-life behaviour. It is possible that a respondent wants to justify their actual behaviour or even try to influence policies.

There is a need to perform a stated preference questionnaire in this thesis, because there isn’t a charging system being used today. Respondents thus have to state their preference since it isn’t possible to reveal this through research.

3.2.2 Design and variables

A questionnaire needs variables that can assume different values or levels. More variables and levels lead to more extensive questionnaires, which in its turn can lead to more time needed for analysis. The variables and levels used in this questionnaire, will be summed up later. The different designs possible in order to create a questionnaire are discussed first. An overview of designs used to create the questionnaire, are summed up below. These are based on Nobuhiro (2001).

- Orthogonal design: all the variables used are varied independently from one another and thus eliminates any chance of multicollinearity. Multicollinearity is a statistical phenomenon, meaning that two variables are highly correlated and can be predicted from the others;
- Full factorial design: every possible combination of variable levels is used;
- Randomised choice sets creation: each respondent has to answer a certain amount of random selected hypothetical situations.

Nonetheless, there are some issues inherent to full factorial design. These are discussed but don't necessarily mean that they arise in the questionnaire coupled to this thesis.

Trivial questions are questions on which the answer is already known before the respondent even answers. There are some hypothetical situations where one choice might dominate all others, or a hypothetical situation wherein one choice is dominated by the other choices. In such a hypothetical situation, it is already clear what the respondent will or definitely will not choose leading to a low information response. If trivial questions are presented continuously, the respondent tends to answer more quickly and less thoroughly, reducing data reliability. The researcher can remove trivial questions to counter this problem, although it can be useful to leave one trivial question in the questionnaire to more easily identify a respondent making choices at random or illogically.

Contextual constraints point at situations that aren't possible in real-life situations due to technologically impossible or because they are unreasonable, e.g. asking if the respondent visits an amusement park often at night. These questions can be removed from the questionnaire.

Caution is necessary when removing trivial questions and questions with contextual constraints, since the removal of those questions also leads to orthogonally losses.

Another possible influencing factor on the results, is the acceptability of road charging by the general public. Of importance for the implementation is the political acceptability, but that is an altogether other question. Respondents who are against a road charging scheme, might state they use the car in any hypothetical situation they have to answer as to influence the results. If multiple respondents react in such a way, the results are influenced and invalid.

There are some variables necessary to create a successful questionnaire about road charging. Ubbels & Verhoef (2005) use different scenarios in their research. The scenarios are composed out of the same variables: price variation, revenue use and time of day. The Flemish government wants to include several variables in the final road charging scheme: the location/type of road correlated to a set price and the time of day (Reynaers & Huyghebaert, 2014). Using a set charge per kilometre and using monetary corrections for certain users or the time of day, the final charge will be calculated.

In the questionnaire for this thesis, the four selected variables are a charge composed out of 5 levels, time of day composed out of 2 levels, distance composed out of 10 levels and purpose of travel composed out of 2 levels. Purpose of travel and distance are correlated because work related trips are generally further than non-work related trips. Therefore, work related trips have increments of 10 kilometres, starting from 10 kilometres to 50 kilometres. Non-work related trips have inclinations of 5 kilometres, starting from 5 kilometres to 25 kilometres. Based on the distance and charge applicable, the

monthly cost for the trip is calculated to give respondents a more clear idea of the meaning of the charge.

With a full factorial design, this results in 100 different scenarios. Using randomised choice sets results in each respondent having to answer 10 situations. There are no trivial questions nor contextual constraints. There is also no fear for respondents to justify their current behaviour nor to influence policy since this isn't a state-supported research.

In order to randomly select these questions, an internet application called Qualtrics is used. Qualtrics allows for online questionnaire design and execution. Participants can be contacted by a personal mail with the link to the questionnaire, or a link can be posted to social media. In this thesis, both have been used. Furthermore, Qualtrics allows the user to download the questionnaire data and compose descriptive statistics from this data.

Foreigners, being cars with a non-Belgian license-plate, will not be taken into account. The sample group has to be a representation of all foreigners and of sufficient size to make qualified conclusions. Because of the small scale of this research, it would prove too difficult to obtain such a representative sample group.

3.2.3 Questionnaire

The goal of the questionnaire is to determine if the mode choice is influenced by introducing road charging. In order to attain this goal, specific information is needed from respondents to facilitate later use in FEATHERS. In Appendix 2: questionnaire, all questions of the questionnaire are shown.

Information about the household needed to run FEATHERS

General information about the household of the respondent is necessary. This information is, among others, the amount of children and age category residing in the household, how many persons are responsible for the household and if they are employed or not etc.

Information regarding the respondent

General information about the person filling in the questionnaire is needed also. Year of birth, gender, current occupation (employed, unemployed, student or retired) and driver's license possession are required here.

Information regarding the person's stated travel behaviour

A hypothetical situation is created, using the random variables as described in the table.

In order for the person to have a more exact understanding of the potential price change, the question is displayed in such a way that the cost difference is shown, changing dependent on the random distance and random cost.

Four variables are used in the examples: distance, charge, time and purpose of travel. In the next section, these are explained more elaborately.

Respondents can choose from four modal choices as an answer to each hypothetical situation:

- On foot or by bicycle;
- Public transport;
- Car;
- Carpooling.

On foot or by bicycle is considered as one answering possibility since both are regarded as slow modes of transport.

Variables subjected to randomization

TABLE 6 Variables subjected to randomisation

Subject	Description	Explanation
Cost	5 tariffs, in increments of € 0,04, lowest tariff is € 0,04 and highest is € 0,20	Using incremental pricing, it is possible to find a charge per kilometre at which peoples' mode choice is influenced.
Time	Peak hour or off-peak hour	People's behaviour can change varying to the time of day they are to make the trip.
Distance	<ul style="list-style-type: none"> • For work-related trips: varying from 10 to 50 kilometres, in steps of 10 kilometres; • For non-work related trips: varying from 5 to 25 kilometres, in steps of 5 kilometres 	<p>Instead of asking for people's actual distance to their current workplace, suggest different scenario's in which the costs are calculated without and with road pricing. The distance-costs relation is researched.</p> <p>OVG indicated that 43% of working people live within 10 kilometres of their workplace, 23% between 10 and 20 kilometres, 16% between 20 and 30 kilometres and 17% 30 kilometres or more.</p> <p>For non-work related trips, the increments are smaller.</p>
Purpose of travel	Work-related trip or non-work related trip	FIGURE 13 at Appendix 3: mode choice for work and non-work related trips shows that for work related trips, the car is the mode of choice compared to all trips. Even for non-work related trips, the car is the mode that is chosen the most.

Inclusion of peak and off-peak hours

Peak and off-peak hours aren't correlated to the cost. With the implementation of a road charging scheme, this will be unlikely. From a mobility management point of view, peak hours should be charged more to discourage driving during these busy hours. From the perspective of the respondent, they might want to pay more for driving in less congested, off-peak hours compared to high congested peak hours. It will be interesting to see if respondents react to different times and might be willing to pay more for driving in peak hours or off-peak hours, or it might be they don't respond at all to the different time frames.

Examples

Below there are 2 examples of the tables that are shown to the respondent.

TABLE 7 Example 1

	No charge	Charge of €0,12 per kilometre
Distance	30 kilometres	30 kilometres
Trip cost	€2,70	€6,30
Total cost (monthly basis)	€108,00	€252,00
Time	Off-peak hour	Off-peak hour

TABLE 8 Example 2

	No charge	Charge of €0,08 per kilometre
Distance	15 kilometres	15 kilometres
Trip cost	€1,35	€2,55
Total cost (monthly basis)	€54,00	€102,00
Time	Peak hour	Peak hour

Calculation of trip cost

In the examples, a trip cost is displayed. This is based solely on the average fuel prices that were applicable during collection of responses. A weighted average of diesel, petrol and LPG for the past 3 years has been calculated. Then the average fuel consumption of a diesel, petrol and LPG car are taken into account. Lastly, the share of diesel, petrol and LPG cars was used to calculate a weighted average of fuel cost per vehicle per kilometre driven. The resulting € 0,09 per kilometre is included in the cost.

As to the total cost on a monthly basis, the trip cost has been multiplied with a factor of 2 for the round trip (since the distance is single way) and multiplied again with a factor of 20 (average amount of working days in a month).

Population sample for the questionnaire

In order to create an as realistic possible sample, respondents in all layers of the entire population have been addressed. This is achieved by sending an email with an invitation to respondents, as well as a link to the questionnaire on social media. Through these means, it is attempted to create a healthy and realistic sample of which the answers are a representation of the general population.

The size of the sample has been based on sample sizes used by the Flemish government in questionnaires. In the most recent study about road charging, commissioned by the Flemish government and executed by PwC and VITO, about 1 000 respondents were selected (Mayeres et al., 2014). In this thesis, the goal is to reach about 10% of that number since the scale is much smaller.

The questions shown to each respondent and which had to be answered, were selected completely random by Qualtrics. Furthermore, the input of the questions into Qualtrics weren't done in a specific order (e.g. from lowest to highest distance/congestion charge), randomising the selection even further. It was also ensured there are no correlations between variables among themselves and with respondents.

Chapter IV. Research execution

4.1 Questionnaire

The questionnaire has been emailed to about 100 persons and shared through social media. The total amount of respondents was 96. Unfortunately, due to problems with the software, 70 responses were deemed valid. These 70 responses have been analysed. TABLE 9, TABLE 10 and TABLE 11 give an overview of the total and valid amount of respondents, sex of respondents and work status of respondents

TABLE 9 Number of respondents

	Amounts
Total number of respondents	96
Valid number of respondents	70

TABLE 10 Sex of respondents

Sex	Amount	Percentage
Male	47	76,14 %
Female	23	32,68 %

TABLE 11 Work status

Work status	Amount	Percentage
Employed	51	78,86 %
Unemployed	1	1,43 %
Student	9	12,86 %
Retired	9	12,86 %

Age categories have been constructed according to categories used in FEATHERS, as is shown in FIGURE 3. In this figure, percentages are shown of number of respondents per age category and percentages for total population in Flanders corresponding to each age category.

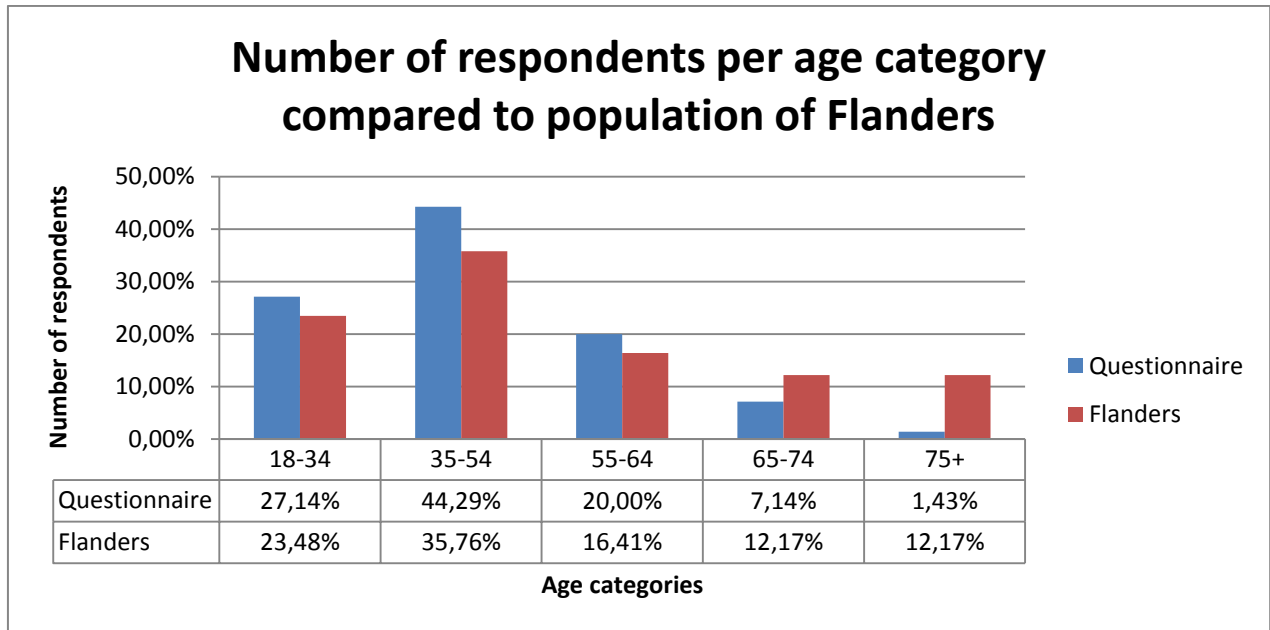


FIGURE 3 Number of respondents per age category compared to population of Flanders (ADSEI, 2015).

Something to bear in mind when analysing the numbers in FIGURE 3, is that the numbers for Flanders are for the whole population. For the numbers from the questionnaire, it is reasonable to assume that only persons who still actively participate in traffic, have completed the questionnaire. Thus, while it may seem that the last age category is underrepresented in the questionnaire, this can be partially explained that the elderly participate less frequently in traffic compared to the other age categories and thus were less likely to participate in the questionnaire. There is a general trend noticeable in the amounts with a small first age category (18-34), then the largest age category (35-54), and dropping lower for the following age categories.

The most interesting bit from the questionnaire however, is the reaction of respondents on the charged price and their corresponding modal choice. The next two figures illustrate those responses.

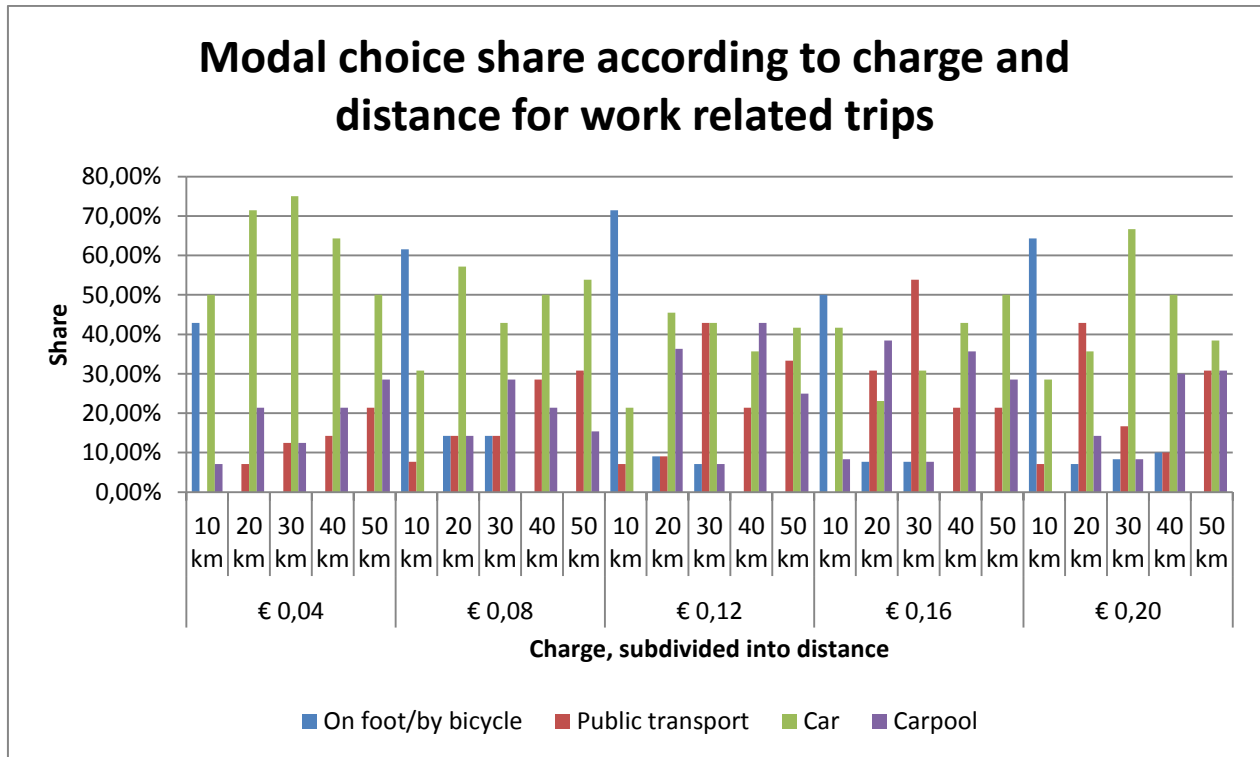


FIGURE 4 Modal choice share according to charge and distance for work related trips.

FIGURE 4 shows the modal choice for work related trips.

The results indicate that, when the distance is low enough (10 kilometres), on foot or by bicycle are popular modal choices. At a charge of only € 0,04, more than 40 % of respondents choose this mode.

When the charge goes up, more respondents tend to travel on foot or by bicycle (up to 70 % at € 0,12).

Public transport was chosen more frequently as distance and charges go up.

The car was chosen less and less if charges go up, although at € 0,20, this doesn't seem to hold true.

Furthermore, as prices and distance go up, carpooling was chosen more frequently.

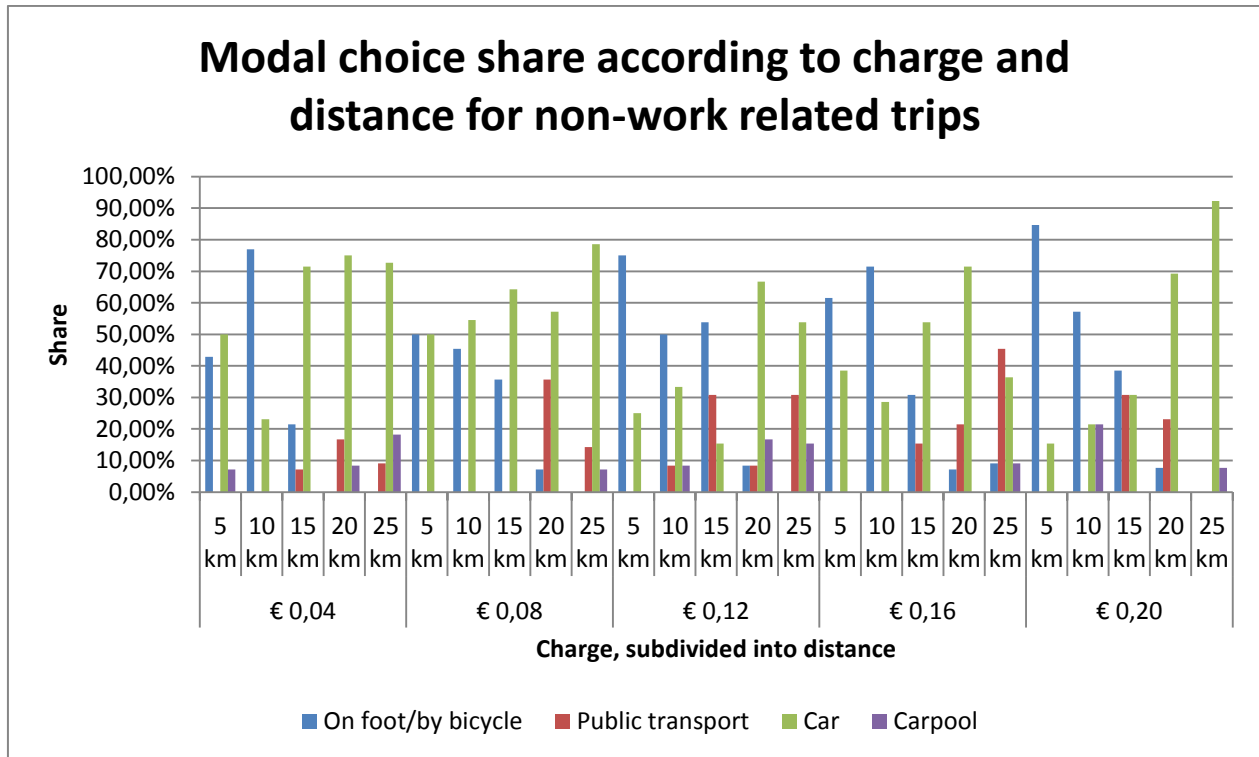


FIGURE 5 Modal choice share according to charge and distance for non-work related trips.

FIGURE 5 shows the responses for non-work related trips.

Striking is that for non-work related trips, respondents are more motivated to travel on foot or by bicycle, compared to work related trips. With work related trips, respondents generally indicated that they are prepared to go on foot or by bicycle up to 10 kilometres. For non-work related trips, they indicate that they are prepared to travel up to 15 kilometres with the same mode, which is 50 % further. As charges go up, more respondents indicated that they would choose public transport for making their trips that stretch further than 15 kilometres. Under 15 kilometres, none of the respondents are interested in this modal choice for this type of trips.

The car seems an overall popular choice, chosen more frequently at higher distances. There's only a slight decline of the car as modal choice as prices go up.

Carpooling is by far the least chosen mode for non-work related trips. This can be due to respondents wanting or needing more freedom when making these kind of trips.

These numbers must be compared to a base scenario, where no road charging is applied. FIGURE 6 shows this comparison.

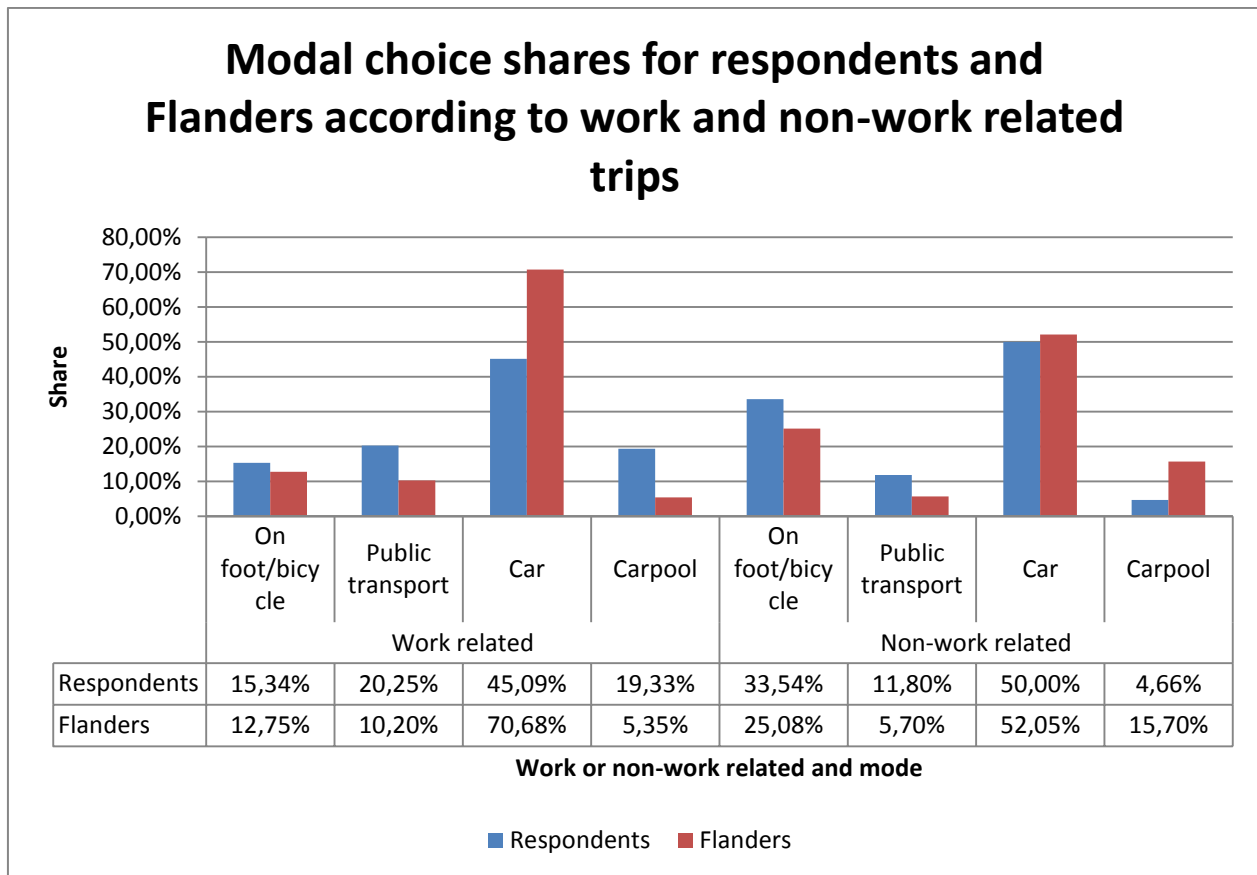


FIGURE 6 Modal choice shares for respondents and Flanders according to work and non-work related trips (Janssens et al., 2012).

The results from the questionnaire have been averaged, thus in FIGURE 6 the different charges aren't represented individually but combined. The lower car share for work related trips can thus be explained partially because of the influence of a higher charge being levied. The higher share of carpool can be explained by the same influence of the charge.

The next two figures (FIGURE 7 and FIGURE 8) show the modal choice share for respondents per distance category, compared to a base scenario for Flanders. The price of the charge hasn't been displayed, the modal choice share for the respondents per distance category has been averaged for all the different charges.

The base scenario is averaged over all possible distances.

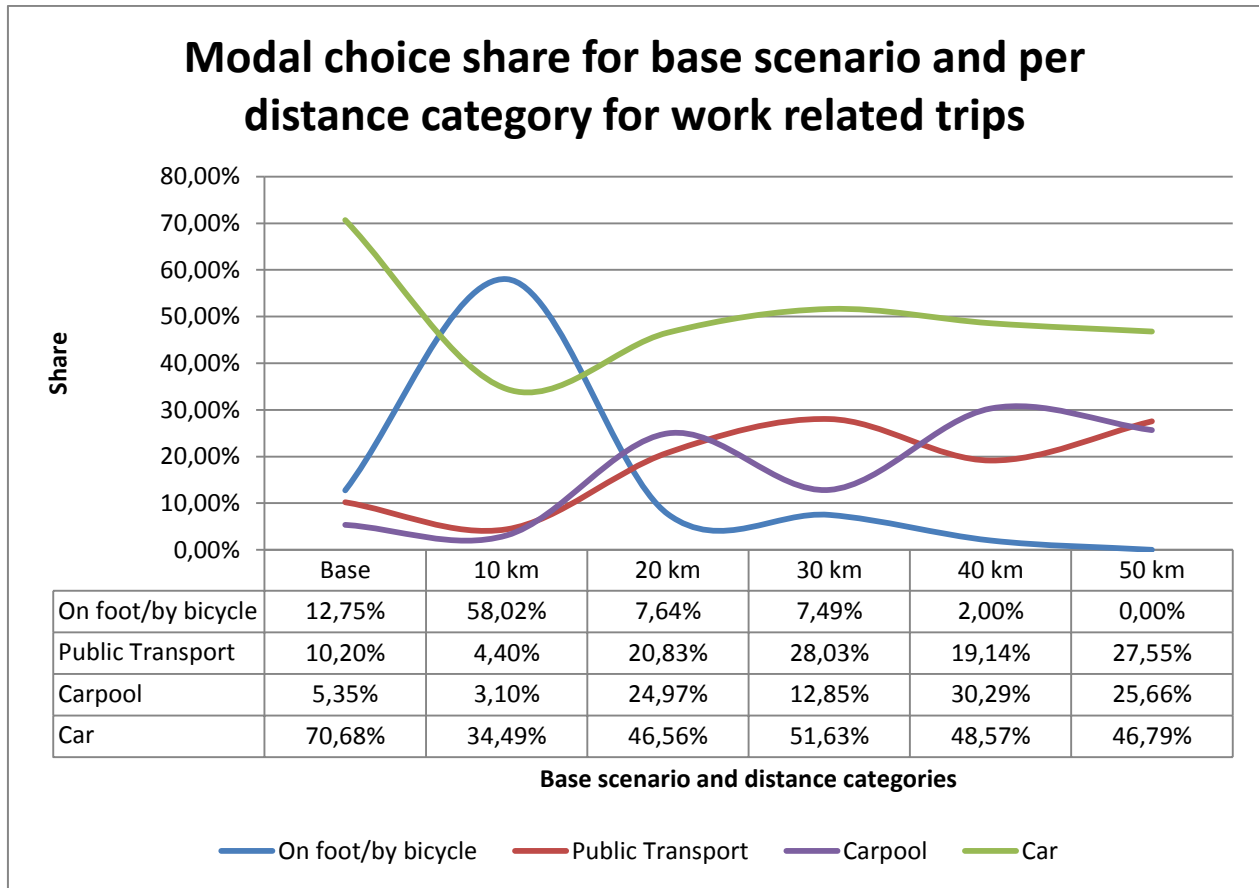


FIGURE 7 Modal choice share for base scenario and per distance category for work related trips (Janssens et al., 2012).

Interesting to note in FIGURE 7, is that the slowest mode (on foot/by bicycle) is chosen majorly for short distances, up to 10 kilometres. Increasing the distance drops its share significantly.

Public transport was chosen more frequently at distances over 10 kilometres.

The car drops to its lowest share at a distance of 10 kilometres, the distance at which the slowest modes level. After this initial drop, it goes up again. It stays about 20 % lower than in the base scenario though, even at higher distances.

Carpool shows a similar growth to public transport with an increased share at distances of 10 kilometres and up.

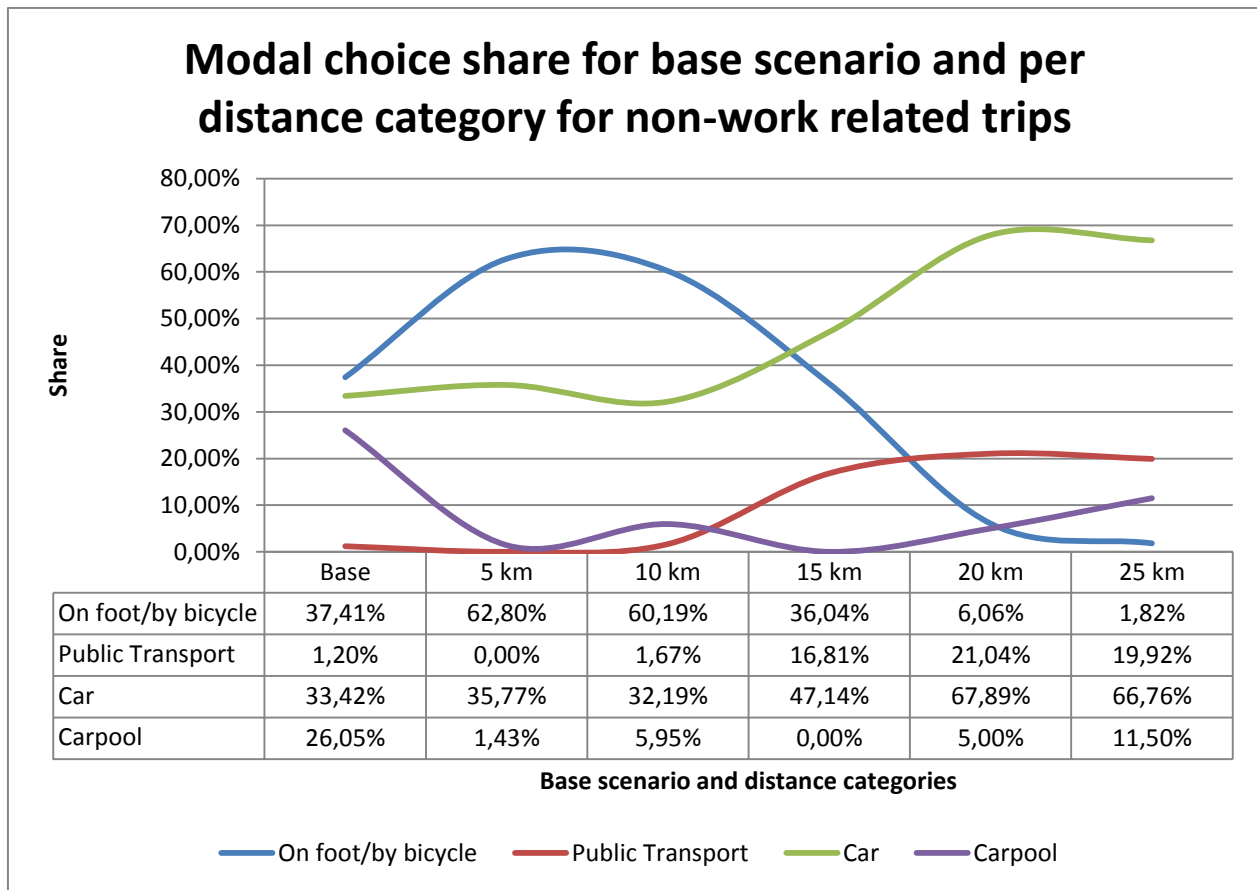


FIGURE 8 Modal choice share for base scenario and per distance category for non-work related trips (Janssens et al., 2012).

FIGURE 8 differs from FIGURE 7, since it focuses on non-work related trips rather than work related trips. The distance leaps are also lower, with increments of 5 kilometres instead of 10.

As was the case for work related trips, slower modes easily attain a high share at low distances. From this figure, it becomes clear that 20 kilometres is the maximum distance people are prepared to travel with slow modes. At 10 kilometres, the share of slow modes for non-work related trips is as high as for work related trips. At 20 kilometres, it has dropped significantly.

In the base scenario, public transport is barely chosen for non-work related trips. When there is a road charge applicable, respondents indicate that they would choose this mode more often for these trips. At a distance of 20 kilometres, both for work and non-work related trips, public transport is the mode of choice for 20 % of respondents.

The car is chosen more frequently as distance goes up. At 20 kilometres, the share of the car for non-work related trips is more than 20 % higher compared to work-related trips. This can be due to the nature of the trip, non-work related trips aren't defined as well as work in time. Also, multiple people have to be at work at the same time, thus facilitating carpooling. For non-work related trips, carpooling is the least popular choice.

The questionnaire yielded some interesting data when analysing the results and comparing the modal choice in two situations. In the first situation, no road charge is applicable and in the second the highest charge presented in the questionnaire is applicable.

TABLE 12 Modal choice change results questionnaire

	No road charge	€ 0,20 per kilometre
Slow modes	29,6 %	29,8 %
Public Transport	15,3 %	15,6 %
Car	44,6 %	44,2 %
Carpool	10,3 %	10,3 %

We can see that there isn't any significant difference between both situations whereas the literature led us to believe that some changes should be noticeable.

One possible explanation might be that the respondents may have experienced some difficulty in imagining the presented hypothetical situation. The questionnaire was made in such a way that each respondent had to answer 10 different hypothetical situations. While the first three of four situations may have been read thoroughly and answered in a similar fashion, they may not have done so in the later situations. This might have led to a discrepancy between their stated preference and their actual preference when confronted in real life.

In part 3.2.2, it was already noted that respondents might state they use the car in any hypothetical situation. This in order to influence the results. For this questionnaire, such behaviour wasn't expected but it might also be a partial explanation as to the insignificant differences found from the questionnaire. A questionnaire executed by VRT (Vlaamse Radio- en Televisieomroeporganisatie, the Flemish public radio and television broadcasting service) and Radio 1, with 1000 respondents, revealed some interesting numbers. One in three don't want any change at all, so no road charging measures in any way (Defosse, 2015). About half of respondents didn't even believe that a road charging scheme would have any influence whatsoever on congestion or their behaviour (Maerevoet, 2015). This questionnaire showed that there is only limited public acceptability concerning road charging in Flanders.

In a study that analyses five years of congestion charging in Stockholm, factors that influenced public acceptability are mentioned (Börjesson, Eliasson, Hugosson, & Brundell-Freij, 2011). One factor was that people didn't believe the congestion charge would have any notable result on the congestion. As soon as it turned out that it has a major effect on congestion, public acceptability rose. This is consistent with the questionnaire performed in Flanders, where half of respondents don't believe that a road charging scheme would have any effect on modal choice and travel behaviour.

A second factor is due to a psychological effect that is known as *cognitive dissonance*. It simply means that people will accept something that seems unavoidable. If the road charging is active, opposing the scheme becomes a lost battle and is deemed less worthwhile than opposing it when it isn't active yet.

Note that the first factor applies to objective reasoning, where people actually notice less travel time losses due to congestion while the second factor influences an individual's attitude concerning road charging.

4.1.1 Alternative data

For further analysis, this data presents a problem. The observed modal changes aren't in line with the modal changes that were to be expected according to literature. For example, a trial conducted in Stockholm revealed that the introduction of a road charging scheme led to reductions from 3 to 11 percent of car travel for all trip purposes (except shopping) (Becker, 2008). The questionnaire didn't yield anything similar and thus becomes unusable at this point. If this data is used for the ZCPMs, there wouldn't be any changes noticeable in predicted amount of crashes for the null scenario compared to the road charging scenarios. Continuing would be self-defeating, since it would become impossible to have any conclusion other than that the questionnaire outcome isn't according to literature.

An alternative is necessary, an alternative travel demand management measure that yields the expected modal choice change. In the literature study a similar measure has been discussed already, namely a fuel cost increase. In part 2.1.2, the advantages and disadvantages of a fuel cost increase and road charging scheme have been compared. Although a fuel cost increase is socially less favourable and leaves no room for differentiation in time and place compared to a road charging scheme, it eliminates the necessity to install OBU's, implement a completely new and possibly complicated system (and thus is more transparent) and also influences air pollution in a more direct manner. The manner in which drivers have to contribute to the road charge is different, but the outcome is believed to be the same (Litman, 2014b). Because of a higher cost for driving, people will have to rethink their travel behaviour and choose for less costly modes of transport.

Data from another study (Pirdavani et al., 2012) was used to create the null scenario. Then two more scenarios were created, one in which the fuel cost increased with 4 cents and a second one where the fuel cost was increased with 8 cents. This to still reflect the original idea of having multiple road charge schemes to analyse. Due to time restrictions, only two new scenarios were chosen on. The modal choice was then evaluated through FEATHERS and yielded far better results concerning modal choice change. The exact numbers can be seen in TABLE 13. It has to be noted that carpool was interpreted as car passenger.

TABLE 13 Modal choice change results new data

	Null scenario	4 cent increase	8 cent increase
Slow modes	23,5 %	25,6 %	27,6 %
Public Transport	7,8 %	8,6 %	9,2 %
Car	56,0 %	52,9 %	50,5 %
Carpool	12,6 %	12,9 %	12,7 %

A note that has to be made with this data is that the data was run only once through FEATHERS. In part 3.1.1 it was already stated that FEATHERS is a stochastic model and multiple runs are advised to get a more complete image of the general outcome of the data. Due to time restrictions, FEATHERS was run one time. Therefore, we can't go on the raw numbers but instead must analyse the general changes in

the numbers. The data in TABLE 13 clearly indicates that, when the cost of driving goes up, the modal choice is influenced. There is a change noticeable from car to slow modes and public transport.

When a modal shift from car to cycling occurs, there is a general tendency of increased crashes and casualties. This seems like a paradox, since there are several factors that positively influence the road safety effect of a modal shift from car to bicycle (Schepers & Heinen, 2012):

- Cyclists are less exposed to hazards per kilometre compared to car drivers. They have access to a more refined network that includes roads, cycle tracks and short cuts inaccessible to cars;
- The 'safety in numbers' effect. More cyclists mean they become a more visible part of traffic, where other traffic participants will react to. They will take into account a possible encounter with cyclists more often when the amount of cyclists increase. This effect is also clearly visible since numbers show that countries with a higher share of cyclist use have a lower number of cyclist deaths per year (de Hartog, Boogaard, Nijland, & Hoek, 2010);
- More cyclists mean that authorities might be driven to improve infrastructure to accommodate cyclists better. The opposite holds true too (Dill & Carr, 2003).

The reason for the increase of crashes and casualties, is that there is an increase in the exposure rate for slow modes. As stated before, exposure is a main predictor for the expected amount of crashes or casualties. As the exposure rises, so does the amount of accidents and casualties. In countries such as The Netherlands, this is addressed through more intense training and guiding of future cyclists (young children) and drivers in an attempt to reduce the risk ("Bicycle Training in the Netherlands," 2010). While exposure in The Netherlands may be high, the attempt to reduce the risk influences safety for slow modes in a positive manner. Per million inhabitants, only 45 are killed each year in The Netherlands (Sterling, 2008). This number includes fatalities from all traffic, not solely slow modes.

4.2 Zonal crash prediction model (ZCPM)

With the data available at this moment, two zonal crash prediction models or ZCPMs have to be developed suited to the task of predicting the amount of crashes. The type of crashes selected in this thesis, are car-car crashes and car-slow modes crashes. Slow modes here are defined as the most vulnerable users; pedestrians and cyclists. These crashes are the most commonly occurring crashes in traffic and thus have the highest influence on safety figures.

TABLE 14 Descriptive statistics of selected variables to develop ZCPMs

	Description	Average	Minimum	Maximum	SD
Dependent variables					
Car-Slow Crashes	Total Car-Slow modes injury crashes observed in a TAZ (2004-2007)	11,43	0	218	19,38
Car-Car Crashes	Total Car-Car injury crashes observed in a TAZ (2004-2007)	22,04	0	218	22,92
Independent variables					
Speed	Average speed driven in a TAZ	69,40	31,00	120,00	10,91
Intersection	Amount of large intersections in a TAZ	5,80	0	40,00	5,90
Highway	Presence of a highway in a TAZ 0 means 'no' 1 means 'yes'	0	0	1	-
Urban	Is the TAZ an urban area? 0 means 'no' 1 means 'yes'	0	0	1	-
Suburban	Is the TAZ a suburban area? 0 means 'no' 1 means 'yes'	0	0	1	-
Exposure variables					
NOTs car	Average daily number of car trips originating/arriving from/at a TAZ	2.829,60	0	26.974,00	2.748,11
NOTs slow	Average daily number of slow mode trips originating/arriving from/at a TAZ	1.103,58	0	8.850,00	1.338,39

TABLE 14 shows the descriptive statistics of chosen variables for both ZCPMs. The crash data for car – car and car – slow crashes for the 2004 to 2007 period comes from the Flemish Ministry of Mobility and Public Works. Based on this data, two ZCPMs were created using a statistical data analysis program, in this case SPSS (“IBM SPSS Software - Belgium,” 2015). One model predicts the number of car-car crashes, while the other model predicts the number of car-slow crashes. To develop each of these models, first a correlation table was created. After the correlation table was created, the variance inflation factor

(O'Brien, 2007) or VIF in short, was calculated for the variables. This is carried out to see if there was multicollinearity between two or more variables. Through trial and error, two suitable sets of general explanatory variables were found, one for the car-car and one for the car-slow model.

The model type chosen is a negative binomial trip based model. Earlier models were based on a multiple linear regression. A study by Abdel-Aty & Radwan (1999) revealed that MLR has some 'undesirable statistical properties when applied to accident analysis'. Therefore, newer models are based on a Poisson distribution. The Poisson distribution in its turn has some issues with overdispersion of data (Caliendo, Guida, & Parisi, 2006). Data that exhibits overdispersion has a larger variance than the mean. In this case, the variance for car – slow crashes is 347,45 and the mean is 11,43. For car – car crashes, the variance is 525,26 and the mean is 22,04. Overdispersion can be addressed by using a negative binomial distribution, as is now done in almost all cases regarding crash prediction models.

From the reviewed literature, one model was widely used by different researchers (Abdel-Aty & Radwan, 1999; Pirdavani, 2012):

$$E(C) = \beta_0 \times (Exposure)^{\beta_1} \times e^{\sum \beta_i x_i} \quad (1)$$

Where:

$E(C)$: expected crash frequency;

β_0 and β_1 : model parameters;

$Exposure$: exposure variables;

x_i : other explanatory variables.

The model was rewritten to calculate the new, unknown variable: the expected amount of crashes for each scenario. This looks as follows:

$$\frac{E(C)}{E^*(C)} = \frac{\beta_0 \times (Exposure)^{\beta_1} \times e^{\sum \beta_i x_i}}{\beta_0 \times (Exposure^*)^{\beta_1} \times e^{\sum \beta_i x_i}} \quad (2)$$

Where:

$E^*(C)$: expected crash frequency for the chosen scenario;

$Exposure^*$: exposure variables for the chosen scenario.

The factors β_0 and $e^{\sum \beta_i x_i}$ cancel out each other, so from (2) follows:

$$\frac{E(C)}{E^*(C)} = \left(\frac{Exposure}{Exposure^*} \right)^{\beta_1} \quad (3)$$

$$E^*(C) = E(C) \times \left(\frac{Exposure^*}{Exposure} \right)^{\beta_1} \quad (4)$$

With this final version of the model (4), the expected amount of crashes for each scenario was calculated.

TABLE 15 model estimates for the chosen ZCPMs

	Car-slow model	Car-car model
Intercept	-5,5440	-3,9272
log (NOTs slow modes)	0,9602	-
log (NOTs car)	-	0,6321
Speed	0,0128	0,0135
Intersection	0,0267	-
Highway	-0,1449	-
Urban	0,6632	-
Suburban	0,2139	-
Capacity	-	0,0004

TABLE 15 shows the model estimates for the chosen ZCPMs.

For the car – slow modes ZCPM, almost all of the model estimates are positively associated with the number of crashes. The higher the number, the higher the influence of the corresponding variable. The natural logarithm for number of trips of slow modes (log(NOTs slow modes)) has the highest influence. The second largest influence is if the TAZ is in an urban area. This makes sense because in an urban area, the NOTs or number of trips of slow modes is higher than in rural areas. The model estimate for ‘Highway’ is negatively associated. This means that if there is a highway present in the TAZ, the number of car – slow modes crashes decreases. Again, this is logical since slow modes aren’t permitted on highways thus no conflicts can abound on these locations.

For the car – car model ZCPM, all the model estimates are positive. The NOTs of cars have the largest influence on amount of crashes. Speed and capacity play a far smaller part but still are of influence. When speed increases, the risk of being involved in a crash increases. In the literature study, it was stated that amount of crashes is determined by risk and exposure. When exposure stays stable and risk increases, more crashes will occur.

Chapter V. Analysis of research results

To present the data in a comprehensive manner, the program ArcGIS has been used to visualise the data. Four figures illustrate two scenarios, being a scenario with a 4 cent fuel cost increase, and one with a 8 cent fuel cost increase. For each scenario, two figures are presented where one indicates the increase or decrease of the expected amount of car – slow mode crashes for each TAZ compared to the null scenario, the second indicates the same data for car – car crashes.

The category sizes for the two car-car figures are the same, as are those of the car-slow figures. This allows us to compare the impact of the different fuel cost increases.

5.1 Fuel cost increase results on car – slow modes crashes for the study area

FIGURE 9 and FIGURE 10 both represent the percentage of change in predicted number of crashes between cars and slow modes, respectively for the 4 cent fuel cost increase and 8 cent fuel cost increase scenario. Since the size of the categories is kept the same for the two figures, the colours also represent the same percentages of change. There are two categories where there's a reduction in predicted amount of car-slow modes crashes, and three categories where an increase is predicted. While this might seem weird at first, it is possible since most of the trips that aren't made using a car anymore, are now completed by use of other modes. Since the predicted amount of crashes is dependent on the exposure, it is to be expected that for some TAZs the amount of crashes for slow modes will also increase. This can be because of some sort of shock effect after the introduction of a fuel cost increase. After a while these increases are expected to drop due to the fact that traffic participants get used to a higher slow mode share. All traffic participants will be more attentive towards each other compared to the null scenario, because they cross paths more frequently. For the 4 cent fuel cost increase scenario, the car share drops 3,1 %, from 56 % to 52,9 %. At the same time, slow mode choice goes up 2,1 %, from 23,5 % to 25,6 %.

TABLE 16 Share for each category for car – slow mode crashes

	Percentage of change	4 cent fuel cost increase	8 cent fuel cost increase
Decrease	< -10	0,64%	0,45%
	-9,99 - 0	22,11%	9,74%
	Subtotal	22,75%	10,19%
Increase	0,01 - 10	75,39%	87,26%
	10,01 - 20	1,27%	1,73%
	> 20,01	0,59%	0,82%
	Subtotal	77,25%	89,81%
Total		100,00%	100,00%

As TABLE 16 indicates, in about one fifth of the TAZs the predicted amount of crashes is going to decrease or stay the same compared to the null scenario. This also means that in more than four fifth of TAZs, the predicted amount of crashes is going to increase compared to the null scenario. In three quarters of the TAZs, the predicted amount of crashes between cars and slow modes is going to increase with up to 10 %.

TABLE 16 shows that in one tenth of the TAZs, the predicted amount of crashes will decrease. In nine tenth of the TAZs, the predicted amount of crashes will increase, with a majority in the 0 % to 10 % range.

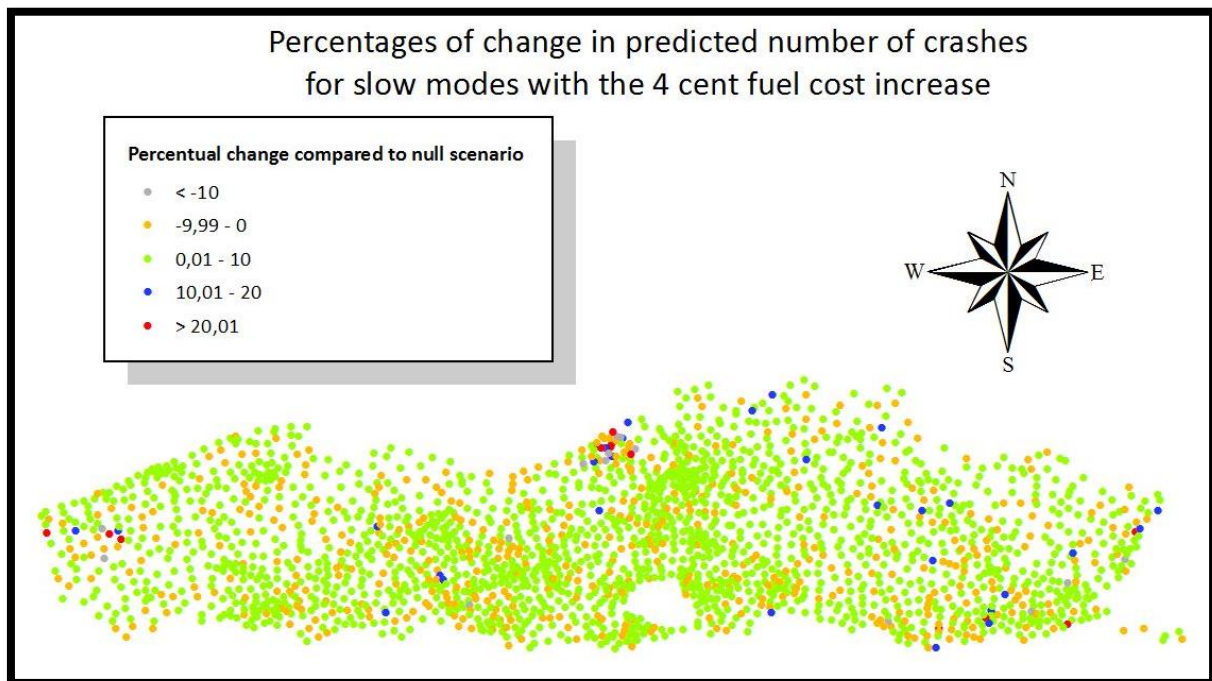


FIGURE 9 Percentages of change in predicted number of crashes for slow modes with the 4 cent fuel cost increase.

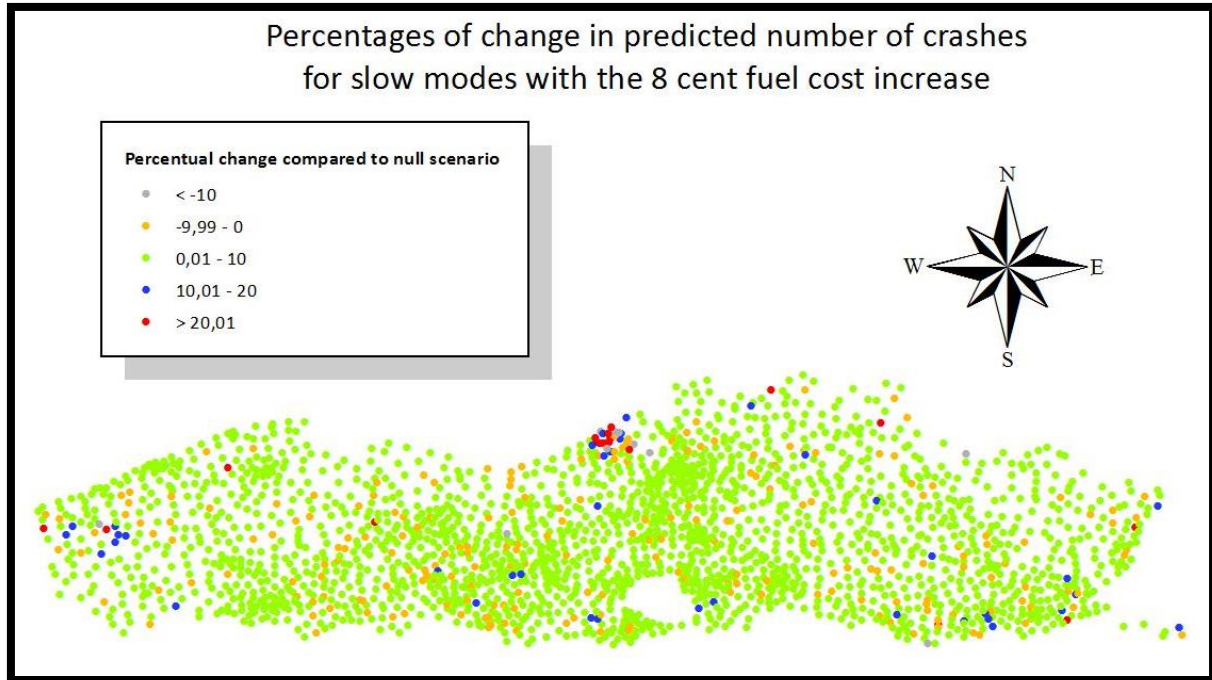


FIGURE 10 Percentages of change in predicted number of crashes for slow modes with the 8 cent fuel cost increase.

The two scenarios can be compared visually through FIGURE 9 and FIGURE 10. In both figures green is the prevailing colour, indicating that for the majority of TAZs the predicted amount of crashes is going to increase with up to 10 %. In FIGURE 10 (8 cent fuel cost increase) there are more green coloured TAZs compared to FIGURE 9 (4 cent fuel cost increase scenario). In FIGURE 9 there is more orange compared to FIGURE 10, indicating a decrease of predicted amount of car – slow mode crashes with up to 10 %.

As can be seen on the figures, there are some TAZs with a relatively high increase of predicted amount of crashes. The maximum increase and maximum decrease percentages for both scenarios are shown in TABLE 17. These are outliers, as also can be determined from the data gathered in TABLE 16.

TABLE 17 Maximum increase and decrease of car – slow modes crashes in percentage for both scenarios

	4 cent fuel cost increase	8 cent fuel cost increase
Maximum increase	109,54%	141,00%
Maximum decrease	-65,17%	-70,64%

These numbers are very high but can be explained fairly easy. In the crash data used to create the null scenario, it is possible and plausible that for some TAZs, there weren't a whole lot of car – slow modes crashes to begin with. If, for example, in a certain TAZ there were 2 crashes and in the new scenario there are 4 crashes in that same TAZ, the percentage of change is very high. Relatively speaking, the increase is enormous but in absolute terms, the increase doesn't seem to be that high. The percentages are comma noted numbers since the predictions from the models have been used and these often had multiple decimal places.

5.2 Fuel cost increase results for car – car crashes for the study area

FIGURE 11 and FIGURE 12 both represent the percentage of change in predicted number of crashes between cars, respectively for the 4 cent fuel cost increase and 8 cent fuel cost increase scenario. Since the size of the categories is kept the same for the two figures, the colours also represent the same percentages of change. There are four categories where there's a reduction in predicted amount of car – car crashes, and only one category where an increase is predicted.

TABLE 18 Share for each category for car – car crashes

	Percentage of change	4 cent fuel cost increase	8 cent fuel cost increase
Decrease	< -3	1,41%	4,96%
	-2,99 - -2	3,14%	10,15%
	-1,99 - -1	20,66%	54,14%
	-0,99 - 0	66,11%	28,71%
	Subtotal	91,31%	97,95%
Increase	> 0,01	8,69%	2,05%
	Subtotal	8,69%	2,05%
Total		100,00%	100,00%

The car share in the 4 cent fuel cost increase scenario drops with 3,1 %, from 56 % to 52,9 % (see TABLE 13). This results in a decrease of the predicted amount of crashes in more than nine tenth of the TAZs. In two thirds of the TAZs, there is a reduction of up to 1 %, one fourth note a reduction of more than 1 %. In less than one tenth of the TAZs, the predicted amount of crashes increases.

For the 8 cent fuel cost increase scenario, in only 2 % of the TAZs an increase is noticeable. In all the other TAZs, reductions are predicted. While in the 4 cent fuel cost increase scenario the most reductions were between 0 % and 1 %, in this higher fuel cost increase scenario the majority of reductions lies between 1 % and 2 %. Almost seven tenths of TAZs have more than 1 % reduction of the predicted amount of car – car crashes.

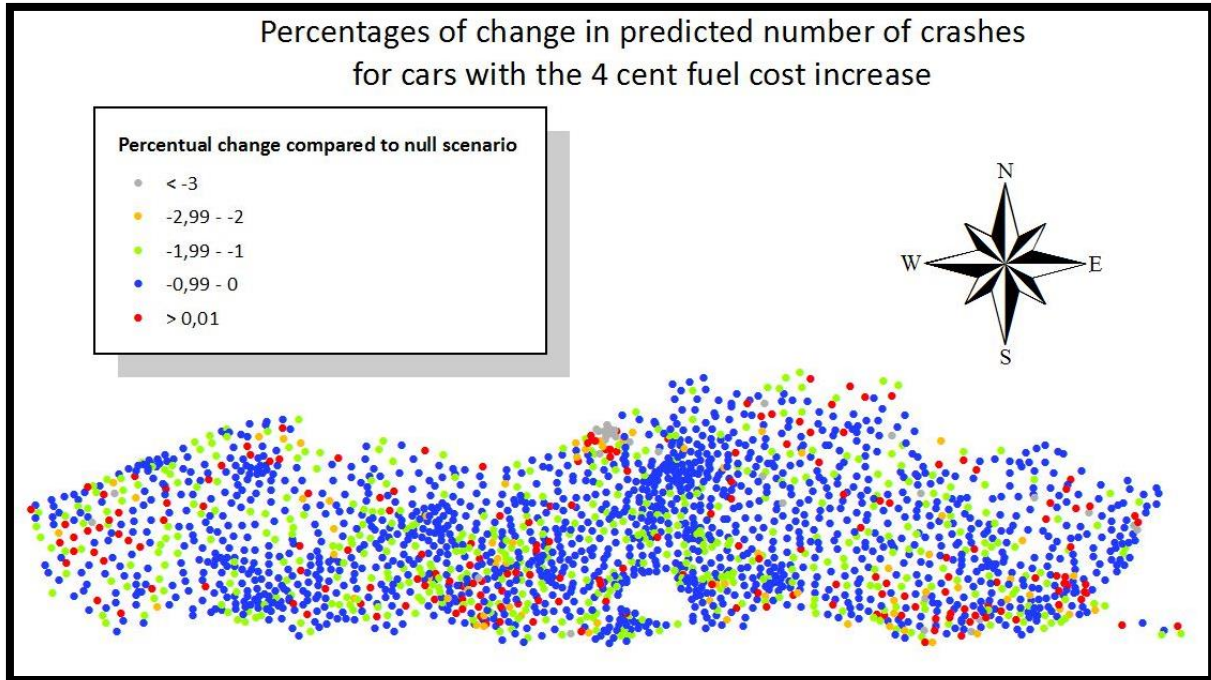


FIGURE 11 Percentages of change in predicted number of crashes for cars with the 4 cent fuel cost increase.

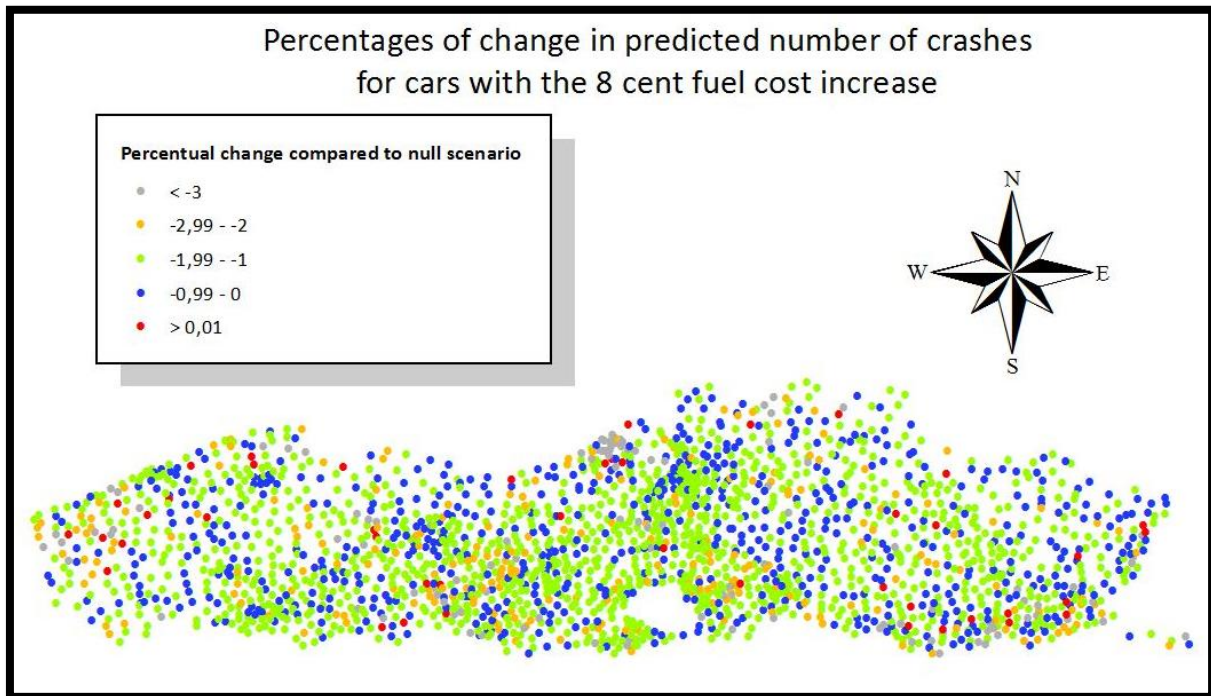


FIGURE 12 Percentages of change in predicted number of crashes for cars with the 8 cent fuel cost increase.

The two scenarios can be compared visually through FIGURE 11 and FIGURE 12. Blue is the prevailing colour in FIGURE 11, indicating reductions in predicted amount of crashes up to 1 %. FIGURE 12 has a

more even spread of the colours blue and green. As TABLE 18 indicates, more TAZs are coloured green and indicate a reduction of predicted amount of car – car crashes between 1 % and 2 % in FIGURE 12.

TABLE 19 Maximum increase and decrease of car – car crashes in percentage for both scenarios

	4 cent fuel cost increase	8 cent fuel cost increase
Maximum increase	5,03%	4,91%
Maximum decrease	-22,21%	-13,76%

The maximum increases and decreases aren't as outspoken as with the car – slow mode crashes.

An analysis of the types of crashes wasn't possible with the data set, but some extra explanation is in order. Although the predicted total amount of crashes will drop, it may lead to crashes with higher severity. Since less motor traffic also leads to higher speeds, the crashes that do occur may be more severe than before.

5.3 Total results

The consequences for both car – slow mode crashes and car – car crashes have been discussed, but what do these numbers reveal when combined. Do increases in costs for driving have effects on the total amount of crashes occurring in TAZs?

TABLE 20 Overview table predicted amounts of crashes

	Car – slow modes crashes		Car – car crashes		Total	
	Amount	Percentage	Amount	Percentage	Amount	Percentage
Null scenario	24849,67		51180,38		76030,05	
4 cent increase	25057,73	0,84%	50854,34	-0,64%	75912,07	-0,16%
8 cent increase	25243,08	1,58%	50580,00	-1,17%	75823,08	-0,27%

TABLE 20 shows an overview of the predicted amount of crashes for all scenarios and for car – slow modes crashes, car – car crashes and their combined total.

The amount of car – slow modes crashes is predicted to increase as the costs increase. The amount of car – car crashes is predicted to drop as the costs increase. In total, a reduction of amount of crashes is predicted.

While the percentages of change for car – slow modes crashes are higher than those for car – car crashes, they have a lower influence on the predicted total amount of crashes. This is attributable to the fact that the predicted amount of car – slow modes crashes are 50 % lower than the predicted amount of car – car crashes. TABLE 20 illustrates these numbers. For the null scenario, there is a prediction of 24 850 car – slow modes crashes versus 51 180 car – car crashes. Other scenarios show an increase for car – slow modes crashes and a decrease for car – car crashes but these numbers are still in the same magnitude as in the null scenario. A reduction in car – car crashes thus has a higher influence on the total amount than car – slow modes crashes.

We have to keep in mind that there are more crashes to be expected in total, and that, compared to the null scenario, higher reductions might be attained. An analysis has been performed of car – car crashes and car – slow modes crashes, but not for any other forms of crashes. Crashes where car passengers or public transport are involved, haven't been analysed due to very small expected changes.

Chapter VI. Conclusion and discussion

6.1 Research questions

At the very beginning of this work, a central research question was posed. In order to answer that central research question, there were other questions that had to be answered as well. At this point, a discussion will ensue to determine if the research questions have been answered adequately throughout this thesis.

The central research question will be discussed last.

- What defines a road charging scheme?

In the first part, the literature study, a road charging scheme was defined as a travel demand management measure, more specifically one from the incentives-group, a subdivision of road pricing.

A road charging scheme means that users of specific modes (most prominently cars) have to pay a cost to make trips within the boundaries of a specified area. In a certain way, users already do this through the cost of purchase, the cost of maintenance and repair, time cost, insurance cost etc. When not using a certain mode, it still has those costs. A road charge is a cost levied based on the actual usage of the mode. The usage can be further defined through:

- Time based charge. Takes into account the hour of the day or day of the week when the trip is made and a charge is applied accordingly;
- Distance based charge. Takes into account the distance driven to make the trip, e.g. a kilometre-based charge;
- Location based charge. Takes into account the location(s) where the trip takes place, e.g. driving in a urban area versus a rural area;
- Fixed charge;
- Dynamic charge.

The difference between a fixed and dynamic charge is the following. A dynamic charge is best applied when policy wants to steer traffic flows. When a certain part of the network experiences high congestion, a higher charge may be levied on that route or a lower charge on an alternative route so other drivers may choose a different route and the congestion at the hotspot can reduce. With a fixed charge the charge is always the same, regardless the amount of congestion. Therefore, a fixed charge is more transparent than a dynamic charge since the latter can change at any time. It requires a lot more information about the current situation and exchanging this information as soon as possible with possibly interested drivers. An important note here is that a fixed and dynamic charge are mutually exclusive.

A road charging scheme always consists out of a fixed or dynamic charge, combined with one or more of the other factors. Adding more factors does complicate the charge and can be more difficult to understand towards users.

- What would be the impact of a road charging scheme on travel behaviour decisions?

In order to answer this question, a stated preference questionnaire was designed. Respondents were asked to state their preferred modal choice when confronted with increased costs due to a road charging scheme. Different prices were used in order to try to determine what charge yields the most promising results. After analysis of the questionnaire it was found that no reliable results were obtained and thus rendered the results of the questionnaire and the questionnaire itself almost unusable. Available data from another study into the effects of a TDM measure, a fuel cost increase, has been used henceforth to continue with the study. The study was conducted at IMOB by Pirdavani et al. (2012). Two scenarios were created, one with a fuel cost increase of 4 cent and a second with an 8 cent increase. This led to results that were to be expected, according to literature and relevant studies. When a kilometre-based cost is introduced, modal choice changes from expensive (car) use to slow modes primarily.

- How do the changes in travel behaviour decisions influence the traffic performance?

Due to the late time shift to an alternative data set, this research question hasn't been researched as thoroughly as wished. The data set has been run through FEATHERS, which yielded an origin-destination matrix. Subsequently a traffic flow chart would be created. Due to time restrictions, this hasn't been done. An analysis of the traffic flow could reveal changes in travel behaviour decisions, and their consequences on traffic performance. Travel behaviour decisions could mean:

- The person can choose not to make a certain trip in order to avoid paying for the trip;
- The person can choose to make the trip on a different time;
- The person could combine multiple trips in order to reduce the kilometres travelled and thus the cost;
- The person can choose a different mode to make the trip.

The only behavioural changes that can be analysed through the origin-destination matrix is the modal choice change behaviour, which has been discussed at the scenarios. Reductions in car usage and increases for slow modes and to a lesser extent, public transport, were noted. Since there is a lower car share, it is to be expected that there will be less congestion in certain TAZs. This can lead to better traffic flow, increasing efficiency of public transport. To state this with numbers isn't possible unfortunately. So from the data, it can't be determined how much traffic performance would increase or decrease. It would be realistic however to expect that traffic performance will rise when a fuel cost increase is to be applied.

- How do the changed traffic flows influence the traffic safety?

As said with the previous research question, no traffic flow analysis has been performed but the origin-destination matrix still gives insight in the situation.

Both cost increase scenarios predicted that, for car – car crashes, the amount of crashes in almost all TAZs will drop. When a higher fuel cost increase applies, higher reductions are predicted. For car – slow modes crashes, an increase of up to 10 % was predicted for most TAZs. It was also explained that this is to be expected when a modal choice shift occurs towards slow modes.

- What are the effects of a road charging scheme on traffic safety in Flanders?

Since the questionnaire didn't have the expected outcome, modal choice change data from a similar study into TDM measures has been used. A fuel cost increase is believed to have similar results on modal choice changes as a road charging scheme.

Traffic safety in Flanders is predicted to increase, thus fewer crashes occurring. More specifically, a reduction in car – car crashes would envelop. Simultaneously, an increase in car – slow modes crashes is predicted. This might seem a paradox, but is explained through a higher exposure for slow modes users, leading to a higher chance of being involved in a crash.

6.2 Conclusions and previous research

A road charging scheme can be a very complex and powerful tool for policy to address certain issues. First, congestion can be targeted head on. A road charging scheme exists to reduce the congestion. As studies in Flanders revealed, if 10 % of morning car commuters used a motorcycle, congestion would be reduced by up to 40 % in both length and duration.

Second, the income can and should be invested in alternatives. These alternatives in turn should lead to more reductions of congestion. They aren't limited to mobility in the first line, so investments in public transport, better infrastructure etc. Congestion in Flanders is a consequence of many commuting taking place. Income from a road charging scheme can be used to reward those who choose to live nearby their working place. It can be invested in spatial planning and creating workplaces with a high variety of supply to reduce commuting distances.

Third, it has a positive effect on health and liveability. More use of less polluting modes leads to less pollution, leading to healthier air. Consequently, a modal shift to slower modes leads to a better condition and health for those users.

Fourth, the safety effects cannot be ignored. Although it is believed to increase the amount of car – slow mode crashes, it is believed to have an overall positive influence on traffic safety. In this thesis, two types of crashes have been analysed but there are more types to be distinguished. Another study, focused on this modal shift and its consequence on traffic safety revealed that the amount of seriously injured from cyclist crashes does increase. The amount of fatalities does not however. For car – car crashes, the amount of crashes is reduced.

Throughout the thesis, I've learned to value the strength of models such as activity-based transportation models and crash prediction models. When one has never worked with such programs before, they can be overwhelming and difficult to understand but when one does, they become invaluable. It was unfortunate that, due to time restraints, the data couldn't be further analysed.

There have been similar efforts at determining the behavioural effects of a road charging scheme. Concerning the traffic safety consequences, far less research has been conducted. There are some research papers worth comparing, to get a feel of the reliability of the outcome of this thesis.

Increasing the fuel cost will lead to a modal shift. This hasn't only been discovered through this thesis but is also supported by literature. One Dutch study by Ubbels & Verhoef (2005) showed that implementing a road charge scheme does lead to reductions in car usage. From this thesis, the same results couldn't be reproduced unfortunately. Using a fuel cost increase as an alternative did reveal changes in modal choice although they weren't as outspoken as in the Dutch study. This is most likely due to a different methodology and approach in analysis of the data. Another explanation can be the different views on mobility between The Netherlands and Flanders. In The Netherlands, there is a general higher tendency to move closer if you live far from your work and thus leading to shorter trips that can be made with different modes (than the car). In Flanders, there isn't such a high willingness to reduce the distance between home and work in such a way.

A second research paper supports the finding that an increase of amount of crashes when a modal shift occurs from car to slow modes is to be expected. Schepers & Heinen (2012) concluded that more cycling trips do increase the amount of crashes. Their study went more in-depth and showed that, despite a higher amount of crashes, the amount of fatalities stayed the same. Some explanations provided by them were that a modal shift led to less cars and more cyclists led to a 'safety-in-numbers' effect. There was an increase in seriously injured but these were caused by a higher number of cycling crashes with no other vehicle involved.

With an increase in fuel costs, the amount of car – car crashes will drop. Exact percentages are difficult to predict since a stochastic model has been used to analyse the modal shift, and the modal shift leads to a lower car share in the modal choice. At the same time, the total amount of car – slow crashes will increase. Again, exact percentages are hard to come by. This finding is also supported by Pirdavani et al. (2012).

There seems to be very little, if almost none, public support for the introduction of a road charging scheme in Flanders. The results from the questionnaire unexpectedly indicated no significant changes. A questionnaire by the VRT also indicated a low public support for the introduction of a road charging scheme.

6.3 Recommendations

Some issues were encountered creating this thesis. They also yielded recommendations for future research.

The initial data set that was created with a questionnaire, turned out to be unusable since there weren't any significant changes in behaviour. A lot of time was put into this but yielded no usable results. A stated preference questionnaire was necessary but could have been an explanation for the poor results. Expanding the questionnaire so more respondents can be addressed, making it more comprehensive and increasing the general quality may yield better results. The use of data gathered with a revealed preference approach is preferable though. Existing data might be retrieved from studies performed in the scope of a road charge implementation. There are studies performed in Flanders that have revealed an influence on driver's behaviour when applying a road charge.

A limitation of the analysis, due to time restraints, is the fact that the activity-based transportation model FEATHERS could be run only once. Since it is a stochastic model, multiple runs are recommended and lead to a better null scenario. When a similar research is conducted, more time must be made available to run such a model multiple times. It will make an analysis more sturdy and the numeric results predict the actual consequences better. In this case, statements have been made about increases and decreases in amounts of crashes, but the numbers couldn't be validated thoroughly.

Continuing with the analysis, it also is a pity that only two types of crashes have been analysed. These were chosen though because they represent the majority of crashes in traffic. It would be interesting to create an analysis for all modes.

There is one modal choice that could have an impact on traffic and traffic safety: motorcyclists. Due to limitations of the activity-based transportation model that cannot represent this mode, it was decided to leave them out altogether. It would be interesting if these could be included, since it is believed that this mode can have a large impact on congestion and traffic safety.

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Appendix

Appendix 1: calculation company cars

Calculations:

- 770.000 company cars;
- 325.000 company cars of self-employed workers;
- 5.300.000 cars in total in Flanders;
- $(770.000 + 325.000) / 5.300.000 \times 100 = 20,66$ % share of company cars of total amount of cars in Flanders.

- 29.596 km driven annually by company cars;
- 20.700 km driven annually by private owned cars.
- $(770.000 + 325.000) \times 29.596 = 32.407.620.000$ kilometres driven annually by all company cars;
- $(5.300.000.000 - (770.000 + 325.000)) \times 20.700 = 87.043.500.000$ kilometres driven annually by private owned cars;
- $32.407.620.000 / (32.407.620 + 87.043.500.000) \times 100 = 27,13$ % company car share of kilometres driven annually by all cars.

Appendix 2: questionnaire

Information about households needed to run FEATHERS

- The number of persons in the household responsible for the household and if they're currently employed.
 - Composed out of a single person who is currently unemployed [1];
 - Composed out of a single person who is currently employed [2];
 - Composed out of two persons who both are currently unemployed [3];
 - Composed out of two persons of which one is currently employed [4];
 - Composed out of two persons who both are currently employed [5].
- How many adults there are in the household.
- How many children under the age of 18 there are in the household.
- Year of birth of the oldest person in the household.
- Information about the youngest child of the household and in which category he/she is situated. This question is asked because it is assumed that the youngest child determines the travel behaviour of the household.
 - Younger than 6 years of age [1];
 - Between 6 and 12 years of age [2];
 - Older than 12 years of age [3];
 - No children / Not applicable [4].
- The amount of cars the household has available.
 - 1;
 - 2;
 - 3;
 - 4;

- 5 or more.

Information about the person filling in the questionnaire

- The birth year of the person.
- The current situation of the person.
 - Unemployed [1];
 - Employed [2];
 - Student [3];
 - Retired [4].
- The gender of the person;
 - Male [1];
 - Female [2].
- If the person currently is in possession of a (full) driver's license.
 - Yes [1];
 - No [2].

Appendix 3: mode choice for work and non-work related trips

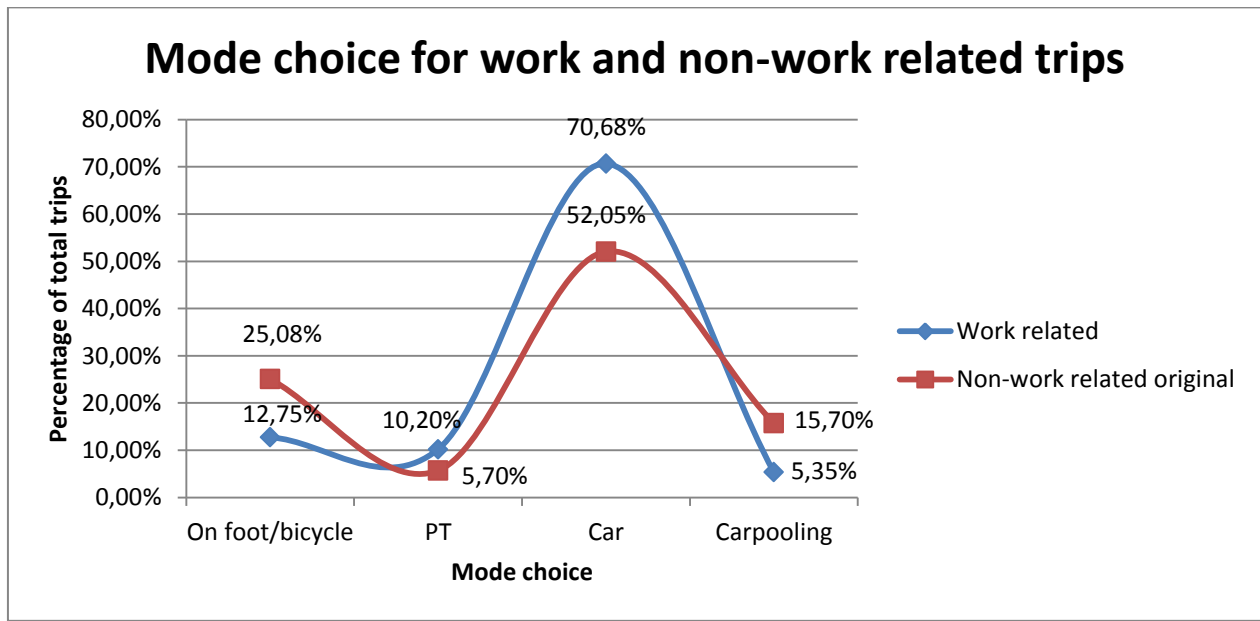


FIGURE 13 Mode choice for work and non-work related trips.

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