Pay-As-You-Drive

A model case study to find the different safety and accessibility effects of Pay-As-You-Drive strategies in the Netherlands

M.Sc. Thesis
J. Zantema, June 2007
Delft UT
Civil Engineering and Geosciences
Section of Transport and Planning

Thesis Committee:
Prof. Dr. Ir. P.H.L. Bovy
Dr. M.C.J. Bliemer
Ir. D.H. van Amelsfort
Ir. L.J.J. Wismans
Ir. P.B.L. Wiggenraad
Dr. Ir. V.A.W.J. Marchau
Ir. P.L.J. Morsink

Goudappel Coffeng
Adviseurs verkeer en vervoer

TU Delft
Delft University of Technology

Master Thesis

Pay-As-You-Drive

A model case study to find the different safety and accessibility effects of Pay-As-You-Drive strategies in the Netherlands

Deventer, June 2007

Jacobus Zantema

Delft University of Technology
Faculty of Civil Engineering and Geosciences
Section of Transport and Planning
Student number: 1107046
Email address: kzantema@goudappel.nl

Thesis committee:
Prof. Dr. Ir. P.H.L. Bovy
Dr. M.C.J. Bliemer
Ir. D.H. van Amelsfort
Ir. L.J.J. Wismans
Ir. P.B.L. Wiggenraad
Dr. Ir. V.A.W.J. Marchau
Ir. P.L.J. Morsink

Preface

This Masters thesis is the result of my research towards Pay-As-You-Drive, on which I have been working for the past months. With this research I will also complete my studies of Civil Engineering and Geosciences at the Delft UT. During my thesis I have worked at Goudappel Coffeng in Deventer, where a lot of expertise on traffic and transport is available.

In this thesis a transportation model and traffic safety model are used to estimate the effects of Pay-As-You-Drive on accessibility and traffic safety. This research was part of the TRANSUMO study “Verzekeren per kilometer” in which a model study was needed for the estimation of large-scale effects of Pay-As-You-Drive. The TRANSUMO program and study are described in the background, section 2.6. For those who are interested in the modeling framework, chapter 5 will be essential. For the main results of this thesis, the introduction, conclusion and discussion and recommendations should be read.

Last I want to thank those who supported me with the writing of this thesis. First of all my parents, who made sure that I kept going and always had a positive word if things became difficult. Also, I want to thank my thesis committee for investing their knowledge, time and support in my research. I hope that this report will contain enough detailed and interesting information to make it a pleasant read.

Thesis committee:

Prof. Dr. Ir. P.H.L. Bovy	Delft UT, Civil Engineering and Geosciences
Dr. M.C.J. Bliemer	Delft UT, Civil Engineering and Geosciences
Ir. D.H. van Amelsfort	Goudappel Coffeng BV
Ir. L.J.J. Wismans	Goudappel Coffeng BV
Ir. P.B.L. Wiggenraad	Delft UT, Civil Engineering and Geosciences
Dr. Ir. V.A.W.J. Marchau	Delft UT, Technology, Policy and Management
Ir. P.L.J. Morsink	SWOV

Deventer, June 2007

Kobus Zantema

Summary

This study compares the safety and accessibility effects of different Pay-As-You-Drive (PAYD) strategies, which are simulated using a transportation model. PAYD is a new insurance policy for car owners where insurance premium is paid per actual kilometer driven. As the number of insurance claims increases with annual kilometers driven, see Figure 6, the average premium for a driver with a high kilometrage will increase to reflect the average yearly claim pattern. With more advanced technologies, the PAYD insurance premium can be further differentiated to reward safe driving behavior with a lower premium. This study is part of the TRANSUMO research project "Verzekeren per kilometer" (PAYD), which applies the concept of PAYD in a real life pilot study. The objective is to measure and explain the behavioral effects of PAYD on individual drivers. In order to assess the possible network (safety) effect of large scale implementation of PAYD, this study uses a modeling approach that takes into account part of these expected behavioral responses in individuals.

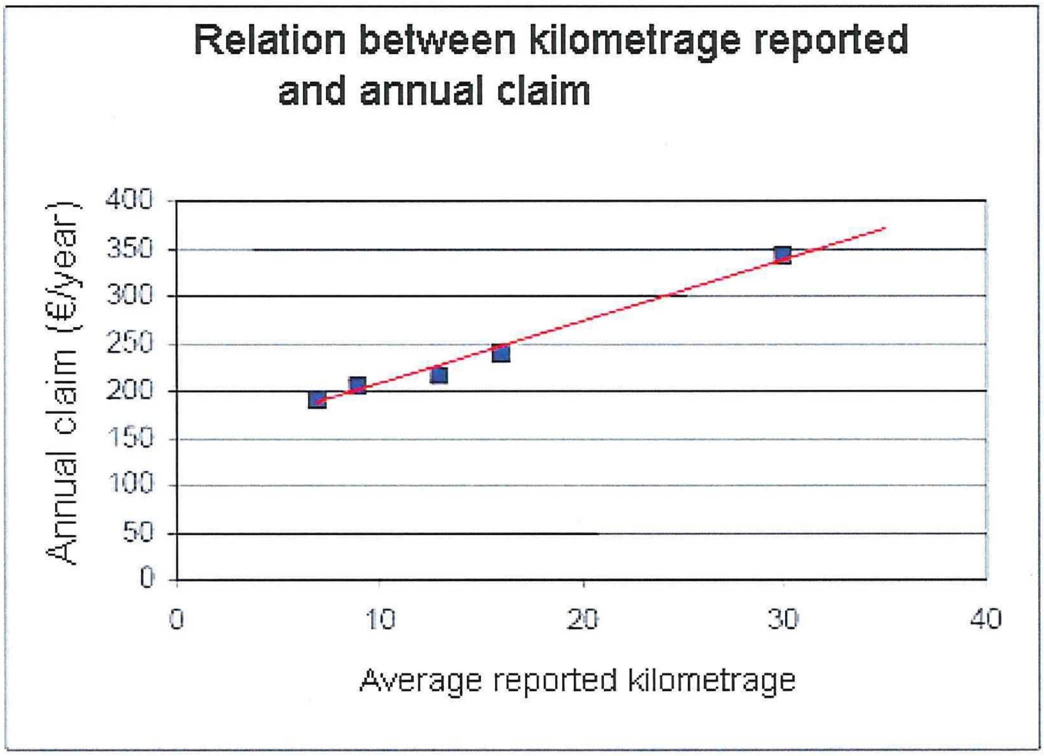

Figure 1 Relation between kilometers reported and annual claim. Source: TNO Inro, 2003.

To investigate the before mentioned network effects, seven PAYD strategies were tested in this study, in which the PAYD kilometer prices were varied for road types, time of day and young drivers. Also the level of participation in PAYD was varied, since it is expected that not all drivers will voluntarily 'buy' PAYD car insurance. The overview of the PAYD strategies that were tested is shown in Table 1. The safety effects of these strategies were determined based on kilometers driven per road category, together with historic safety data per road category. To compensate for the increased crash risk during the night, a factor for the unsafety of nighttime driving was used.

Strategy	Premium basis		Road category	Time of day	Young drivers	Percentage participants
	Fixed	Km based				
Ref.	X					
1		X				50
2		X				100
3		X	X			50
4		X		X		50
5		X	X	X		50
6		X	X	X		100
7		X	X	X	X	100

Table 1 Tested PAYD strategies

The seven strategies were evaluated in a case study model environment that was developed for the region of 'Haaglanden' in the Netherlands. This model environment consists of a transportation model and a traffic safety model. The macroscopic dynamic traffic assignment model INDY was extended to cope with elastic demand and departure time choice. Currently INDY does not take into account blocking back or delays at intersections. The traffic safety model was created to estimate traffic safety from the traffic flows calculated in the transportation model. The network model that is part of the transportation model is shown in Figure 2.

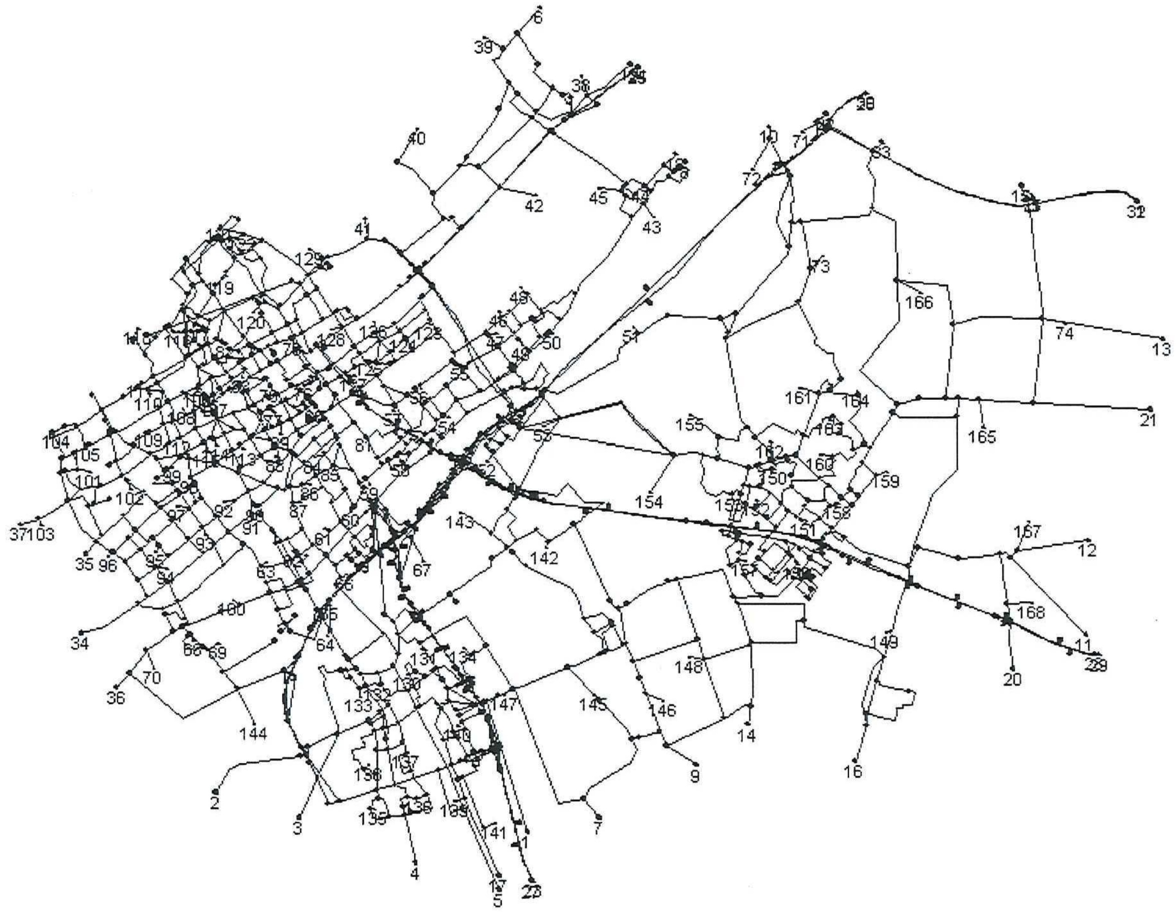

Figure 2 The network model of the region 'Haaglanden' in OmniTRANS

The results of the model runs for the seven strategies show that:

Behavioral responses to PAYD vary greatly depending on the design of the PAYD strategy. The most common effects found in this model study are mode/trip making choice (elastic demand effect) and route choice. In mode or trips making choice, the driver decides not to make the trip or to use another mode, to save on insurance premium. With route choice, the PAYD participants attempt to find the route with the lowest generalized cost. With all PAYD strategies, drivers tend to reduce the number of car trips made. Participation level only has an effect on the height of the network effects and no additional responses are found.

For all PAYD strategies the total car demand decreases. As the price per kilometer increases for these strategies as will, this seems plausible. The strategies, for which the biggest decreases in total car travel demand are found, are those in which all drivers are forced to have a PAYD insurance. With these strategies, decreases in number of car trips of over 2% are found. In the young driver strategy also a large reaction in trip choice is found. As young drivers have less money than older drivers they are more likely to reduce trips in order to save money. For the Young Drivers strategy this group reduces it's number of trips with 14%.

Route choice is again highly dependent on the design of the PAYD scheme. In the model drivers will always try to take the route with the lowest generalized cost. For a PAYD strategy where the kilometer price is not differentiated to road category, this will mean that drivers will take the shortest route (distance) more often than in the reference. This shortest route is often less safe than other routes. If travel demand would remain constant this would give a decrease in traffic safety. The tendency of drivers to choose the shortest route in a strategy not differentiated to road category, results in lower levels of congestion on motorways. Since the model underestimates delays on lower levels roads due to junction delays. A tradeoff between accessibility and safety will have to be made when choosing a specific PAYD strategy. Because when faced with a premium differentiated towards road category, drivers shift towards the safer motorways. At this time the cheapest route and the safest route are the same. Therefore drivers will generally take the safest route more often. This tradeoff is the same for the comparison of PAYD and kilometer charge. For kilometer charge the main goal is to improve accessibility, while the goal of a PAYD strategy is to improve safety. A strategy that differentiates in road category for PAYD and kilometer charge would be opposites. In the PAYD strategy the motorway would be made cheaper than average, where by kilometer charge the motorway would be relatively more expensive to reduce motorway congestion further. However, as the level of demand will drop due to the increased trip costs, this decrease of exposure will compensate for the relatively unsafe routes.

For non-participants reactions are opposite to those expected. In the case that traffic conditions improve as a result of trip reduction of PAYD-participants and route choice adjustments, it is to be expected that the number of trips increase for non-PAYD-participants. These effects are not found, which may be the result of a low number of iterations used in the model run small to reach equilibrium. So if traffic conditions improve because there is less traffic, there will be less driving. This may lead to the model not being in equilibrium state when simulation is ended. These unexplainable behaviors are found for both route choice and mode/trip making choice.

For network effects, the level of motorway congestion depends on the PAYD strategy structure. The best effects for reducing the level of motorway congestion occur when the PAYD strategy has a flat charge per kilometer driven and all drivers are participants. In this case the fewest motorway kilometers are driven. Total kilometrage and travel time for strategies with all participants are shown below in Table 2.

	Reference	PAYD for all drivers	Full differentiation (Obligatory)
Mean travel time (minutes)	11.53	11.22	11.60
Mean distance (kilometers)	11.27	11.19	11.36

Table 2 Mean travel times and distances for different strategies

When the objective would be to improve traffic safety, the best strategy would be to differentiate to both road category and time of day for all drivers. This way, drivers optimize towards traffic safety and the lowest cost. Total crash reduction is estimated to be more than 5% with the model, resulting in a reduction of 60 fatalities and over a 1000 injured by traffic. See Figure 46 for traffic safety effects in reduction of traffic injuries in percentages to the current situation.

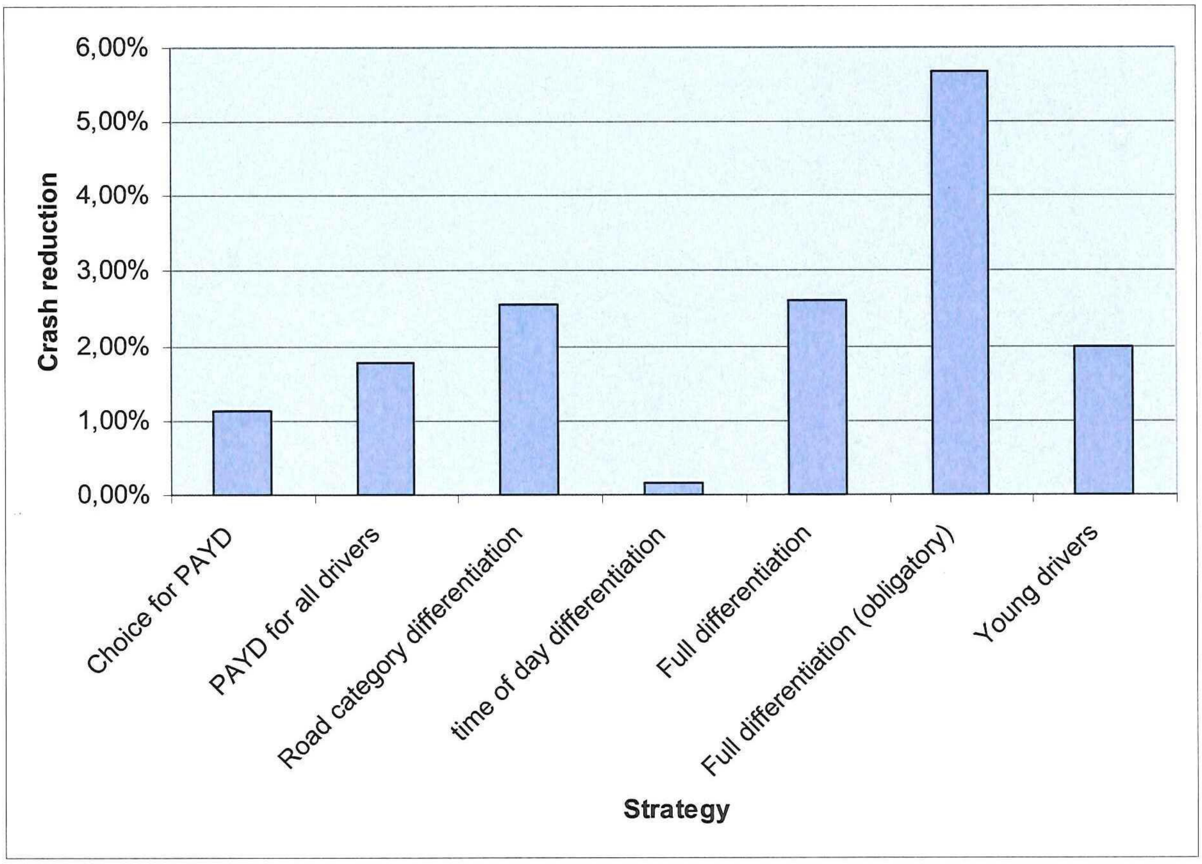

Figure 3 Crash reduction for the different strategies

If PAYD were to be implemented in the Netherlands, it is important that the structure is differentiated to road category, as this leads to a great improvement in traffic safety. Also the safety effects are greater when all drivers are participant, forcing PAYD, however, may give problems with acceptability, as drivers who drive much, will have an increased insurance premium with PAYD.

Index

Preface iii
Summary iv
Index ix
1 Introduction 1
1.1 Main contributions 2
1.2 Report outline 2
2 Background 3
2.1 Current car insurance system 3
2.2 Safety related factors 4
2.2.1 Kilometers driven in relation to safety 4
2.2.2 Speed in relation to safety 6
2.2.3 Road category in relation to safety 9
2.2.4 Nighttime driving in relation to safety 9
2.2.5 Risk Groups: Young Drivers 10
2.3 Other PAYD systems and results 11
2.3.1 PAYD strategies and technologies 11
2.3.2 PAYD and pilots about PAYD 14
2.4 Responses towards PAYD 16
2.4.1 Behavioral responses 16
2.4.2 Acceptability 17
2.5 Relation between PAYD and Road Pricing 18
2.5.1 Basics of road pricing 18
2.5.2 Similarities between PAYD and road pricing 19
2.5.3 Differences of PAYD and road pricing 19
2.6 Setup of the PAYD TRANSUMO project 19
3 Research questions and methodology 21
3.1 Research questions 21
3.2 Research objectives 22
3.3 Research methodology 22
3.3.1 Introduction 22
3.3.2 Method 1: Comparison of PAYD strategies 23
3.3.3 Method 2: Case study approach 24
3.3.4 Method 3a: Transportation modeling framework 25
3.3.5 Method 3b: Traffic safety model 26
4 PAYD variants 27
4.1 Research questions revisited 27
4.2 Dimensions of tariff differentiation 27
4.3 Hypotheses of effects 30
4.4 PAYD strategies and hypotheses 32
4.4.1 Reference strategies 32
4.4.2 Strategy 1 – Choice for PAYD 32
4.4.3 Strategy 2 – PAYD for all drivers 33
4.4.4 Strategy 3 – Road category differentiation 33
4.4.5 Strategy 4 – Time of day differentiation 35
4.4.6 Strategy 5 – Full differentiation 38
4.4.7 Strategy 6 – Full differentiation (obligatory) 38
4.4.8 Strategy 7 – Young drivers 39

4.5 Evaluation approach: criteria and indicators ... 40
5 Modeling framework ... 42
5.1 Behavioral responses and expected effects ... 42
5.2 Overall framework ... 43
5.3 Elastic demand ... 45
5.4 Departure time choice ... 47
5.5 Route choice (INDY) ... 48
5.5.1 Route set generation model ... 49
5.5.2 Route choice model ... 50
5.5.3 Dynamic network loading model ... 51
5.6 Traffic safety model ... 52
5.6.1 Network level safety model ... 52
5.6.2 Route safety level ... 53
6 Case study: Region of Haaglanden ... 56
6.1 Model setup ... 56
6.1.1 Network description ... 56
6.1.2 Travel demand ... 58
6.1.3 Model parameters ... 62
6.1.4 Assumptions ... 64
6.2 Participant creation ... 66
6.2.1 50% participation rate ... 66
6.2.2 Young drivers ... 67
6.3 Reference situation ... 69
7 Model results ... 74
7.1 Strategy 1 – Choice for PAYD ... 74
7.1.1 Model results ... 74
7.1.2 Hypotheses revisited ... 79
7.2 Strategy 2 – PAYD for all drivers ... 79
7.2.1 Model results ... 79
7.2.2 Hypotheses revisited ... 82
7.3 Strategy 3 – Road category differentiation ... 82
7.3.1 Model results ... 83
7.3.2 Hypotheses revisited ... 87
7.4 Strategy 4 – Time of day differentiation ... 87
7.4.1 Model results ... 87
7.4.2 Hypotheses revisited ... 91
7.5 Strategy 5 – Full differentiation ... 91
7.5.1 Model results ... 92
7.5.2 Hypotheses revisited ... 95
7.6 Strategy 6 – Full differentiation (obligatory) ... 96
7.6.1 Model results ... 96
7.6.2 Hypotheses revisited ... 99
7.7 Strategy 7 – Young drivers ... 100
7.7.1 Model results ... 100
7.7.2 Hypotheses revisited ... 104
7.8 Comparison of strategies ... 104
8 Conclusions ... 109
9 Discussion and recommendations ... 111
References ... a

1 Introduction

In current car insurance policies the insurance premium is, dependent of insurance company, differentiated by attributes like driver age, gender, car type and self estimated kilometrage and claim behavior. As the number of insurance claims a person has on average increases with annual kilometers driven, see Figure 6, insurance premium will be affected by risk more clearly if differentiated to actual kilometers driven.

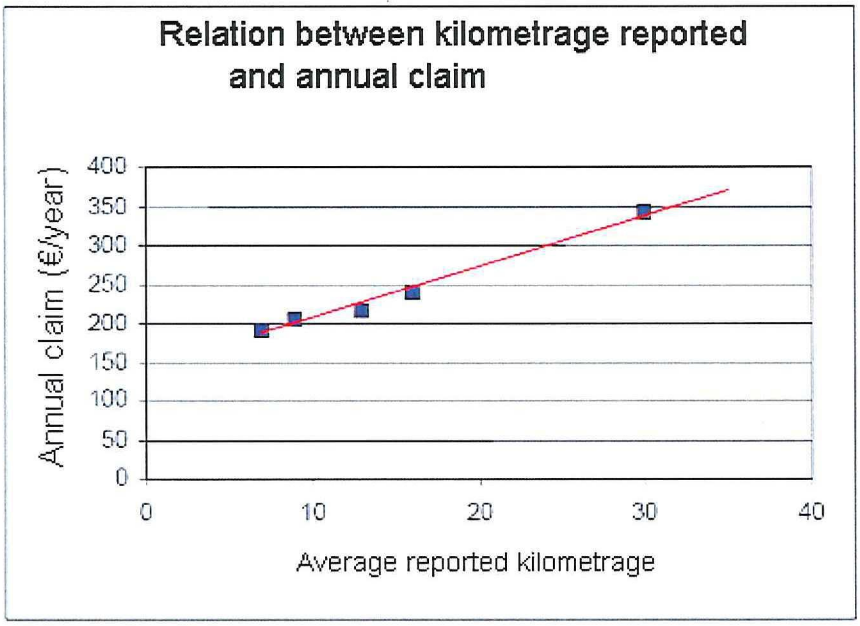

Figure 4 Relation between kilometers reported and annual claim. Source: TNO Inro, 2003.

Pay-As-You-Drive (PAYD) is a new insurance policy for car holders in which car drivers pay at least part of their insurance premium per actual kilometer driven. With PAYD, drivers with a low kilometrage are better off, while high kilometrage drivers are worse off than in the current situation. With more advanced technologies, the PAYD insurance premium can be further differentiated to reward safe driving behavior with a smaller premium.

It is expected, that higher, possibly involuntary, levels of PAYD participation, have substantial network level effects on accessibility, safety and possibly also the environment. This study is part of the TRANSUMO project "Verzekeren per kilometer" (PAYD), which involves a real life pilot study to measure (behavioral) effects of PAYD on individual drivers. To assess the effects of PAYD for large-scale implementation on network level a modeling approach is used. This study focuses on the effects of PAYD on network level and compares the safety and accessibility effects of different Pay-As-You-Drive (PAYD) strategies simulated with a transportation model.

The PAYD strategies evaluated in this study are differentiated on five levels, these differentiations are

- Fixed or kilometrage differentiated premium
- Road category differentiation
- Time of day differentiation

- Participation level
- Young drivers

The model is capable of dealing with route choice, departure time choice and elastic demand/mode choice. The strategies are compared on the basis of accessibility, network safety and route safety in order to give a clear indication of the network effects of PAYD.

1.1 Main contributions

This study clearly demonstrates the possible safety and accessibility benefits of PAYD, which, as we will show, will depend largely on the level of premium differentiation. Furthermore, a comprehensive macroscopic dynamic transportation modeling framework is used for the estimation of general network effects and traffic safety. For the latter a special traffic safety model had been created on a network and route level. With this model, different safety levels for pricing strategies can be assessed. Also, the macroscopic dynamic transportation model framework calculates an equilibrium situation between elastic demand, departure time choice and route choice.

1.2 Report outline

After this introduction, the first chapter will present in more detail the background of this study. In chapter 3, the research questions and methodology are discussed. For more information about the chosen PAYD strategies, chapter 4 is of main importance. In chapter 5 then, the modeling framework is discussed, followed in chapter 6 by the overview of the case study area, the region of 'Haaglanden' in the Netherlands. In chapter 7, the modeling results of the different PAYD strategies are presented. In chapter 8, the research questions are answered in the 'Conclusions' chapter. Finally, chapter 9 covers the discussion and recommendations.

2 Background

After the introduction in which an overview of the report has been given, the background of this study is discussed here. In the next chapter (chapter 3) the research questions and methodology will be discussed.

This chapter starts with an explanation of the current car insurance system used in the Netherlands. In section 2 factors that have a relation to traffic safety are discussed, followed by PAYD systems and projects in section 3. The next section holds information about responses that may happen when PAYD is applied. In section 5 an overview is given about road pricing and kilometer charge, which may at some point be introduced in the Netherlands as well. Finally in section 6 the setup of the PAYD TRANSUMO project is given.

2.1 Current car insurance system

Everyone bears the risk of an accident of some sort, whether it is a car crash, a fire or even a slip down the stairs. As these accidents often bear high cost, people insure themselves against these costs. The insurance company charges a small amount of money from all of its clients every month. With this money, the claims from those who had an accident are paid. This way, in which everyone pays for the misfortune of some, is called the principle of insurance.

Next to the principle of insurance, there is the principle of solidarity. With solidarity, those who are able to afford the price pay for those who cannot afford their costs. For example, those who work, pay for the benefit of those without work. Also, people who have a higher risk, pay more, which is called the principle of fairness.

The current vehicle insurance system bases the premium on many different attributes. These attributes can be listed as driver related and car related. Driver related attributes include:

- Driver age;
- Gender;
- Time since acquiring drivers driver license;
- Living location;
- Self estimated kilometrage;
- Claim history.

For the car the following attributes are of importance:

- Age;
- Brand and type of car;
- Type of fuel;
- Price of the car;
- Type of anti-theft system.

While these factors already give a variabilisation in insurance premium, adding the real kilometrage or other factors to the system can further variabilize it. Average premium per person can stay the same (currently approximately 600 in the western part of the Netherlands), but people with less risk would pay less as well.

2.2 Safety related factors

In this section, factors that are related to traffic safety are discussed. Each of these related factors can be used in PAYD strategies and some of them will be used during this study, as shown in section 4.4.

2.2.1 Kilometers driven in relation to safety

An often-used formula for the calculation of number of crashes is (Wegman, 2003)

Number of crashes = Exposure x Risk

The risk in this formula depends on the driver, this is explained in more detail at the end of this section. The indicator used for exposure is mobility, or kilometers driven per year. The indication that increased mileage leads to higher claim frequencies can also be found in American research. A study about claims in northern Texas by Progressive Insurance shows an approximated linear result between mileage and claim frequency, see Figure 5.

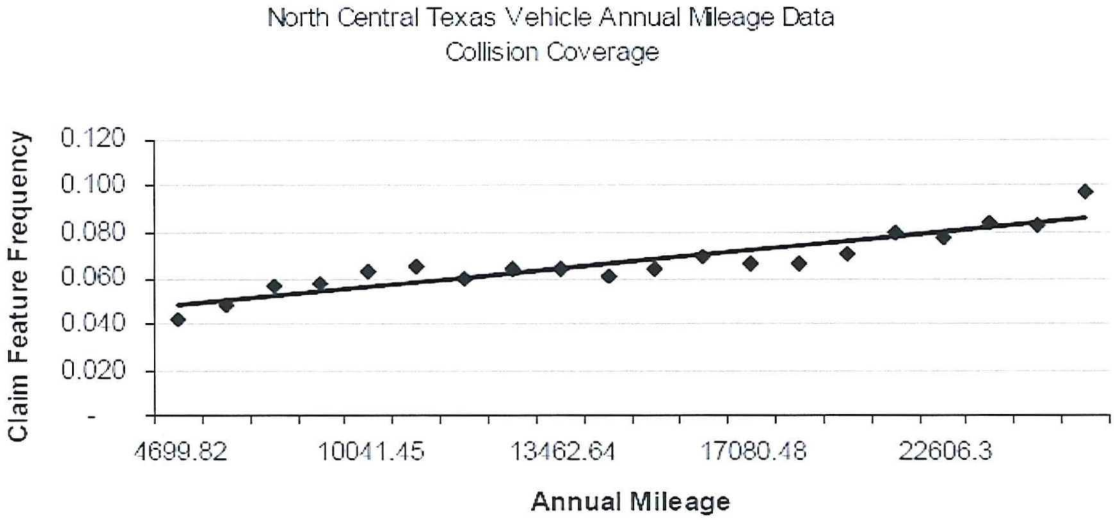

Figure 5 Claim frequency for all crashes as a function of mileage. Source: Progressive Insurance, 2005.

An estimated formula for claim frequency would look like this:

$$F = \alpha + \beta * m \qquad (1)$$

Where

$F =$ claim frequency

$\alpha =$ fixed claim risk for standstill car

$\beta =$ claim frequency increase per mile

m= annual mileage

In Dutch research from Van Kampen, he also states that more car/passenger kilometers give a higher exposure and therefore a higher crash rate (van Kampen, 2003). From data of the Dutch centre of insurance statistics (Centrum voor Verzekeringsstatistiek (CVS)) a similar line can be presented as in the Texas research. Data of over 3 million vehicles has been used to complete the graph. This data has been presented in a report from TNO (TNO Inro, 2003). Though this data is highly aggregated, it gives the impression of a linear relationship. Formula (1) would also be appropriate in this relation, except that instead of risk, actual payout is calculated. See Figure 6.

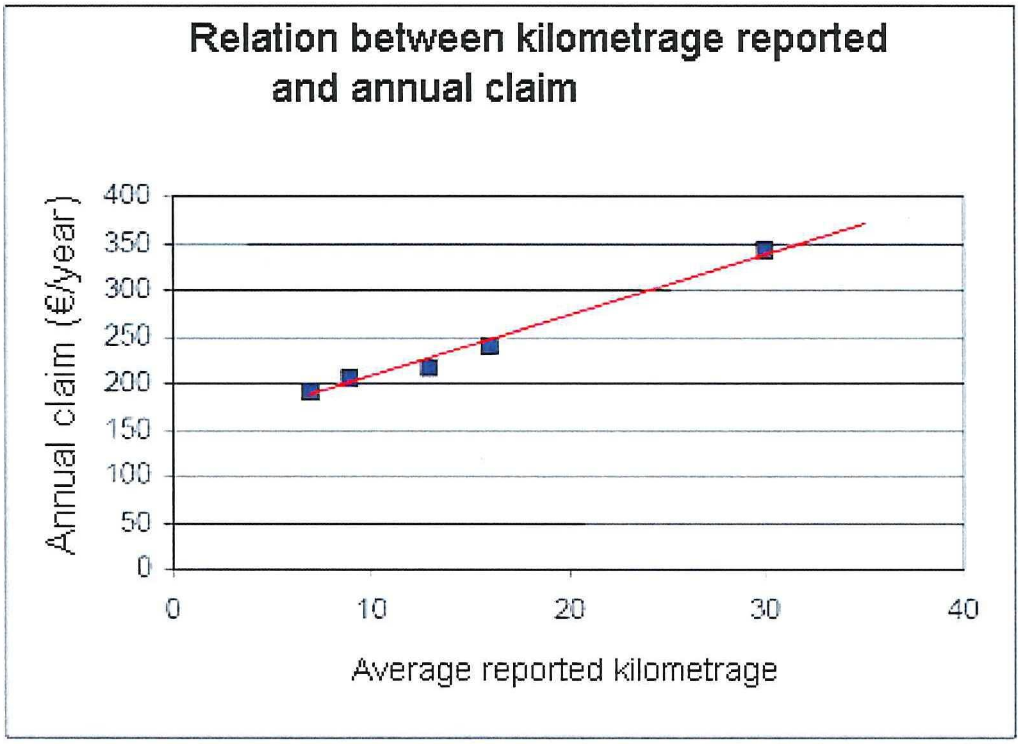

Figure 6 Relation between kilometers reported and annual claim. Source: TNO Inro, 2003.

Researcher Todd Litman also comes to the conclusion that there is a relation between mileage and number of crashes (Litman, 2006). His studies also show a near linear relation between annual mileage and number of crashes, see Figure 7.

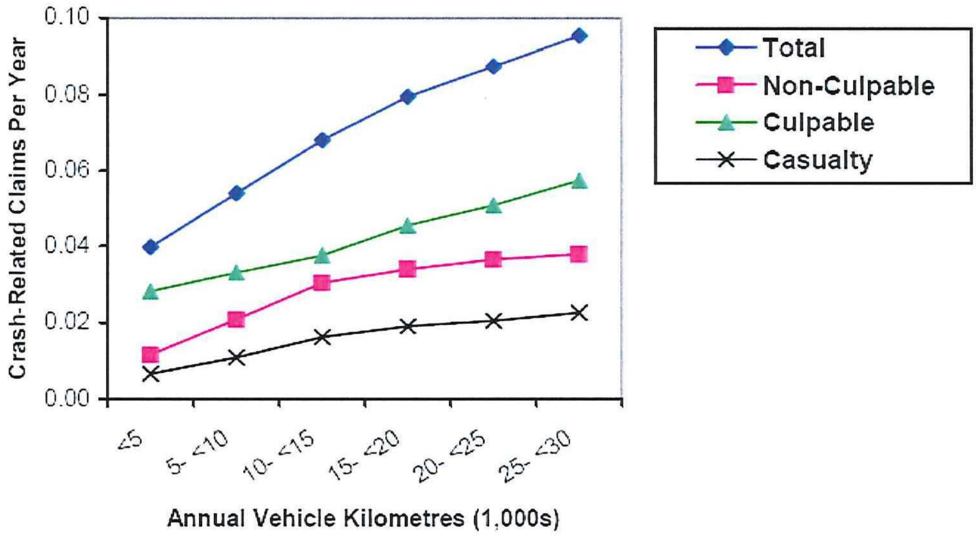

Figure 7 Crash related claims per year as function of kilometers driven. Source: Litman, 2006.

From the same research, however, there is concluded that higher mileage drivers have a lower crash frequency per mile than lower mileage drivers, see Figure 8. Reasons for this may be:

- Higher mileage drivers tend to drive safer vehicles
- Higher mileage drivers have more experience
- Drivers who have higher risk tend to drive their vehicles less than average
- High mileage motorists tend to do a greater share of driving on safer, grade-separated motorways
- Urban drivers tend to have higher crash rates and lower annual mileage
- There may be other types of offsetting behavior, by which higher mileage drivers take more precaution to limit their risk

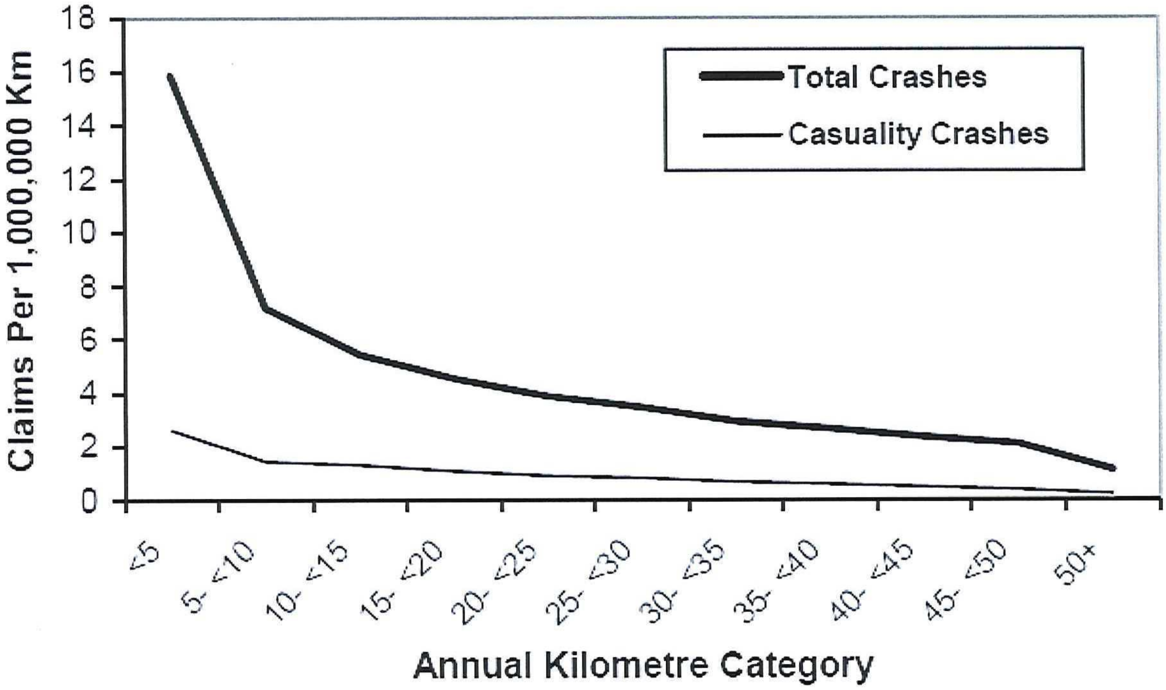

Figure 8 Risk per kilometer decreases with higher annual kilometer category. Source: Litman, 2006.

2.2.2 Speed in relation to safety

The relation between speed and crashes can be divided into two groups, namely research that focuses on the actual velocity of a vehicle and research that focuses on the relationship between the speed of a vehicle in accordance to the speeds of other road users. The research about the effects of speed already date from a long time back, as in 1964 Solomon concluded his research about the relation of speed and crashes. From his studies the conclusion was that a reason more important than exact speed for the cause of crashes was the difference in speed of the road user with the average speed on the road (Solomon, 1964). The same conclusions were found in other studies of that time (Cirillo, 1968; RTI, 1970). In a literature review, the results of Solomon and Cirillo have been placed in one graph, from which results are shown in Figure 9.

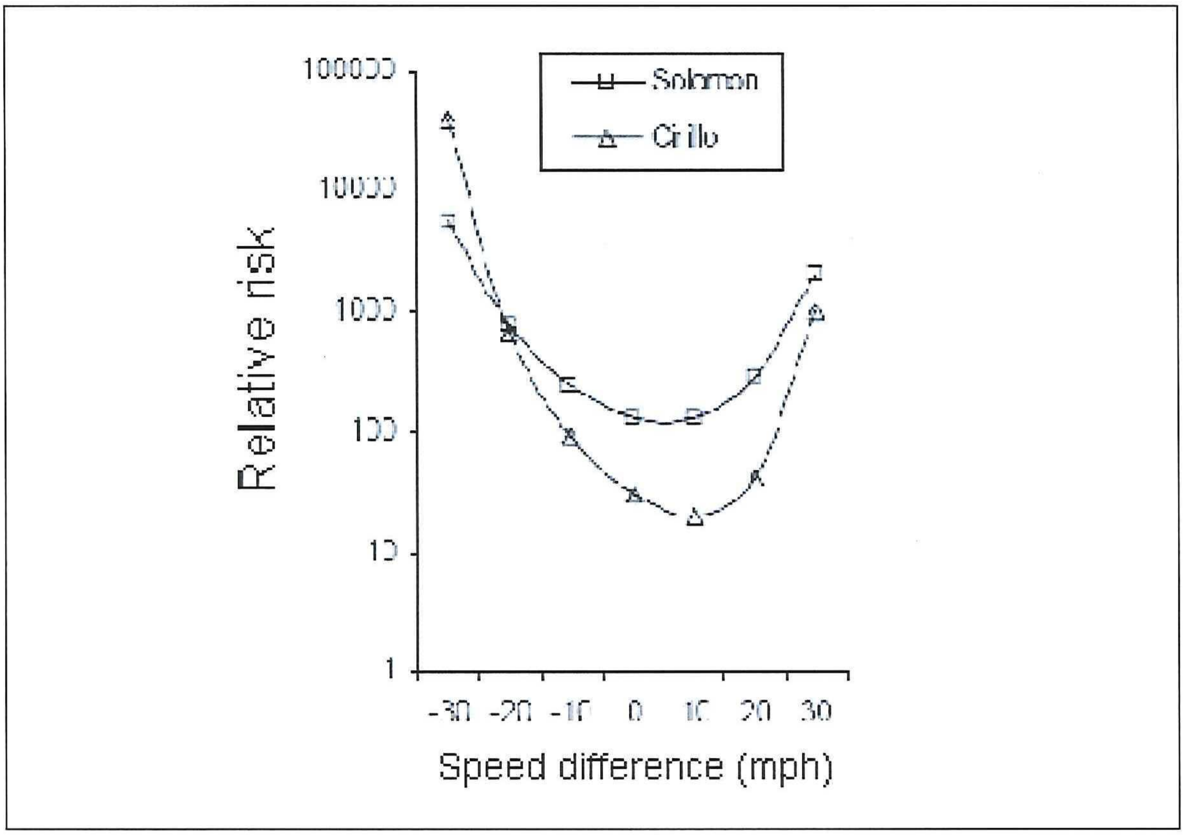

Figure 9 Comparison of relative risks of Solomon and Cirillo because of differentiation of driving speed. Source: Aarts, 2004.

Later studies on the differences in speed no longer showed the U-shaped curve that was found in the early years, but instead only found an increase in risk with higher than average speeds (Kloeden et al., 2001). They also concluded that the higher risk of driving at lower speeds than average, which was found by Solomon and Cirillo was because of traffic maneuvers and was therefore not caused by speed alone.

Also in Dutch research the conclusion is drawn that traffic safety decreases when more people neglect the speed limit (van Schagen et al., 2004). Though in this research it is also stated that an increase of speed gives a direct decrease in safety. A quote from the article is the rule of thumb from Finch et al. is that an increase in speed of 1 kilometer per hour, gives an increase of risk of 3% (Finch et al., 1994).

A review of the speed and speed difference literature shows us that the relation between speed and risk is often found to be either an exponential or power function (Aarts & Van Schagen, 2005). This relation is likely to hold, though studies from other countries are likely not to be completely the same for the Netherlands, as the roads in the Netherlands have many more junctions and more slow traffic (Aarts, 2004). Also this relation is stronger with urban than with interurban traffic (Kloeden et al., 2001).

A main reason for the increased unsafety of higher speeds is that a higher speed gives less time to react on sudden situations than lower speed and that the braking distance is longer (SWOV, 2007). Also, it is clear that higher speed give worse crashes. This is because the kinetic energy from the car is released during the crash and the kinetic energy has a quadratic relation with speed (Aarts & Van Schagen, 2005).

In a Swedish study from Nilsson (Nilsson et al., 1982), the effects of the changing of the speed limits on several Swedish motorways are taken into account. It was found that the reduction of speed limit was accompanied by a reduction in average speed and a reduction in crashes as well. The relation found between speed and number of crashes are shown in (2), (3) and (4). In Figure 10 taken from a SWOV report (Aarts, 2004) the percentages of crashes are plotted in relation to the speed limit. The crashes on 110 kilometer per hour have been set at 100% and the percentages for 90 kilometer per hour have been calculated from this level. The power function of these lines is therefore also less clear, as the area shown is not near the centre of the parabola.

$$\left(\frac{100\%}{\%crash_{after}}\right)=\left(\frac{\max speed_{before}}{\max speed_{after}}\right)^2 \tag{2}$$

$$\left(\frac{100\%}{\%crash_{after}^{at\_least\_injury}}\right)=\left(\frac{\max speed_{before}}{\max speed_{after}}\right)^3 \tag{3}$$

$$\left(\frac{100\%}{\%crash_{after}^{fatal}}\right)=\left(\frac{\max speed_{before}}{\max speed_{after}}\right)^4 \tag{4}$$

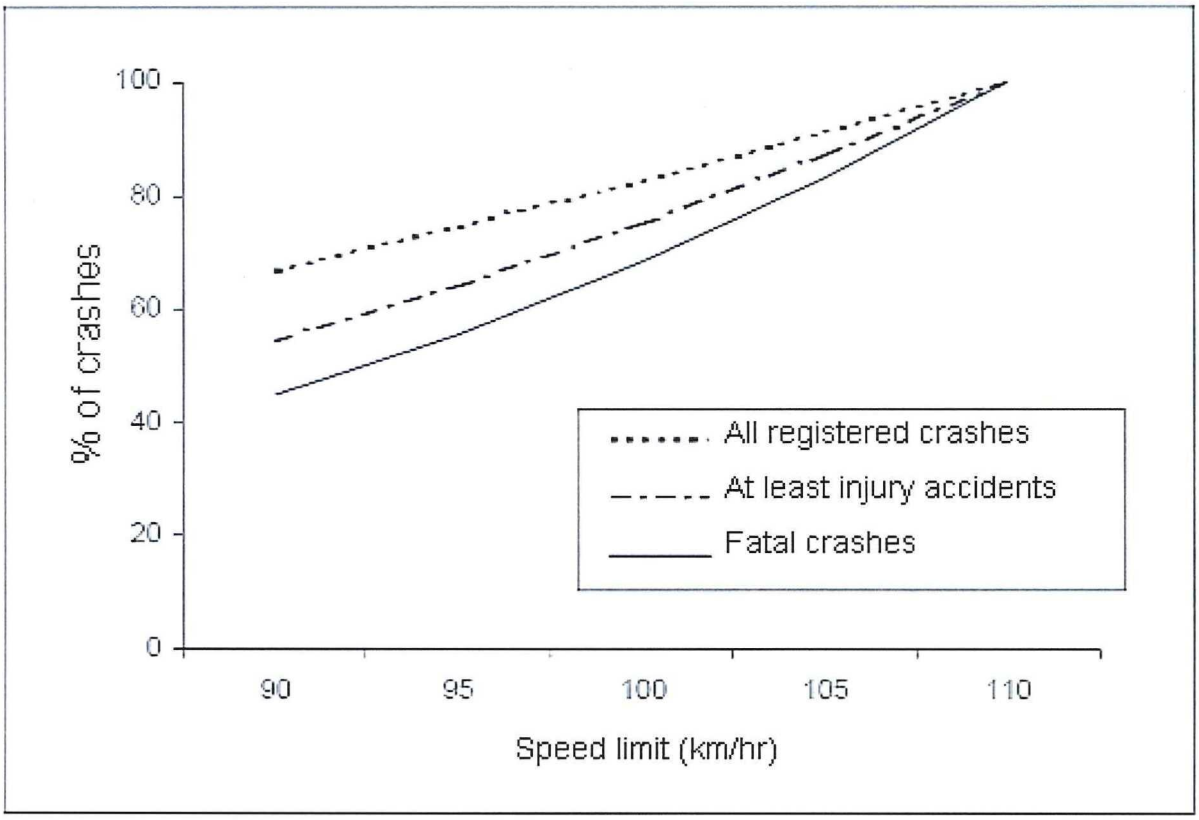

Figure 10 The difference percentage in registered crashes in accordance to the formulas of Nilsson. Source: Aarts, 2004.

2.2.3 Road category in relation to safety

The relation between road category and crashes is mainly related to other factors in driving, such as allowed speed, actual speed, number of lanes, width of the lanes, number of crossings or on and off ramps, type of crossings, oncoming traffic, etc. The safety aspects of some of these factors have been described earlier, others have not.

During this research it will be important to quantify safety by kilometers driven, therefore safety parameters per road type are needed. From Dutch research an estimate of accident risk is shown in Table 3 (Janssen, 2005). Accident risk is here defined as the number of traffic injuries divided by million car kilometers per year. Also fatalities are mentioned per hundred million car kilometers.

Road category	Number of injury accidents per million car kilometers	Fatalities per hundred million car kilometer
Freeway	0.06	0.24
Motorway	0.08	0.75
Interurban road	0.22	1.05
Interurban road for all traffic	0.43	2.29
Urban flow road	1.10	1.51
Home zone Street	0.57	0.74

Table 3 Number of injury accidents per million car kilometers and road type averaged for 1997-1999

2.2.4 Nighttime driving in relation to safety

Driving during nighttime is more dangerous than during day. One of the reasons for this is the worsened visibility due to poor lighting. Even though most roads have streetlights nowadays, it is still darker than during daytime. There are less people on the road at night, yet research shows that approximately 35% of all accidents happen during those hours (OECD, 1980). This percentage is also found looking at the data from the VOR (verkeersongevallenregistratie) for the past few years. The unsafety of nighttime driving is related to a lot of different aspects, one of the main aspects being alcohol. German research states that during the night approximately 15-20% of all accidents are drink-drive related, while during daytime this is only approximately 2% (Brühning, 1988). With younger drivers, this percentage is even higher, having a drink-drive relation of 70%.

The nighttime in which most of these crashes occur is Friday and Saturday night between 0-6. With young drivers, many have been to town for the evening and drive with more people of the same age in one car. Often it is found that the driver has drunk more than allowed and speed limits are neglected (Brühning, 1991). Other reasons for the high risk of young drivers at night are the low level of experience, fatigue, heavy loaded vehicles and low seatbelt use. These crashes are for 69% one-vehicle crashes. Also over all ages the percentage of one-vehicle crashes is higher during night than day. This percentage is approximately 33% instead of 13%.

The effect of weather is also more notable at night than during day. A higher percentage of crashes occur with snow, ice, rain, fog or wet roads. Number of weather related crashes increase with approximately 10% during the night (Brühning, 1991).

2.2.5 Risk Groups: Young Drivers

Young starting drivers have a relatively high risk of being involved in a crash. In the Netherlands the risk of young drivers is more than four times as high as the risk of experienced drivers (SWOV, 2006), see Figure 11. The insurance premium in current insurance systems for young drivers is therefore also higher than that of older, more experienced, drivers. However, as young people do not drive much, variabilisation of the insurance premium towards miles driven may lead to a reduction in premium. And as young drivers may not have as much money as older drivers, the cost per kilometer may make them change to a cheaper option easier than people with more money. This way the insurance company will have less risk of a claim.

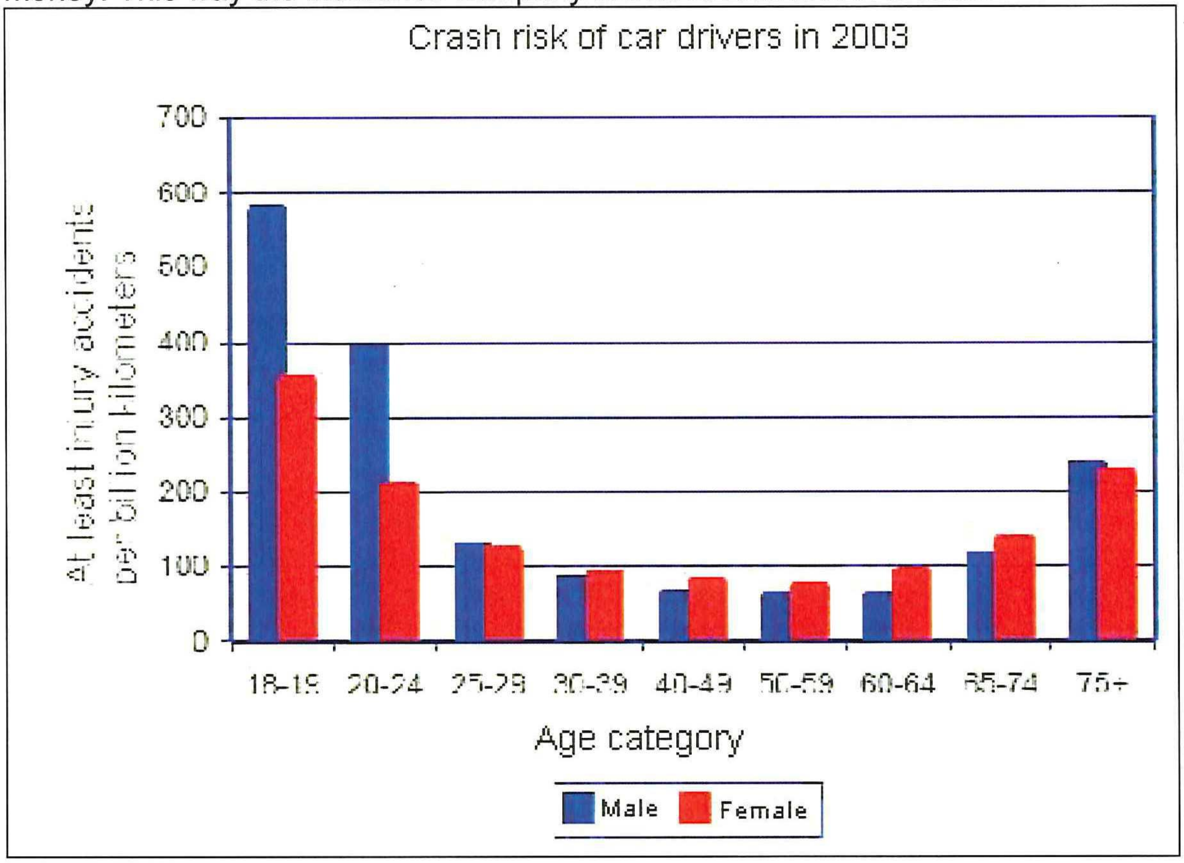

Figure 11 Crash risk for car drivers in 2003. Source: SWOV, 2006.

Vlakveld (Vlakveld, 2005) gives a list of reasons for the higher risk of young drivers. Mostly being based on lack of experience, this list includes:

- Relatively high chance of losing control of vehicle
- Not giving right of way to other drivers
- Wrongly estimating stopping distance
- Driving too close to the predecessor
- Late notice of person, object or other vehicle
- Missing of traffic signs
- Starting too late on evasive maneuvers
- Driving on the wrong place of the road

- Ignoring the speed limit
- Often driving in less safe cars
- Driving with multiple passengers
- 'Showing off' for passengers

A part of these reasons are based on behavior instead of the lack of experience. Also alcohol often plays a role in crashes, especially during nighttime driving. The risk of a young driver with a 0,5 g/l alcohol in his blood already is six times the normal risk (SWOV, 2005). This use of alcohol is one of the main factors of the increased risk for young drivers at night. Especially during the weekend nights risk of a crash increases, as young people have gone out to town with friends, may have drunk and are stimulated to drive faster by their passengers.

2.3 Other PAYD systems and results

2.3.1 PAYD strategies and technologies

Different variations of PAYD and possible technologies have been developed throughout the years. A small overview of the different options have been found in literature, is shown below (Todd Litman, 2006).

Mileage Rate Factor
With the mileage rate factor, vehicle insurance is incorporate mileage as factor. People predict their annual mileage and insurance fee is calculated, premiums are increasing with higher mileage categories. This is already the case in the Netherlands, though effects on price are not very high. Estimates are inaccurate, as travel cannot be predicted perfectly. Fraud would be easy, because it is hardly possible to check the correctness of the reports. Due to the unreliability of this data, insurance companies limit price differences between mileage classes.

As a mileage rate factor would only have a few categories, consumers would have little incentive for efficient travel behavior. More marginal pricing would require smaller categories. Mostly mileage rate factor is already incorporated in other parts of the insurance premium, like fuel type and age of the car. As the mileage of the consumer is not checked, effects of a more differentiated Mileage Rate Factor are estimated to be small.

Mileage checking is in this case done with self-reporting. In a more sophisticated program, users of the insurance program will once in a while logon to the Internet and report the current number of kilometers of their vehicle. As fraud in this case is possible, random checks could be performed in order to keep fraud to a low level. The insurance differentiation is in this case limited to kilometers driven per year.

Another possibility is to perform odometer audits. With odometer audits, an audit would be performed at the beginning and end of the policy term. In this case a legalized person, who may for example be a garage employee, reads the odometer results and reports them to the insurance company. For most cars it could be performed together with yearly check up APK and would not cost much. Fraud is difficult as odometers become increasingly tamper resistant and most new cars are equipped with electronic-digital odometers that cannot be reset. Fraud with odometers is as of yet not punishable by law in the Netherlands, which should be changed, in order to make odometer audits possible.

An additional system that could be used together with the Odometer Audits is the Nationale autopas (NAP). This system has been implemented to reduce the possibility of odometer fraud for secondhand cars. During the obligatory annual periodical checkup of cars in the Netherlands (APK) and at the selling of the vehicle the odometer level is recorded and added to the NAP. The NAP could be used as additional security measure for odometer audits. The possible insurance with odometer audits is based on the kilometers driven per year. A problem is that the APK only has to be performed on cars that are older than three years, so it would not be possible to check on new cars. Also, in the near future, the government may decide to have the APK checkups only once every two years.

Pay-at-the-Pump (PATP)
Pay-at-the-Pump uses a surcharge on vehicle fuel purchase to fund vehicle insurance. All basic coverage is provided and pay will be per kilometer driven. An advantage with this option is that there will be no uninsured driving, as people will have to get fuel and are thus automatically insured. Problems with this structure lie in people being able to purchase fuel across border in order to avoid having to pay the insurance premium. Also people are likely to find this option unacceptable, as they perceive PATP as just another fuel tax, instead of insurance premium. Last, it is perceived that some people will pay more than others, while they may not necessarily have more risk. Groups in stop and go traffic will have relatively higher charges, while the heavy injury and fatal accidents are reduced (Brownfield et al., 2003). Impacts of PATP on travel behavior are expected to be low.

Usage-Based Premiums
A usage-based premium will reflect the driver's kilometers driven in the insurance fee. At the beginning of the policy term, the odometer is checked and the current kilometers driven recorded. At the end of term, there is another odometer audit and the final insurance fee is calculated, resulting in money being paid back to the insured, or additional money being charged. Instead of vehicle kilometers, also minutes can be recorded. In this case, the user is charged for the use of the car, if the engine is on. Equity issues are well addressed, as on average, a higher income motorist drives more kilometers or minutes per year than a lower income driver. Some drivers will of course be worse off, but if implemented as a choice option, it will increase consumer savings and choice.

Next to odometer audits, it is in this case possible to make use of a Vehicle Use Detector And Recorder (VUDAR) to measure kilometers or minutes driven. This device is installed near the engine that can measure when the engine is active and how fast is driven. In this way Insurance can be based on minutes or kilometers driven. The speed of the car is measured as well, but as no driving location is known, only speed above the maximum limit can be used for insurance premium. The VUDAR will need to be read out, either by a specialized person or by attaching a special memory stick to the home computer.

GPS based pricing
GPS based pricing can be the most actuarially accurate form of pricing strategy, as it can incorporate nearly any rating factor, including time, speed and location. This way, people living in a high-risk area, but work well out of that area only pay the increased fee of the high-risk area at the beginning of the trip and then start paying the lower insurance fee. This insurance system also incorporates actual kilometers driven as a part of the price. Bills could be sent monthly or bi-monthly, similar to other utilities.

In addition to the pricing system, other GPS-based services may be provided at reduced cost. This is possible because the GPS device is already installed. Other services are often needed to make the GPS-based pricing cost effective, as the device and telecommunication are relatively expensive. Additional services could include:

- Route planning
- In-vehicle entertainment
- Emergency crash notification systems
- Kilometer charge
- Parking place finding
- Theft recovery

However, the people who are interested in these additional services (people who drive their vehicles much) are not in the group of people who are interested in PAYD insurance.

Because of the high expenses, GPS-based pricing will often not be available for lower income group drivers. Privacy may also be a problem for some motorists, this is especially a problem in the case of a mandatory system. Because of the high price and the privacy concerns, market penetration of an optional insurance program is estimated to stay below 25%.

Disadvantages of a GPS based system are

- High implementation costs make GPS based pricing unsuitable for mandatory implementation
- Privacy issues may arise
- Costs of data communication are relatively high at the moment
- Problems with 'line of sight', in high-density area's a GPS signal may be lost. The car can't also be tracked in tunnels, while in a steel box or even if the antenna is wrapped with silver wrapping
- Not 100% fraud proof, because of an identification problem, in the case that the GPS system is put into another car, the registration won't work properly
- The system is based on American satellites, which makes it vulnerable to decisions of the American government, i.e. in the case of war or with protective measures against terrorist threats the system could be disabled or accuracy lowered.

Overview
During the last section different pricing techniques have been mentioned among the pricing alternatives. Of these techniques a small comparison is made, showing the compatibilities of the different systems. Depending on the goals of the insurer, different options would be best. The comparison is presented below in Table 4. The

sign (+ +) in the table stands for the lowest costs and lowest possibility of fraud, versus (- -) to be the highest costs and highest possibility of fraud.

	Self-report	Odometer Audits	VUDAR	GPS
Kilometrage	Yes	Yes	Yes	Yes
Driving location	No	No	No	Yes
Driving time	No	No	Yes	Yes
Speed	No	No	Only maximum	Yes
Implementation cost	+ +	+	-	- -
Operation cost	+ +	-	+	- -
Possibility of fraud	- -	+	+ +	+

Table 4 Comparison of technologies for PAYD

2.3.2 PAYD and pilots about PAYD

In this section there will be a short overview of PAYD insurance already available and pilot studies still going on in the world.

1. Norwich Union – Pay As You Drive (UK)

Description

After a successful pilot study in 2003 with 5000 participants, Norwich Union fully implemented the PAYD insurance. Recording is done with a GPS based black box in the vehicle which registers how often, when and where the vehicle is driven. The price for the black box is set at £50, which is to be paid once by the customer. Different insurance rates apply for young drivers (23 and younger) and other drivers (24-65). The young drivers have to pay heavily for nighttime (23:00-5:59) driving. The price per kilometer is £1 at these hours. For the older drivers night (0:00-4:59) and morning peak (7:00-9:59) are most expensive, though this is not as much higher as with young drivers. Billing is done on a monthly basis.

Status Project

Implemented

Website

http://www.norwichunion.com/pay-as-you-drive/index.htm

2. Polis Direct – KM Polis (NL)

Description

A few years ago Polis Direct started with a kilometer polis, which only takes into account kilometers driven. The insurance owners report the kilometers driven online from the readings of their odometer. Checks on this are performed by the use of the 'Nationale Autopas' (NAP) and odometer checks in the case of damage. The insurance is available for those drivers 24 and over, with cars priced below €75.000. Insurance is paid in advance, based on estimated kilometers that will be driven (either by last years result, or consumer estimate). Maximum rebate of premium for one year is 50%, rebate or additional payment is settled at the end of the insurance period.

Status Project

Implemented

Website

http://www.kilometerpolis.nl/

3. Corona Direct – Kilometerverzekering (BE)

Description

The 'Kilometerverzekering' of Corona Direct is about the same as the KM Polis of Polis Direct. The only difference lies in the fact that Corona Direct has random checks for odometer audits instead of checking with the NAP. There are also no limitations to the people that can be insured with the Kilometerverzekering.

Status Project

Implemented

Website

http://www.kilometerverzekering.be/kv/nl/index.html

4. Progressive Insurance – Tripsense (Minnesota, US)

Description

The Tripsense insurance program was launched in August 2004 and works on the basis of a VUDAR. This device is able to detect engine start and stop, kilometers driven, number of sudden starts and stops, speed and connect and disconnect date and time. As location is not taken into account, allowed speed cannot be used. At the end of a policy year a rebate is calculated on the basis of kilometers driven and speed above the highest speed limit. This is done by 'reading out' the Tripsensor at the home computer. A rebate of at least 5% and maximum 25% is given if the data from the Tripsensor is loaded to the insurance company. Reports from the Tripsensor about driving behavior are generated and returned to the insured.

Status Project

Implemented

Website

https://tripsense.progressive.com/about.aspx

5. AXA – Traksure (IRE)

Description

Launched in 2001 after a pilot test, the Traksure insurance is created for young male drivers. The focus of the Traksure insurance is on speed instead of distance. Using a GPS device with digital speed map, speeds are recorded and send to the insurance company. Safe driving (keeping to the speed limits most of the time) will result in a reduction of the insurance premium (with a maximum reduction of 45%).

Status Project

Implemented

Website

http://www.celtrak.com/tracsure.aspx

6. Progressive Insurance – Texas Mileage study (Texas, US)

Description

This two phase pilot program started in August 2005, starting with a research together with insurance companies to determine the relation between speed and

crash rate. This first phase is now complete and the second phase, a pilot in which vehicles are GPS equipped, is halfway. In this second phase, the reactions to an insurance incentive to drive less are monitored for 3014 participants (Progressive, 2007). Only mileage is considered in this study.
Status Project
Second phase started
Website
http://www.nctcog.org/trans/air/programs/payd/PhaseI.pdf

Overview
The six mentioned PAYD options and pilots are summarized below in Table 5.

Company	**Techno-logy used**	**Premium basis**	**Status**	**Possible safety effect**	**Costs**
Norwich Union (UK)	GPS	Time of the day, road category and kilometers driven	Implemented	Large	Large
Polis Direct (NL)	Self report	Kilometers driven	Implemented	Minor	Negl.
Corona Direct (BE)	Self report	Kilometers driven	Implemented	Minor	Negl.
Progressive Insurance (Minnesota, US)	VUDAR	Kilometers driven and excessive speed	Implemented	Average	Small
AXA (IRE)	GPS	Speed	Implemented	Large	Large
Progressive Insurance (Texas, US)	VUDAR	Mileage	Phase 2 pilot	Minor	Small

Table 5 PAYD and PAYD pilots

2.4 Expected responses towards PAYD

2.4.1 Behavioral responses

When drivers are faced with additional costs for driving, a series of choices are made whether or not to pay the additional costs. These choices depend on the variations in PAYD used. Possible responses are shown in Figure 12. The responses are ordered to how much time is spent before the choices take effect and how much effect is found due to PAYD. In section 4.3 the choices that are modeled are described.

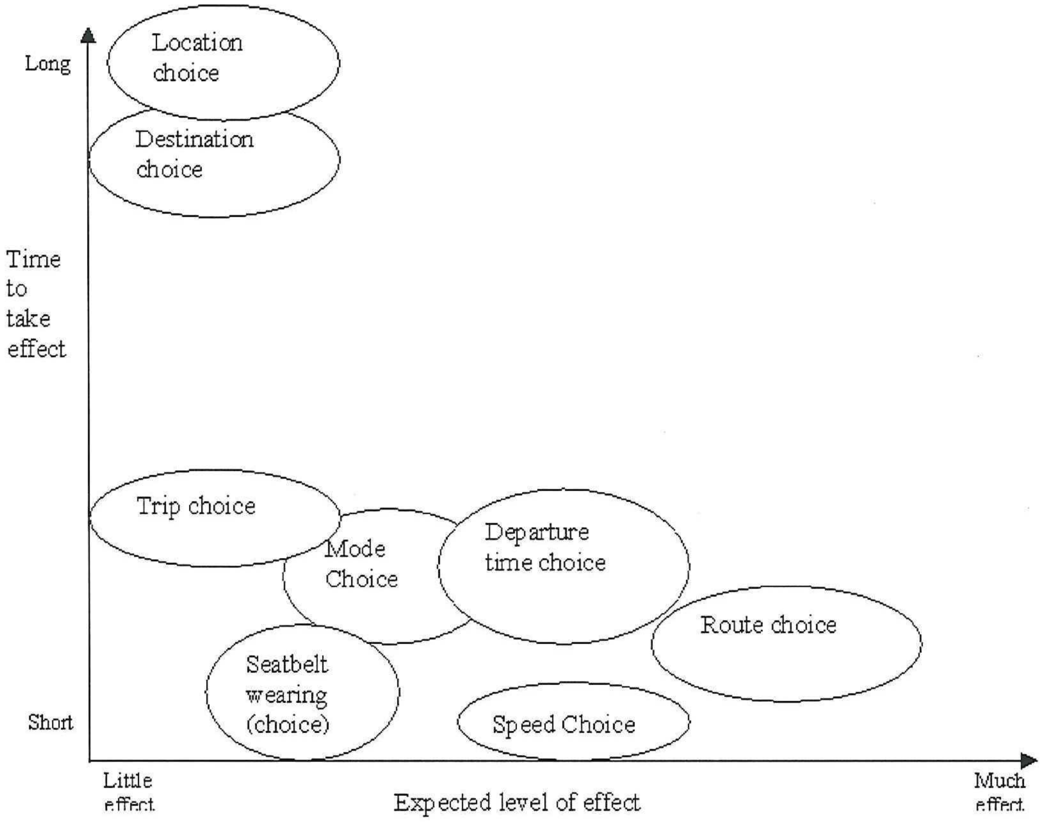

Figure 12 Possible responses to PAYD insurance

2.4.2 Acceptability

Before PAYD can be applied, both political and social support will be important. When political support is lacking, it is possible that PAYD would not allowed by the government. As PAYD bears implementation costs and the main positive effects are on traffic safety, the benefits from PAYD go to society as a whole. From this point on, political support could lead to subsidizing of PAYD programs and pilots. When social support is lacking, it is unlikely that there will be many households to choose PAYD as vehicle insurance.

As PAYD may have a positive effect on the basis of equity, welfare, affordability and choice, support is likely to be high. Also traffic components like congestion, environmental impacts and road safety can be improved. American research shows a percentage of 52% support (Todd Litman, 2006). If proposed as a consumer option the acceptability increases. Disadvantages of the system are that it bears high implementation costs, as kilometrage checking will have to be introduced.

From Dutch research great acceptance is found as well. Before Polis Direct started their KM Polis, a stated preference research was done in order to find the interest in car insurance based on kilometers driven. The research had more than 500 participants and the following conclusions were drawn from the research (Polis Direct, 2004)

- 71% thought PAYD was a good option;
- 67% would drive less if rebate goes up to 50%, about 50% would drive less if rebate goes up to 30%;

- 57% thinks to be able to reduce current premium with 1-10%;
- 24% thinks to be able to reduce current premium with more than 20%;
- 33% thinks that there will be less driving with a kilometer polis.

2.5 Relation between PAYD and Road Pricing

There is much discussion going on about implementing kilometer charge in the Netherlands. There are plans to introduce road pricing before 2012. Therefore information is given about the similarities and differences of PAYD and road pricing.

The road pricing scheme that is planned for introduction in the Netherlands includes a flat premium per kilometer differentiated to time of day. Only in the peak hours this premium will be applied to reduce congestion. Drivers are equipped with GPS in order to monitor their driving behavior. For information on the history of road pricing in the Netherlands, refer to (Van der Sar & Baggen, 2005).

2.5.1 Basics of road pricing

There are many forms of road pricing possible, for example toll at certain points in the network, a price per kilometer or a price at specific times. A kilometer charge characterizes itself in the way that people pay an amount of money per kilometer driven, which may still be differentiated to location, time of travel or even on level of congestion. People pay the price for kilometers driven to the government and the government will distribute the revenues. Drivers pay for the effects they cause on congestion, giving weight to the idea that the consumer pays. Less financially strong drivers may have to switch mode of transport or change time of departure in order to avoid the kilometer charge.

Another option in road pricing includes pay lanes. In this version of road pricing, special infrastructure is designed for the decrease of congestion. Drivers who use the lane pay a price, but have a congestion free road. The other road users however, are often stuck with the same, or worse congestion (Fanoy, van Amelsfort & Thuissen, 2001)

Acceptability of road pricing is often found to be low. Only in the case of very big congestion problems, road pricing may be found acceptable. Effects of road pricing are often limited. Most of the time, the travelers pay the extra price and continue their current behavior. Only very high pricing schemes, like the London toll scheme started in 2004, have large behavioral effects, showing traffic decreases of 10-15% and travel time losses decrease with 15-25% (Santos & Shaffer, 2004)

In 2001 in Copenhagen the AKTA road pricing experiment was performed (Nielsen, 2003). In this experiment 2x200 cars were equipped with a GPS to monitor behavior during an 8-10 weeks pilot. In the city of Copenhagen a cordon based pricing scheme was implemented for these drivers, who would pay a price if they would cross a cordon. Height of the toll would be determined on the basis of time of the day (peak/non peak) and how far the cordon was into the city center. Effects were visible in mode choice and departure time choice, with the most expensive scheme having the biggest effect.

2.5.2 Similarities between PAYD and kilometer charge

Both with PAYD and road pricing a fixed car cost is replaced by a cost variable to car use. In the case that a flat premium of equal height is used for both PAYD and kilometer charge, the effects of PAYD and kilometer charge should be equal. In this chapter a flat premium is used as basic for kilometer charge.

Also in both PAYD and road pricing a check is needed for actual driving behavior. As this is needed, both PAYD and road pricing could be implemented at the same time to be able to use the same equipment. This could reduce the cost of the implementation.

2.5.3 Differences of PAYD and road pricing

When road pricing is differentiated per kilometer and PAYD with different possible strategies, one of the main differences, especially important for acceptability, is that PAYD can be implemented as a consumer option, giving drivers the possibility to choose for PAYD insurance instead of a normal insurance. With road pricing this is not possible, as no one will choose to pay an additional fee for driving. A disadvantage of being a consumer option is that the effects on the network will be much smaller. However, as more people will choose for PAYD, other insurance fees may increase. This is because of the lack of low kilometrage drivers to subsidize the high kilometrage drivers.

Another difference is that PAYD structure can be changed from paying to rewarding. In this case the insurer will be paid in front and will give a reward for proper driving afterwards. Proper driving may be related to kilometers driven, driving location, driving speed and time of the day, just as with road pricing.

Also the initiator is different for PAYD or kilometer charge. In the case of kilometer charge, the government is the initiator, having to burden the costs of implementing a system like kilometer charge. With PAYD, the insurance companies are the initiators, with them being able to charge some of the extra costs of the technology to the insured. Also, with the government, revenue use is still uncertain, as changes in politics can happen at least every four years with the elections, where with the insurance companies, the revenues are spread among their PAYD users, or people would not use PAYD anymore.

2.6 Setup of the PAYD TRANSUMO project

The goal of the TRANSUMO program is to research and initiate projects to reduce mobility problems in the Netherlands. As Pay-As-You-Drive (PAYD) may help solve some of the problems, the project 'Verzekeren per Kilometer' (PAYD) is part of the program. A possible behavioral reaction to PAYD insurance is that the driver may use the car less than before, to save money on insurance premium. If the premium is also related to road category or time of driving, behavioral responses are possible in the means of route choice and departure time choice. Paying per kilometer driven and therefore variabilisation of a part of the original fixed costs of insurance, could lead to a lower annual mileage and therefore less congestion. Speed could also be added as insurance variable, as driving according to the speed limit is safer than driving faster.

Several parties are involved within this project, consisting of governmental party's, universities and private companies. A list of party's involved is shown below.
Governmental:

- V&W-AVV
- V&W-DGP
- SenterNovem

Universities:

- Delft University of Technology
- VU University Amsterdam
- University of Groningen

Private companies

- Goudappel Coffeng BV
- STOK
- RVS
- London
- Interpolis
- Nationale-Nederlanden
- Unigarant
- Proteq

Within this TRANSUMO project, a pilot project is planned among three hundred young clients of the six insurance companies. These young drivers will during the test be able to receive money back from the insurance companies if they behave the right way. Behaving the right way involves in all cases driving less and with a part of the insurance companies also driving in accordance to the speed limit.

During this pilot, the three hundred drivers will have their car equipped with GPS in order to check their location. From this location the maximum allowed speed could be found and used as check for the current speed. Driving over the maximum allowed speed can cost some of the bonus that can be earned. How much bonus is lost depends on the severity of the speed violation. Also driving many kilometers or at dangerous hours may cost bonus. The exact structure of earning the bonus is not yet public and will not be supplied here.

Next to this pilot, stated preference data is collected in questionnaires before, during and after the pilot. Next to the participants, also non-participants will be questioned to find out whether there are differences in the groups. Thirdly, a model study will be performed, showing the effects on traffic flow and safety in the case that PAYD would be implemented on a larger scale. This thesis holds the main results of the model study.

3 Research questions and methodology

The previous chapter in this thesis presented the background and the motivation of this study. Now that the reasons for this study are clear, this chapter will elaborate on the research questions to be answered. Following these questions, the chosen methodology to find answers to these questions is presented. In the following chapters (chapters 4 – 6), we will continue by describing the chosen PAYD strategies, the modeling framework and the case study.

3.1 Research questions

Depending on the PAYD scheme design, the implementation of PAYD in the Netherlands may have different effects on both traffic safety and traffic flow. The 'Verzekeren per kilometer' project, as presented in the previous chapter, intends to study the behavioral responses of young car drivers towards a specific PAYD scheme in an experimental set-up. Due to the small scale of the experiment, it is not expected that the project itself will affect traffic safety and traffic flow on a network level.

Since these network level changes caused by PAYD determine the viability of a PAYD project, they are of great importance to both governmental policy-makers and insurance companies who may support and introduce PAYD on a large scale. In order to assess the network impacts of different PAYD scheme designs beforehand and support decision-making processes, prediction models can be used. This research focuses on the question: What are the network effects on safety and accessibility of different PAYD strategies?

As there is much included in this question, it has been split into multiple questions:

- How can individual behavioral responses towards PAYD (participation and travel choices) cause network effects?
  - Which behavioral responses can be expected with PAYD?
  - Which aspects of the strategies are of influence on the behavioral reactions to PAYD?
- Which safety indicators are adequate to quantify traffic safety impacts using a transportation demand model?
- How can we model the network (safety) effects of different PAYD strategies?
- How does PAYD relate to road pricing, specifically the kilometer charge as proposed in the Netherlands?

When drivers have to pay an additional charge for their car trip, it is possible that they may change their normal behavior towards a cheaper option. If the PAYD premium is applied on, for example, fifty percent of the drivers, this change in behavior may lead to a network effect. A network effect will in this case be visible in changed congestion and changed travel times. With these new levels of congestion, new behavior may be triggered, in which, for instance, drivers who do not have the PAYD insurance start driving. Also if a new congestion location arises, drivers on the original route may also start changing their behavior, for example by changing their route and/or departure time. This means that many different responses are possible.

This last paragraph shows that predicting the effects of a PAYD strategy is not straightforward and that it will require specific research to find the effects of a strategy. Within this study a travel demand modeling approach is used. Detailed Information about the modeling framework to be used is given in chapter (5)

Also many different responses are possible. Explanation about the behavioral responses is given in section 5.1. The results of the PAYD strategies on the traffic flow and a travel time is given in chapter 6.

As PAYD is supposed to have beneficial effects on traffic safety, these effects have to be made visible as well. In section 2.2 the relations between different factors and traffic safety have been given. Next to these factors there are more that may have an influence on traffic safety. Because a modeling approach is chosen which does not calculates the amount of crashes and or casualties, a way has to be found to give an indication of the effects of PAYD on traffic safety. More on the traffic safety modeling can be found in section 5.6.

The first two questions must be answered before it is possible to model the network effects on safety and accessibility. As there is much discussion going on about implementing kilometer charge in the Netherlands. It will be interesting to see in what way kilometer charge relates to the PAYD strategies studied in this thesis.

3.2 Research objectives

The overall research objective is twofold. First objective is to develop dedicated modeling tools that specifically can predict the travel and safety effects of different PAYD schemes. The second objective is to use the developed modeling framework in a case study to assess the network (safety) effects of different PAYD strategies. Depending on the policy objectives these schemes can then be ranked.

3.3 Research methodology

3.3.1 Introduction

On the basis of the research questions and objectives, the methodology is designed. This methodology consists of three different components, which are described below. These aspects include the choices on which PAYD is based, explained in section 2. Then the case study approach is reviewed, which description is found in section 3, followed by the transportation model framework in section 4. Finally, in section 5, the traffic safety model is explained. A scheme of the methodologies and research questions is found in Figure 13.

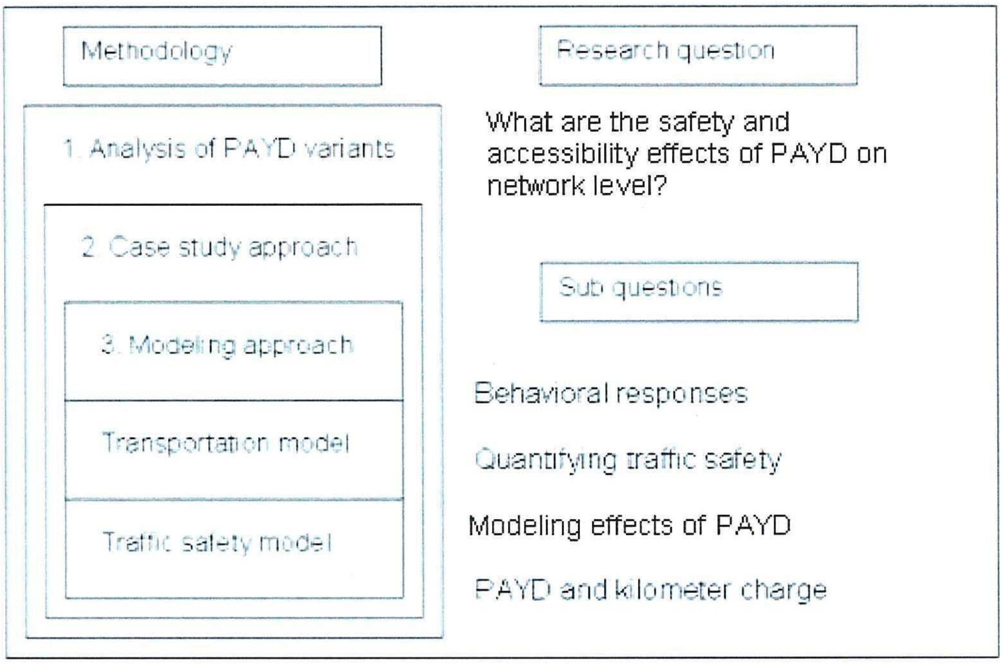

Figure 13 Overview of research questions and methodology

From this figure it can be found that the methodology is divided on three different levels. On the outmost level is the analysis of PAYD by testing various PAYD strategies. In order to do this, a case study approach is chosen, allowing for a smaller part of the network to represent the effects of PAYD in the Netherlands. As the goal is to research the network effects of PAYD with a large level of participation, it is chosen to use a model structure. This model structure comprises of two models, namely a transportation model and a traffic safety model.

3.3.2 Method 1: Comparison of PAYD strategies

As there are many different possibilities of PAYD, it will need to be made clear for different strategies what the effects are. For this an experimental design seems useful. In this design the different PAYD components can be added or removed from various strategies in order to get information about its effects.

Within PAYD, a whole group of different sorts of behavior may be priced. The main strategy of PAYD is to charge per kilometer driven instead of fixed sum, but other behavioral aspects can be priced as well. An overview of which PAYD components will be tested is shown below.

- Kilometrage, all PAYD strategies will pay per kilometer driven
- Road category, in some PAYD strategies the prices will vary, according to safety levels, per road category
- Time of day, some strategies will include additional costs for nighttime driving
- Level of participation, as it is uncertain how many people will participate, the effects of the level of participation is included.

- As special case with the level of participation will be the young drivers. As a risk group for traffic safety, there will be a special strategy concerning this group

As it is found of importance that average insurance premium is not higher than the average insurance premium now, the price per kilometer is determined on averages per strategy. These different components will be varied over the PAYD strategies that are tested in order to see the effects of each of them on traffic safety. The differentiations that are used in the PAYD strategies are:

- Kilometrage
- Road category differentiation
- Time of day differentiation
- Level of participation
- Young drivers

As some of the strategies are based on kilometrage only, these strategies are comparable with the base variant of kilometer charge, which is also varied only on kilometrage. A comparison with other PAYD strategies can then be made. More on the different strategies can be found in section 4.4.

3.3.3 Method 2: Case study approach

In order to assess the effects of the different PAYD strategies described in the last section, a case study approach is chosen. Using a representative and as much as possible real-life environment the different PAYD strategies are tested. The area of this case study is the road network of the region 'Haaglanden'. Within this region lay the cities of The Hague, Delft and Zoetermeer, see Figure 14. The area of the region 'Haaglanden' is useful because of the choice options drivers have. In this area, drivers will have multiple route options, most often using different road categories, and the traffic situation has a lot of congestion during the morning peak, for which changes can be determined.

Figure 14 The case study area: Region Haaglanden

More information about the case study can be found in chapter 6.

3.3.4 Method 3a: Transportation modeling framework

In the last section the area for the case study has been determined. On the network of this area the different PAYD strategies from section 3.3.2 are tested. As having a pilot with all drivers in this area would be very expensive, a modeling approach is used.

The first part of the model will be a transportation model in order to model reactions to the PAYD pricing measure and calculate resulting traffic flows. The second part of the model will be a traffic safety model that can calculate traffic safety on the network from the traffic flows of the transportation model. The traffic safety model will be introduced in section 3.3.5.

The transportation model will work within the case study area on the basis of data from this area. The transportation model should with these data be able to calculate the traffic flows on network, link and OD level. Also it has to be able to model behavioral choice to a PAYD premium. This premium will need to be differentiated to time, location and kilometrage. The explanation of the transportation modeling framework is located in chapter 5.

3.3.5 Method 3b: Traffic safety model

As mentioned in the last section on the transportation modeling framework, indicators will be necessary to asses the effects concerning traffic safety using information that is calculated by the transportation model. Many factors are of influence on traffic safety and different indicators are available to quantify the safety effects. These indicators will be discussed in sections 2.2 and 5.6. The outcome of the model will be a safety value for the PAYD strategy in question. It will also give estimation on the level of improved safety.

4 PAYD variants

In the previous chapter the research questions and methodology have been discussed. In this chapter the PAYD variants are discussed concerning the dimensions of tariff differentiation and hypotheses are formulated concerning the expected effects of these variants. These variants will later be combined to strategies and simulated in the transportation model. For information about the transportation model, see chapter 5. The simulation of the strategies and their results are presented in chapter 6.

In this chapter we start with a quick recount of the research questions, followed by the chosen dimensions of tariff differentiation. In the third section of this chapter we look into the hypotheses of the effects of these differentiations. In section 4.4 the PAYD strategies are discussed and the hypotheses per strategy given. Finally, in section 4.5, we finish of with the evaluation approach which is used to determine the results.

4.1 Research questions revisited

Starting with planning on which aspects of PAYD to price, we first look back at the research questions. The main research question was: What are the network effects on safety and accessibility of different PAYD strategies?

Which was split up into the sub questions:

- How can individual behavioral responses towards PAYD (participation and travel choices) cause network effects?
  - Which behavioral responses can be expected with PAYD?
  - Which aspects of the strategies are of influence on the behavioral reactions to PAYD?
- Which safety indicators are adequate to quantify traffic safety impacts using a transportation demand model?
- How can we model the network (safety) effects of different PAYD strategies?
- How does PAYD relate to road pricing, specifically the kilometer charge as proposed in the Netherlands?

4.2 Dimensions of tariff differentiation

For the study of different PAYD strategies, the tariff differentiation must be determined. An overview of aspects relevant for traffic safety has already been given in section 2.2. A review of those parameters that are included in the model is shown below. At the end of this section, the parameters that are of relevance to traffic safety but are not included in the model are mentioned, with reasoning.

Kilometrage

As mentioned in section 2.2.1, the average number of crashes a person is likely to have is directly related to the number of kilometers driven per year. See formula (5). (Wegman, 2003)

Number of crashes = Exposure x Risk (5)

It was also shown, that the linear line does not go through the origin. This means that there is always a chance of a claim, even without driving. See Figure 15. Also when driving less kilometers the average number of crashes per kilometer was relatively higher than when driving more kilometers. The total average number of crashes, however, is still lower. See Figure 16.

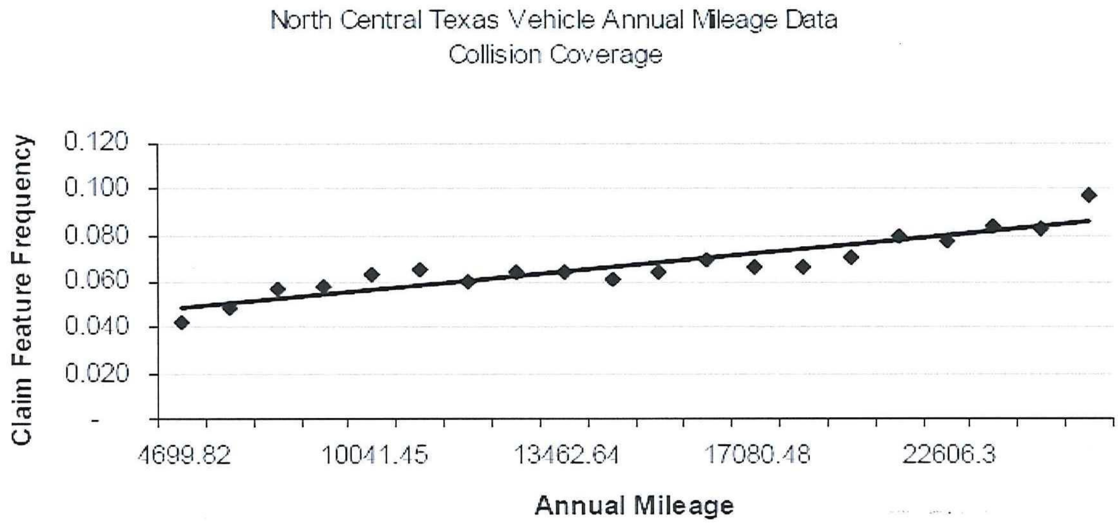

Figure 15 Claim frequency for all crashes as a function of mileage, Texas study

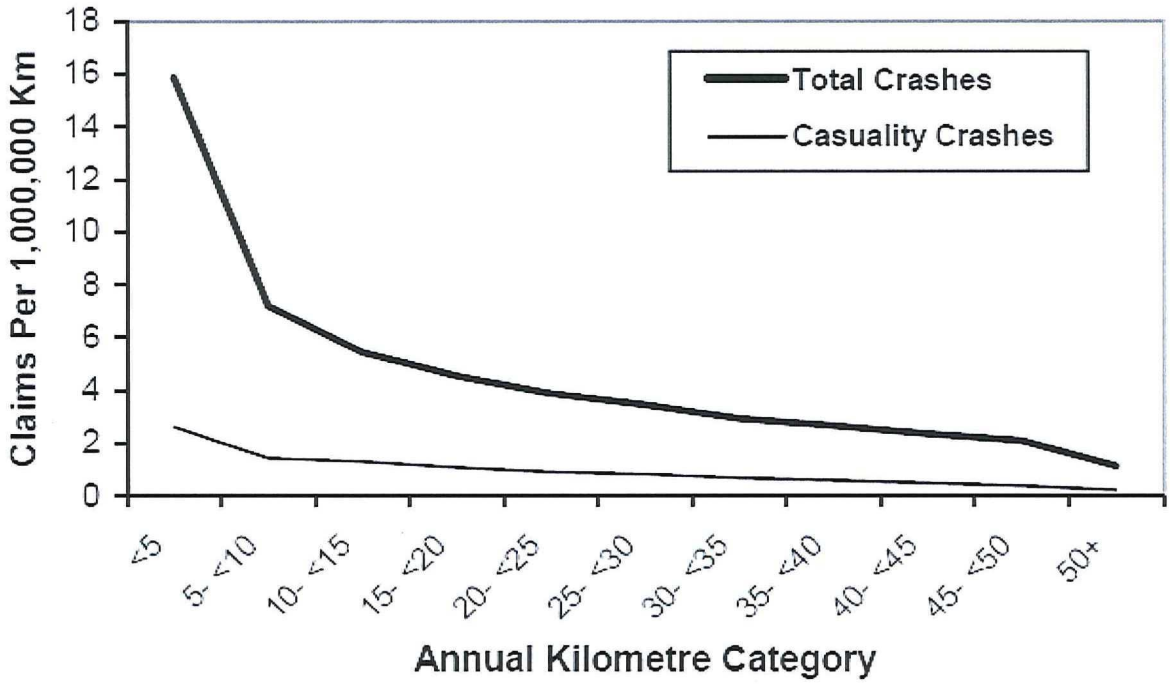

Figure 16 Risk per kilometer decreases with higher annual kilometer category

As the exact location is not known and explaining the system of pricing will be much easier using a linear relation, a linear relation will be used as price differentiation.

This means that each kilometer will add an additional cost to the insurance premium. This is shown in formula (6).

$$\text{Insurance premium} = \text{cost per kilometer} * \text{kilometers driven} \quad (6)$$

Road category
The relation between road category and safety was discussed in section 2.2.3. Even though many other factors are of direct influence on the relation between road category and safety, these factors are not incorporated in other parts of the price differentiation and therefore will not result in double counting. Factors that are of influence for road category on traffic safety include:

- Allowed maximum speed (see section 2.2.2)
- Number of crossings/onramps/of ramps
- Type of crossings
- Lane width
- Number of lanes
- Opposing traffic

Even though these factors are sometimes location specific as well as road category specific, a single value will be set for each road category. It would be better to set a price for each individual road on historical data, but as such data is limited and would cost a long time to collect, we will work with averages instead. In our pricing structure we will determine four different road categories. These categories and their safety values are found in Table 6.

Road category	Unsafety (traffic injuries per million car kilometers)
Motorway	0.06
Interurban road	0.22
Interurban road for all traffic	0.43
Urban road	1.10

Table 6 Road category unsafety values for the premium structure

No home zone streets are determined, as these do not exist in the model either. The two classes of motorway originally set distinguished by the SWOV (Janssen, 2005) have been all set in the highest speed category, also because kilometers driven on the lower speed motorway were much less than on the higher speed. With these parameters a price per kilometer per road category can be calculated.

Time of day
Just as with road category, the effects of nighttime driving on traffic safety are greatly dependent on other factors. These factors include for instance:

- Alcohol
- Speeding
- Fatigue

It is fact, however, that relatively more crashes happen at night than during day, see also section 2.2.4. As neither alcohol, speeding or fatigue can be measured in the transportation model, the factor of nighttime driving can be used without double counting. This factor has been calculated using data from the VOR (Verkeers ongevallen registratie) and the MON (Mobiliteitsonderzoek Nederland) and results in a value of 1.7. This factor is comparable with the factor of 1.6 that was found during research in the VS (Opiela et al., 2003). The calculation can be found in section 4.4.5.

Risk group: young drivers
As mentioned in section 2.2.5, the crash risk of young drivers is about four times as high as for older drivers (SWOV, 2006). As young drivers have no crash free period when starting and have relatively more crashes then older drivers, their insurance premium is higher than that of older drivers. An average insurance premium of €800 is estimated for the region 'Haaglanden' (http://www.ineas.com/Home/Portals/0/2006_goedkoopste07.pdf). As young drivers have relatively less money available, their reactions to additional costs are likely to be greater. This will be taken into account in the model.

Safety aspects that are not included
As the transportation model chosen for the research will be a macroscopic dynamic simulation model, it is impossible to determine the individual driver. Therefore several safety indicators, like speed, safety-belt usage and alcohol are impossible to determine from the transportation model. Some of these factors however are already incorporated in used parameters. Alcohol, for instance, is mostly found consumed during nighttime driving, which price is increased in some of the strategies.

The factor speed is used as a variable for the height of the insurance premium during the TRANSUMO pilot project, but also not included in this report. Effects from price variabilisation for speeding will already be visible for individual drivers during the pilot, but network effects would be difficult to measure.

4.3 Hypotheses of effects

As the effects of PAYD are among the research questions of this study, it will be important to estimate the effects of the differentiations that have been chosen. These levels of differentiation were mentioned in section 4.2. In this section each of the levels of differentiation will be described, with the expected effects.

Kilometrage
With the premium structure differentiated to kilometrage, drivers will attempt to find shorter routes to reduce premium. In this case they are making the tradeoff between time and costs, as the shorter route may use lower level roads on which the maximum speed is limited. It is also likely that some drivers will not make the trip by car at all, either because they do not make the trip, or because they use another mode. Changing of mode will lead to the tradeoff between the comfort and privacy of the car versus the costs of the trip. Not making the trip at all will be a tradeoff between the utility of the trip and the costs. Perhaps telecommuting will be more efficient if faced with additional cost for driving. For an overview of expected effects, see Table 7.

Kilometrage	Est. effect on choice	Est. effect on safety
Elastic demand	Fewer trips	Positive
Departure time choice	Only small secondary	Neglectable
Route choice	Shorter routes	Negative

Table 7 Hypotheses of effects of kilometer differentiation

Road category

With the premium structure differentiated to road category as well as kilometrage, it can be expected that once more route choice will be of main importance, followed by reduced demand due to increased cost. This time, however, drivers will not always take the shortest route, but more the safest route, which will be lowest priced. So in this case the trade off is made between travel time and cost. As motorways are the safest category of road, it can be expected that more drivers will choose routes over the motorways. As the motorways are congested already, secondary effects may happen, such as an extra decrease in traffic demand, or drivers shifting to non-congested periods. An overview is given in Table 8.

Road category	Est. effect on choice	Est. effect on safety
Elastic demand	Fewer trips	Positive
Departure time choice	Secondary from the peak	Very small negative
Route choice	Safer routes	Positive

Table 8 Hypotheses of effects of the road category differentiation of PAYD

Time of day

If nighttime driving is more expensive than daytime driving, it is likely that people before sunup will change departure time to a cheaper period. The main tradeoff that is made is between departure time and cost. Also demand is likely to reduce, as driving in general is becoming more expensive. With this reduction in driving, the effect of more people driving near the peak period will be mostly gone and no or very little effect on route choice is expected. For an overview, see Table 9.

Time of day	Est. effect on choice	Est. effect on safety
Elastic demand	Fewer trips	Positive
Departure time choice	Trips shift to daytime	Positive
Route choice	Very little effect	Neglectable

Table 9 Hypotheses of effects of time of day differentiation of PAYD

Young drivers

The reaction of young drivers will depend on the means of tariff differentiation. Their effects on driving because of PAYD will all have the same direction (positive or negative), only the number of changes will be greater, due to the tendency of being more prone to monetary incentives. The groups of young drivers, however, will be much smaller than all the drivers combined in one group. It is therefore likely that the behavioral responses of the young drivers are often offset by the responses of the other drivers who are not influenced by PAYD and who see improved traffic conditions.

4.4 PAYD strategies and hypotheses

In the model simulation several PAYD strategies will be calculated, following the dimensions of tariff differentiation as shown in the previous sections. The different strategies are shown in Table 10 and are described shortly with their hypothesized effects in the next sections.

Strategy	Premium basis		Road category	Time of day	Young drivers	Percentage participants
	Fixed	Km based				
Ref.	X					50
Ref.	X					100
Ref.	X				X	100
1		X				50
2		X				100
3		X	X			50
4		X		X		50
5		X	X	X		50
6		X	X	X		100
7		X	X	X	X	100

Table 10 PAYD strategies to be tested

4.4.1 Reference strategies

In the reference scenario, the road users behavior is determined for the situation when no action is taken. No elastic demand is applied, so the number of trips will not change. As no charge is applied, the route choice and departure time choice are supposed to lead to the current situation. Route choice and departure time choice mentioned in the scenario hypotheses are relative to the reference variant.

4.4.2 Strategy 1 – Choice for PAYD

Description

In the first strategy – *Choice for PAYD*, drivers are able to choose whether or not they take a PAYD insurance. Only drivers for whom it is financially beneficial are likely to join the PAYD insurance program. These drivers will now pay their premium per kilometer driven, instead of a fixed premium. The price per kilometer will be the average insurance premium (€600) divided by the average kilometrage (15000 km), which leads to 4 cents per kilometer.

Hypothesis of effects

It is expected that given the price sensitivity of car use a limited percentage of PAYD participants will avoid use of the car to reduce insurance premium. Total kilometrage of PAYD participants is expected to reduce further, as drivers make a trade off between a longer trip (in the sense of time) and a reduction in insurance premium if they take provincial roads instead of motorways. Secondary effects will occur due to the reactions of non-participants. These drivers will have improved traffic conditions and are estimated to start driving more and take the motorways more often. Total effect will see a small improvement in safety however, as there will be more trips reduced than increased.

4.4.3 Strategy 2 – PAYD for all drivers

Description

PAYD for all drivers is in many ways equal to the first strategy, only in this case all drivers are forced by legislation to have PAYD insurance for their car. The insurance premium per kilometer is once again 4 cents.

Hypothesis of effects

The first reaction will again be for drivers to start driving less than before, reducing the total number of trips made. As there are now no non-participants the reduction of total traffic will be greater than in strategy 1. The same is true for taking shorter routes. Drivers will generally choose shorter and therefore cheaper routes.

Secondary effect will likely be in departure time choice. As more drivers choose shorter routes and there are fewer drivers, the motorways will become less congested. This means that drivers will be able to get closer to their preferred departure time and change to that time.

4.4.4 Strategy 3 – Road category differentiation

Description

Strategies 3 to 5 are all implemented as a consumer option. In strategy 3 – *Road category differentiation*, the kilometer charge is also differentiated towards road category. This means that motorways will become cheaper and urban roads more expensive. The price structure is calculated below.

Calculation of price structure

The price per kilometer per road category is calculated on the basis of the number of injury accidents per million kilometer and the vehicle kilometers driven (based on the kilometers driven). From the MON the data about number of vehicles is used.

At first the number of kilometers driven per car per road category is calculated. The road categories flow road and Home zone Street have been taken together, because the level of danger for Home zone Street was set equal to that of the flow road. The calculation is to divide the kilometers driven by the number of cars.

$$dist_{car,r} = \frac{dist_r}{n_{car}}$$

Where:

$dist_{car,r}$ = Kilometers driven per car per road category

$dist_r$ = Kilometers driven per road category

n_{car} = Number of cars

Multiplying this distance per car per road category with the crash risk per distance per road category will lead to the number of traffic injuries per car per road category.

$$C_{car,r} = dist_{car,r} * R_{r,dist}$$

Where:
$C_{car,r}$ = Crashes per car per road category
$R_{r,dist}$ = Crash risk per road category per distance

When summing the number of traffic injuries, the average price per crash could be calculated, if there would only be injury or worse accidents. As this is not the case, a factor will be calculated in order to estimate the price per kilometer that needs to be charged. An assumption is made that the damage only accidents are distributed in the same way over the different road categories as the injury accidents.

$$PpCrash = \frac{p}{\sum_r C_{car,r}}$$

Where:
$PpCrash$ = Price per crash
p = Average yearly insurance premium, which equals to €600

Multiplying this factor with the crash risk per road category per distance will lead to a price to be charged per distance. In this case the set distance criteria is kilometer.

$$PpKm_r = f * R_{r,dist}$$

Where:
$PpKm_r$ = Price per kilometer per road category

In the tables below are the values used in calculation

Road category	Number of injury accidents per million car kilometers	Million kilometers driven per road category
Freeway	0.06	47,263
Motorway	0.08	8,649
Interurban road	0.22	20,499
Interurban road for all traffic	0.43	14,773
Flow road	1.10	20,503
Home zone Street	0.57*	8,476

Table 11 Crash risk and kilometers driven per road category

*For calculations, the Number of injury accidents per million car kilometers has been set to 1,10 to equal the value of the flow road, this is done because it is not acceptable to increase traffic on home zone streets.

Factor:	Value:
Number of cars	$6{,}276 * 10^3$
Average yearly insurance premium	€600

Table 12 Factors used in calculation

In the last table the results of the calculation are shown

Road category	Price in euros per car kilometer per road category
Motorway	0.006
Interurban road	0.022
Interurban road for all traffic	0.044
Flow road	0.112

Table 13 Price in euros per car kilometer per road category

The charges for both motorway and freeway have been set at the same level, as this made modeling easier. Also differences in price were minimal, so there is no real difference expected on model results.

Hypothesis of effects
Differentiating the price structure towards road category has a great effect on route choice. This effect will be opposite to the effect from strategy 1, as drivers are now more tempted to take motorway routes instead of routes of provincial or urban roads. Also the number of trips will reduce, as total costs of a trip are increased.

Secondary effects are to be expected in departure time choice and reactions from non-participants. As the motorways are likely to become more congested, drivers will shift towards a less congested time period. Non-participants on routes without motorways may see improved traffic conditions and start driving for that reason. Also non-participants may shift more from motorway to other routes in order to avoid the congested motorways.

4.4.5 Strategy 4 – Time of day differentiation

Description
The *time of day differentiation* strategy involves increased prices for nighttime driving. The price for nighttime driving is multiplied by 1.7 times the daytime pricing. For calculation, see below.

Calculation of price structure
The calculation of the price difference that should be used between day and night is based upon the VOR (Verkeers ongevallen registratie) and the CBS (Centraal Bureau voor de Statistiek). From the VOR the number of fatalities has been taken for

the different hours of the day. The fatalities for which the time of the day was unknown have not been used. The kilometers driven per time of the day per person have been taken from the CBS site. This data was aggregated to several periods of the day, so the data from the VOR needed to be aggregated over these periods as well. From the number of deaths could be divided by the distance, leading to the number of deaths over the number of kilometers. An assumption is made that daylight is from 7am to 7pm and that nighttime is the other twelve hours. This assumption is taken after the average time of sunup and sundown in the Netherlands.

$$R_{t,dist} = \frac{n_{fat,t}}{dist_t}$$

Where:

$R_{t,dist}$ = Risk per kilometer in a certain time period

$n_{fat,t}$ = Number of fatalities in a certain time period

$dist_t$ = Average kilometers driven in a certain time period

An example for the year 2005 are shown in the tables below

Time	km/(day*person)	fatalities/year	million km/ year	fatalities/ million km
0 to 4	0.20	70	1189.91	0.058830
4 to 7	1.29	57	7516.59	0.007580
7 to 8	1.29	31	7548.24	0.004110
8 to 9	1.10	28	6399.10	0.004380
9 to 12	2.37	87	13831.17	0.006290
12 to 13	0.89	25	5190.85	0.004820
13 to 14	0.99	30	5790.58	0.005180
14 to 16	2.21	90	12934.99	0.006960
16 to 17	1.56	41	9099.86	0.004510
17 to 18	1.44	54	8432.95	0.006400
18 to 19	0.86	40	5023.95	0.007960
19 to 20	0.58	35	3371.19	0.010380
20 to 24	1.36	84	7917.92	0.010610

Table 14 Fatalities per million car kilometers per time of day

Time	deaths/million km	relation
Day = 7-19	0.050598	1
Night = 19-7	0.087402	1.73

Table 15 Relation of risk between nighttime and daytime driving

The total overview of crash relation between day and night for the last five years for which there was data available is given in Table 16 below.

Year	Relationship Night : Day
2005	1.73
2004	2.17
2003	1.46
2002	1.80
2001	1.60

Table 16 Relation of risk between nighttime and daytime driving for 5 years

Taking a weighted average, in which the most recent year has the highest weight, the relationship of crash risk between night and day is found at 1.7. This value will be used for the rest of the calculation.

The kilometers per time period had already been found in the CBS tables and could be organized to proportions of kilometers for day and night. The fraction of kilometers at night would be multiplied with the average yearly kilometers for car drivers to calculate the number of kilometers driven at night. The same is done for the kilometers that are driven at day.

The kilometers at night are than increased by the factor of 1.7 to take into account the relative risk of nighttime driving in the insurance premium. The average insurance premium of €600 is than divided by the sum of the daytime kilometrage and the nighttime kilometrage multiplied with 1.7. The result is the price per kilometer for daytime driving.

$$ppkm_d = \frac{P}{km_d + 1.7 * km_n}$$

Multiplying this price with 1.7 leads to the price for nighttime driving. The prices are shown below in Table 17

Time	Price per kilometer
Daytime (7 am – 7 pm)	0.034
Nighttime (7 pm – 7 am)	0.058

Table 17 Price per kilometer per time of the day

Hypothesis of effects

When nighttime driving is priced higher than daytime driving, the obvious effect will be that drivers shift from the nighttime hours to the daytime hours. This effect will be relatively small, however, as there are not many drivers that drive before dawn and if they shift from night to day, their traffic conditions will worsen. General effects will occur in the form of less driving due to increased travel cost. Traffic safety in general is likely to improve

4.4.6 Strategy 5 – Full differentiation

Description

In the *full differentiation* the price structure is differentiated for all the previously used aspects. This means that the price is differentiated to distance, time and location. It is expected that differentiating the price structure for all these factors will lead to large network effects. The price structure and calculation are found below.

Calculation of price structure

By combining the data from scenario 3 and 4, a price per road category per time of day can be calculated. This price can than be increased by a factor to ensure that the average insurance premium per car owner equals €600 once more. To reach the average premium some prices have been slightly increased or decreased. The results of the calculation can be found in Table 18.

Road category	Price in euros per car kilometer	
	Daytime (7 am – 7 pm)	Nighttime (7 pm – 7 am)
Motorway	0.005	0.010
Interurban road	0.020	0.033
Interurban road for all traffic	0.038	0.064
Urban flow road	0.098	0.167

Table 18 Price per kilometer per time of the day and road category

The difference between scenario 5 and 6 lies in the number of participants. In scenario 5, half of the drivers are PAYD participant, while in scenario 6 every driver is PAYD participant. The prices per kilometer are equal for all participants.

Hypothesis of effects

Differentiating the price structure to so many aspects is likely to have an effect from all behavioral choices. As cost of driving increase, there are likely to be fewer trips made by PAYD participants. Routes chosen will mainly go along the cheap motorway routes, while as nighttime driving is more expensive, participants will shift towards the day.

Secondary effects are likely from the non-participants. These drivers will likely show the opposite behavior of the participants, as they will have improved traffic conditions. The effects on the travel behavior of the non-participants are likely to be smaller than the effects of the PAYD participants.

4.4.7 Strategy 6 – Full differentiation (obligatory)

Description

The sixth strategy – *Full differentiation (obligatory)* – is equal to the fifth strategy, with the only difference being that in this strategy all drivers will have PAYD insurance. This may happen if the government decides on legislation for PAYD. The price structure of this strategy is equal to that of strategy 5.

Hypothesis of effects
Having differentiated insurance as close to safety values as done in this thesis and all drivers having PAYD as insurance is likely to lead to the biggest safety improvement. First of all it is expected that due to the increased travel cost, the total number of trips will decrease. Drivers will chose another way of traveling or working without taking the car. Secondly it is expected that drivers will change their routes from the expensive urban and provincial roads toward the cheaper motorways. The effects on departure time are both primary and secondary. As nighttime driving is more expensive than daytime driving, drivers may shift from night to day. The secondary effect is that due to the route choice leading more drivers to the motorways, these may become more congested, forcing drivers towards periods with less congestion. This reaction partly counter effects the reaction of not driving during night.

4.4.8 Strategy 7 – Young drivers

Description
In the seventh strategy, the only drivers using PAYD as insurance are the young drivers. These drivers have relatively a higher risk and therefore insurance premium. As they also tend to drive less on average per year, insurance per kilometer is increased for this group. Having on average a lower value of time and thus a higher reaction to additional costs, young drivers will quicker change mode, departure time or route in order to minimize costs.

Calculation
As young drivers generally have a higher insurance premium than older drivers, this premium is set at €800 instead of €600. They are assumed to have the same driving behavior as other drivers and the same data is used to calculate the price per kilometer. Calculation results are shown below in Table 19.

Road category	Price in euros per car kilometer	
	Daytime (7 am – 7 pm)	Nighttime (7 pm – 7 am)
Motorway	0.010	0.017
Interurban road	0.037	0.062
Interurban road for all traffic	0.073	0.125
Urban flow road	0.186	0.317

Table 19 Price per kilometer per time of the day and road category for young drivers

Hypothesis of effects
Effects on these young drivers because of PAYD with all levels of differentiation is expected to reduce the number of trips of the young drivers with more than that of all drivers in previous strategies. Also route choice and departure time choice are more frequent in order to reduce premium.

The offset of this all is that the group of young drivers is a relatively small group, and most effects on the network are likely to be reduced by the other drivers starting to drive more and on relatively unsafe routes.

4.5 Evaluation approach: criteria and indicators

For the interpretation of the results, different indicators have been determined. These indicators mostly check for traffic safety, but also the level of congestion is of importance. Finally the overall cost of crashes with the reduction of number of traffic injuries will be compared with the estimated costs of implementing the scheme. The criteria will be partially on network level and partially on OD level. For result analysis on OD level, 7 specific OD pairs have been selected on the basis of the following criteria.

- At least 100 hundred trips on the OD relation
- At least 3 different routes possible
- At least 1 route that uses the motorway for a large part of the trip
- At least 1 route that does not use the motorway

A table with the overview of which criteria are tested is shown below in Table 20. The rest of this section will follow with the discussion of the criteria.

Criteria	Network level	OD level
Safety	X	X
Accessibility	X	

Table 20 Overview of criteria

Safety

The traffic safety level is determined for both network level and OD level. For the traffic safety it is assumed that the number of traffic injuries will only change due to changes in exposure, not risk. On network level the average number of traffic injuries that would occur during the modeled morning peak is calculated. This number is compared with the other strategies. On OD level the unsafety values for the different possible routes are taken and compared with which routes are chosen. The more people that take the safest route results in the safest strategy.

With the knowledge of the reduction of average number of traffic injuries on the network level, an estimation is made of other crash reductions. The assumption is made that fatal crashes are distributed among road types and time of day the same way as the traffic injuries. Also the assumption is made that the reduction of crashes would be true in the same way for the rest of the Netherlands and other times of the day. This way an estimation can be made of the total number of traffic fatalities and injuries that can be reduced with the PAYD strategy.

If these reductions are multiplied with the overall cost for crashes, see Table 21 (AVV, 2006), a part of the savings of the PAYD strategy can be expressed in money. This value will then be compared with the estimated costs of implementing and running a PAYD strategy.

Crash type	Cost (2003)
Fatal	€ 2,653,462
At least injury accident	€ 280,442

Table 21 Cost of a crash in the Netherlands, 2003

The costs of strategy are dependent of the measurement technique chosen. In strategies that only include kilometrage, the technique can be set to odometer audits. In the other strategies, the more expensive GPS will have to be used. Estimated costs per car are shown in Table 22. (TNO Inro, 2003)(Various writers, 2006, http://www.andersbetalenvoormobiliteit.nl/index2.php)

Technique	Implementation costs	Annual costs
Odometer Audits	Small	€ 10
GPS	€ 100	€ 75

Table 22 Cost of different techniques per car

Accessibility

The level of accessibility is an important factor of a PAYD strategy. Travel times and distances are given. A lower travel time is assumed to show an improved level of accessibility. This criterion is tested on network level.

5 Modeling framework

After the PAYD variants have been described in chapter 4, the modeling framework is described here. Within this model the accessibility and safety results are calculated. After this chapter the case study is described in chapter 6 and the model results are presented in chapter 7.

In this chapter firstly the behavioral responses and expected effects are discussed. In the second section the overall framework is discussed. In section 5.3 the elastic demand model is presented. After this section the departure time choice is shown in section 5.4, followed by route choice and dynamic loading model in section 5.5. Finally, in section 5.6 we go into detail of the traffic safety model.

5.1 Behavioral responses and expected effects

When faced with an additional cost for driving, in this case variabilized insurance premium, it is possible that drivers will change their driving behavior. The behavioral responses to PAYD have already been listed in section 2.4.1, yet in this section the responses and the way these are incorporated in this study are described, including the expected effects of these responses within the model.

Mode choice and trip making choice

Because of the increased cost of driving, people may choose for another mode. Many factors are involved including cost, travel time, uncertainty and comfort. As we are only interested in car transportation, a simplified mode choice model is used in which mode choice is incorporated in the trip making choice model by determination of the change in the amount of trips by car as a result of increasing costs.

Next to mode choice it is also possible that drivers choose not to make the trip at all because of the increased costs. This is possible because of alternatives like telecommuting, or simply because a non-work trip is cancelled. In both cases (mode choice and trip making choice) the trips will disappear from the network. It is expected that the effect of elastic demand (as we will call the combined effect of trip making choice and mode choice) will be a small decrease in traffic volume of PAYD participants. In scenarios in which there are also non-participants, however, it is expected that the travel cost of non-participants will reduce and therefore will induce extra travel demand from the non-participants. It is expected that the sum participant and non-participants trips will still be lower than the original amount of trips.

Departure time choice

When the insurance premium is varied over time, drivers may change to a cheaper period. Also when in a certain period travel times are high caused by congestion, a secondary effect may occur, which leads to drivers shifting their departure time to a period in which there is less traffic. It is expected that most changes in departure time choice, compared with the reference strategy (in which no PAYD is available), will be caused by time varied insurance premium.

Route choice

Route choice is likely the most prominent form of behavioral response to the different PAYD strategies. The level of variation in the PAYD strategy will be important for the direction of the route choice. In the case of a flat rate strategy, drivers will mainly start shifting from the fastest route to the shortest route, as the shortest route will have the lowest price. When the strategy has a differentiation to road category on the other hand, the drivers may accept the longer motorway route in order to avoid the higher charges.

5.2 Overall framework

The simulation model used in this study is an extended version of the Dynamic Traffic Assignment (DTA) model INDY (Bliemer, 2004). INDY has been developed by TNO and the Delft University of Technology. INDY dynamically assigns traffic to the network, while taking route choice into account. In this study we extended INDY to incorporate departure time choice and elastic demand (trip making choice and mode choice). This way, the transportation model is capable of the behavioral choices that were described in section 5.1. A general framework overview of this model is shown in Figure 17.

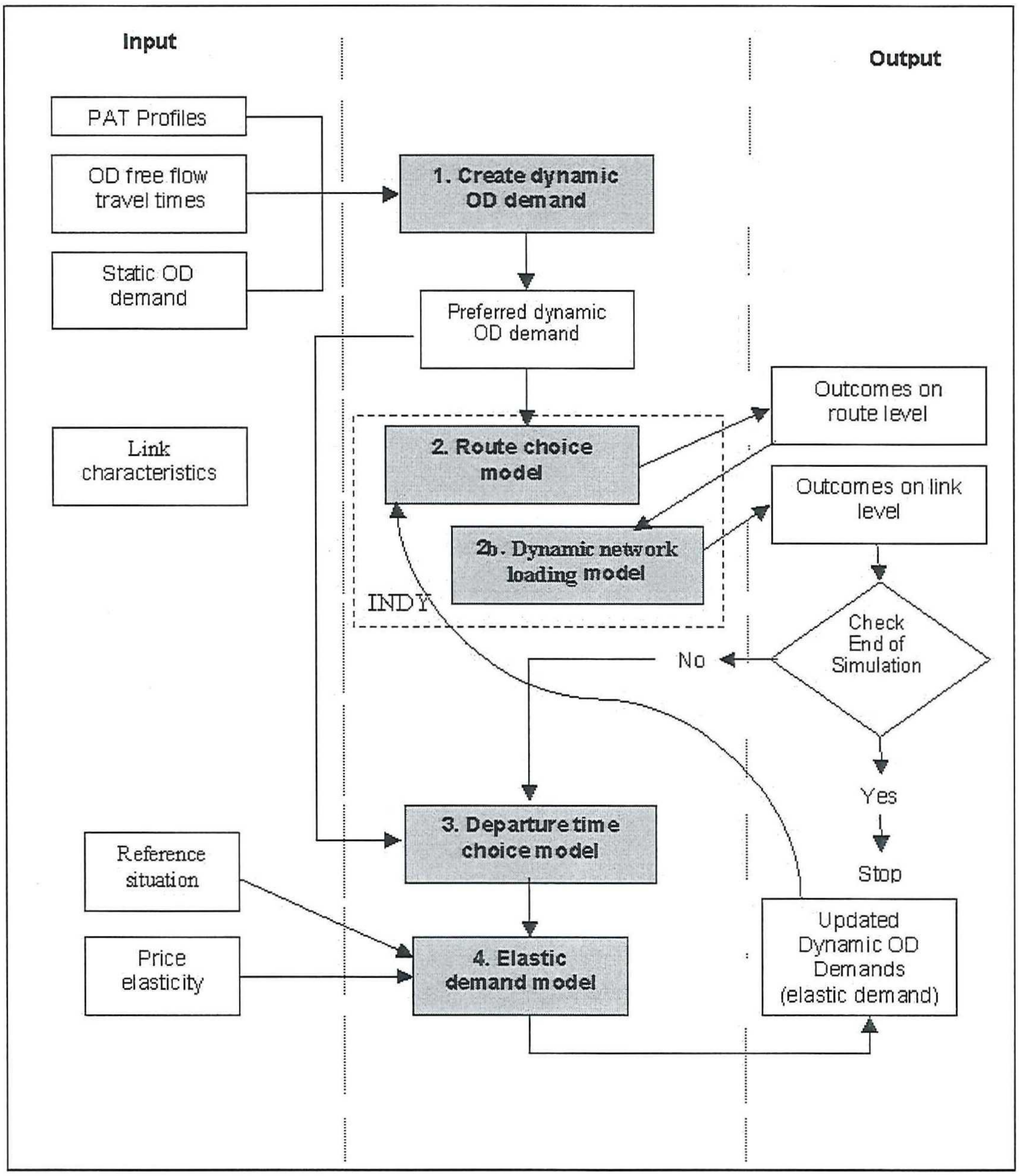

Figure 17 General framework of the simulation model

The model can be divided in four sub models. The first model creates the dynamic OD demand on the basis of the static OD demand, the preferred arrival times (PAT) and the free flow travel times between OD pairs. The PAT profiles have been estimated during the calibration of the model, for more information, see section 6.1.2. The route choice model and the dynamic loading model are combined in the DTA model INDY (see section 5.5). This model assigns the dynamic demand that has been created in the first step. From the route choice model the results are route flows. These are put in the dynamic network loading model from which result link distances, speeds, insurance costs and travel times. These values are saved and used on the next time that the route choice model is used.

The next steps are to model departure time choice and elastic demand. Elastic demand compares the new results with the reference as drivers may change their behavior for changed travel conditions. The departure time model recalculates the departure times on the network taking into account the old departure times and the simulated distances, costs and travel times (see section 5.4). The fourth step is the elastic demand model, which is not used for the reference-case. In this model the total travel demand is changed to show the reaction by the insurance cost. The change in demand is calculated by the means of change in total disutility (see section 5.3).

After the departure time choice and elastic demand model have been applied, the new demand matrices are used in the route choice model to simulate changes in route choice. After iterations in which elastic demand, departure time choice and route choice have been applied, only route choice is simulated before the model stops. A stoppage criterion has been set in order to save calculation time.

5.3 Elastic demand

Elastic demand is implemented in the model to show the effects of increased travel disutility on the change of making the trip by car. Reductions in the number of trips either mean changing of mode or not making the trip at all. The disutility per origin and destination (OD) of all iteration is calculated before departure time choice is applied and the utility is also used during that calculation. This disutility is based on travel time, travel cost and deviation from the preferred departure and arrival time. The formula for the calculation of the disutility is shown below in (7)

$$\begin{aligned} U_m^{od}(k) &= \alpha_m^1 \bar{\tau}_m^{od}(k) + \alpha_m^2 \bar{\theta}_m^{od}(k) + \alpha_m^3 (k - \zeta_m^{od})^- + \alpha_m^4 (k - \zeta_m^{od})^+ \\ &+ \alpha_m^5 (k + \bar{\tau}_m^{od}(k) - \xi_m)^- + \alpha_m^6 (k + \bar{\tau}_m^{od}(k) - \xi_m)^+ + \varepsilon_m^{od}(k) \end{aligned} \qquad (7)$$

Where:

$\bar{\tau}_m^{od}(k) = \dfrac{\sum_r f_{mr}^{od}(k)\tau_{mr}^{od}(k)}{\sum_r f_{mr}^{od}(k)}$ = the average travel time for the relation (o,d), mode m and departure time k over all routes r

$\bar{\theta}_m^{od}(k) = \dfrac{\sum_r f_{mr}^{od}(k)\theta_{mr}^{od}(k)}{\sum_r f_{mr}^{od}(k)}$ = the average travel cost for the relation (o,d), mode m and departure time k over all routes r

$\tau_{mr}^{od}(k)$ = the travel time for mode m, route r, relation (o,d), and departure time k

$\theta_{mr}^{od}(k)$ = the travel cost for mode m, route r, relation (o,d), and departure time k

The calculation of the averages $\bar{\tau}_m^{od}(k)$ and $\bar{\theta}_m^{od}(k)$, instead of a log sum approach, which is used in nested logit, the weighted sum is taken. This is done for implementation reasons.

And:

$f_{mr}^{od}(k)$ are the route flows for relation (o,d), mode m and route r for departure time k

$(k - \zeta_m^{od})^- \equiv \max\{\zeta_m^{od} - k, 0\}$ = departure scheduling delay early

$(k - \zeta_m^{od})^+ \equiv \max\{k - \zeta_m^{od}, 0\}$ = departure scheduling delay late

$(k + \bar{\tau}_m^{od}(k) - \xi_m)^- \equiv \max\{\xi_m - k - \bar{\tau}_m^{od}(k), 0\}$ = arrival scheduling delay early

$(k + \bar{\tau}_m^{od}(k) - \xi_m)^+ \equiv \max\{k + \bar{\tau}_m^{od}(k) - \xi_m, 0\}$ = arrival scheduling delay late

$\zeta_m^{od} = \xi_m - \bar{t}^{od}$ = preferred departure time for mode m and relation (o,d)

ξ_m = preferred arrival time for mode m

$\bar{t}^{od}$ = free flow travel time for mode m and relation (o,d), rounded up to the equal x times the time step used for k, where x is a natural number

The parameters α_m^1 to α_m^6 are user group (participant and non-participant) related behavioral parameters. The term $\varepsilon_m^{od}(k)$ is a random unobserved component that represents all other cost components. Parameter values α_m^1 to α_m^6 are listed below in Table 23. These parameters are from the MD-PIT research program (yet to be published).

Parameter	Unit	Parameter weight for	Average driver	Young driver
α_m^1	1/time	Travel time	-0.0246556	-0.0242508
α_m^2	1/€	Travel cost	-0.11579	-0.159968
α_m^3	1/time	Departure time scheduling delay early	-0.0162071	-0.0519039
α_m^4	1/time	Departure time scheduling delay late	-0.079123	0*
α_m^5	1/time	Arrival time scheduling delay early	-0.029226	-0.0204814
α_m^6	1/time	Arrival time scheduling delay late	-0.0338927	-0.0413064

Table 23 Parameter values in the utility calculation

*The parameter for departure scheduling delay late was not significant for young drivers and has been set to zero for the simulation.

The weighted average travel utility over all time periods is computed. The level of demand decrease depends on the elasticity of the change in travel disutility.

$$\overline{U}_m^{od} = \frac{\sum_k U_m^{od}(k) * f_m^{od}(k)}{\sum_k f_m^{od}(k)} \quad (8)$$

$$\%U_m^{od} = \frac{\overline{U}_m^{od}(iter) - \overline{U}_m^{od}(iter-1)}{\overline{U}_m^{od}(iter-1)} * 100\% \quad (9)$$

$if\,(iter-1) = 0, \overline{U}_m^{od}(reference)$ is used instead

$$\%D_m^{od} = e_m * \%U_m^{od} \quad (10)$$

$\%D_m^{od}$ = The percentile change in demand due to the change in disutility

e_m = The parameter for the elastic demand

If the total disutility will increase, the demand on the OD relation will decrease, hence $e_m < 0$. Similarly, if due to the effect that a user group on an OD pair will start traveling less, disutility for another user group may decrease, leading to increased demand for that user group.

Using elastic demand on the basis of total disutility is not standard. Normally elastic demand is applied either on travel cost, or on travel time and based on disutility. As we work out of the standard, there is no known elasticity value for disutility. We therefore use the value of elasticity for travel cost as the elasticity for disutility. Shown below in Table 24 are the user group related elasticity's (DGP, 2005), (Ubbels, 2006)

User group	Non-participants	Participants	Young Drivers
Elasticity	-0.3	-0.3	-0.5

Table 24 Elasticity's per user group

5.4 Departure time choice

The second model that is added to the DTA model is a departure time choice model. This model will allow drivers to change departure time in order to avoid high charges or congestion. The change of departure time is dependent of the route travel times, route costs and the disutility of changing departure time. A flowchart on the change of the dynamic OD demand is shown in Figure 18.

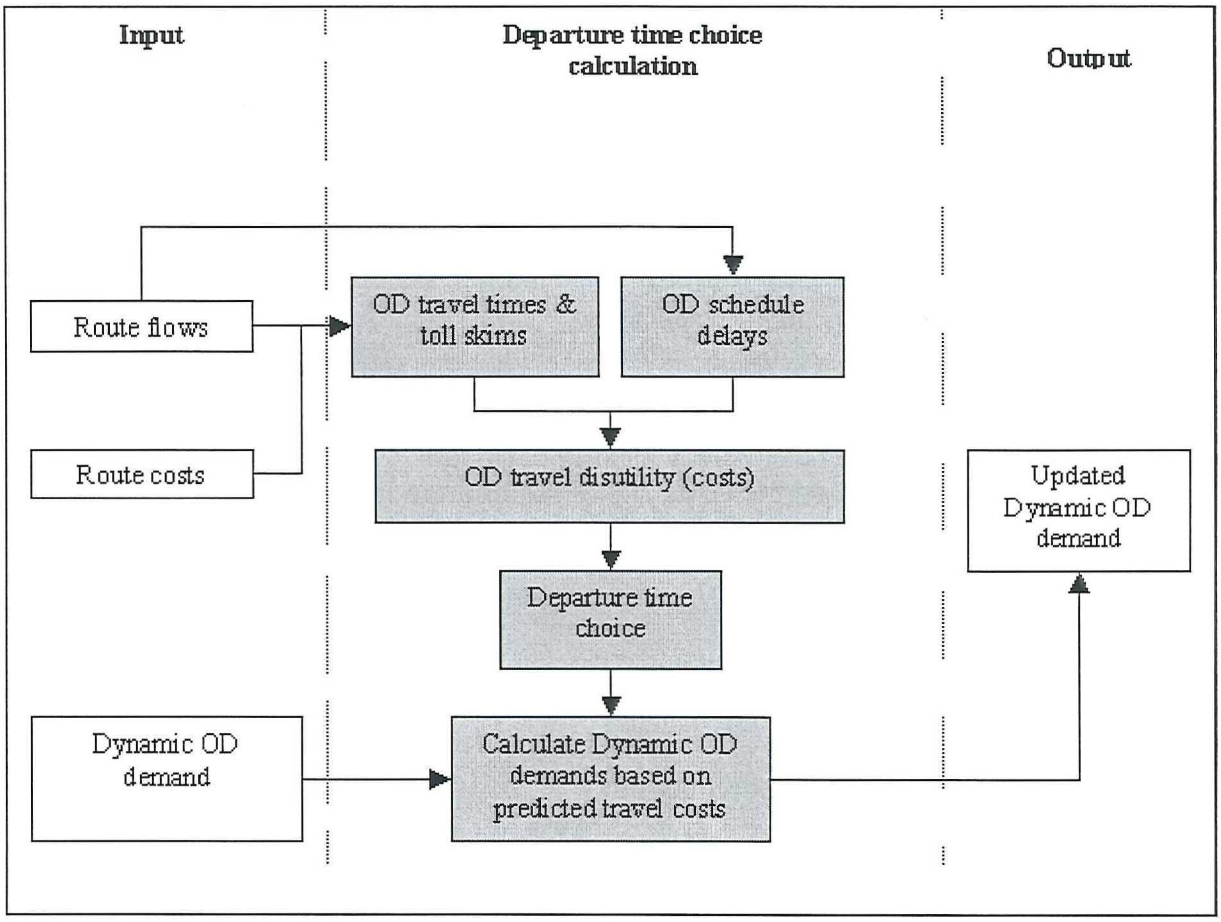

Figure 18 Departure time choice model structure

Departure time choice is currently modeled apart from route choice. It would be better to simulate route choice and departure time choice at the same time, but as the route choice model is incorporated inside INDY and the departure time choice model is not, this is not done within this study. Differences are estimated to be small, as drivers will likely select a departure time first and then decide on which route they take.

Change of departure time is based on perceived utility. The first departure times chosen in the model are the preferred departure times (see section 6.1.2). The disutility of each departure time is calculated for each preferred departure time using the total utility formula (7). Again assuming that the random error components $\varepsilon_m^{od}(k)$ are independently extreme value type I distributed over all departure times, the fraction of car drivers with preferred arrival time ξ_m choosing departure time k is given by

$$\varphi_m^{od}(k,\xi_m) = \Pr(U_m^{od}(k) \le U_m^{od}(k'), \forall k') = \frac{e^{(-\mu_2 c_m^{od}(k))}}{\sum_{k'} e^{(-\mu_2 c_m^{od}(k'))}} \quad (11)$$

Where $c_m^{od}(k)$ is given by:

$$\begin{aligned} c_m^{od}(k) &= \alpha_m^1 \overline{\tau}_m^{od}(k) + \alpha_m^2 \overline{\theta}_m^{od}(k) + \alpha_m^3 (k-\zeta)^- + \alpha_m^4 (k-\zeta)^+ \\ &+ \alpha_m^5 (k + \overline{\tau}_m^{od}(k) - \xi)^- + \alpha_m^6 (k + \overline{\tau}_m^{od}(k) - \xi)^+ \end{aligned} \quad (12)$$

For which the parameters are the same as in formula (7)

The parameter μ_2 is a scaling parameter (which is inversely related to the variance of the random unobserved component). Multiplying the fractions with the total number of car drivers preferring to arrive at arrival time k, $\widetilde{D}_m^{od}(k,\xi_m)$, gives the total number of drivers that will actually depart at time k. Integrating over all preferred arrival times, the total number of drivers departing at time k, is given by

$$D_m^{od}(k) = \sum_{\xi_m} \varphi_m^{od}(k,\xi_m) \widetilde{D}_m^{od}(k,\xi_m) \quad (13)$$

5.5 Route choice (INDY)

For each departure time period, car drivers have several route possibilities, each having route specific attributes like length and insurance premium, and time specific attributes like congestion (and in some PAYD schemes also premium). Car drivers are supposed to choose their optimal route for traveling, based on travel time and cost. The routes that drivers can choose from are generated before the simulation, adding routes most likely to be chosen to the set for each origin-destination (OD) pair. After a route is chosen, it is loaded in the Dynamic network loading model. From this model the output will be link flows, link speeds and link travel times. From there the route cost for each OD pair can be determined. See Figure 19.

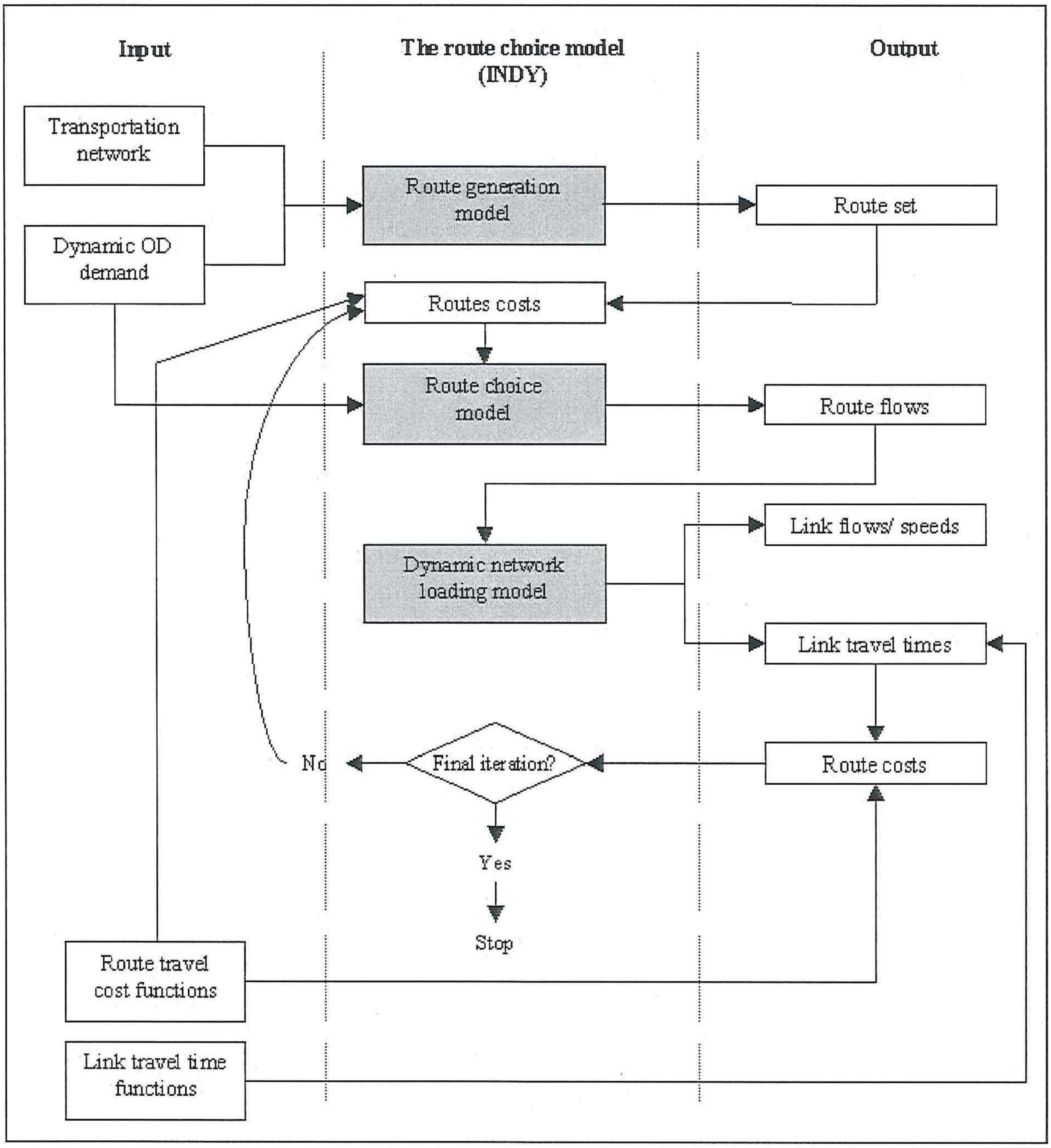

Figure 19 Route choice model (INDY)

5.5.1 Route set generation model

Route set generation is done once before the start of simulation. The route set will influence the simulation, as only the generated routes can be chosen. The same route set can be for each strategy, but this is not necessary. INDY has its own route set generation model incorporated in the traffic model. Two approaches of route set generation are available, static equilibrium assignment and Monte Carlo simulation. Monte Carlo simulation is described below.

A route set generation approach is an approach using Monte Carlo simulation. This approach starts with the shortest route and will add additional routes to the route set that are consistent with several criteria. The criteria on which new routes are selected are as follows:

- The number of iterations; the more iterations that are used, the more routes that will be found.
- The route is within the limit of the "spread" of the shortest route; this spread starts at zero (the shortest route) and increases with ever iteration. If no routes are found during iteration, no new route will be added to the set. The spread is automatically increased within each iteration and cannot be manually changed
- Maximum level of overlap; the maximum percentage (with respect to route length) that a generated route may overlap when generating routes. The higher this number is set, the more routes will be found.

With static equilibrium assignment, routes with many small changes are added to the route set. In dense networks of urban areas, this will lead to a large number of routes in the set and therefore a large set in total. Using this route set will result in long calculation times. On interurban networks this approach is much more useful, as there aren't as many short detours as in the urban network.

With Monte Carlo simulation, different options are more or less useful for different kind of network types. For urban networks, there are many different routes available and setting both maximum overlap and maximum number of iterations to a high value will lead to a large route set. Having a low maximum overlap will possibly lead to a lot of strange routes in the route set, as large detours will have to be made to find alternative routes. In this case it seems most practical to allow for a large overlap with little iteration. This way all urban roads will be used equally by different OD relations and congestion will be spread over the network as much as possible while limiting calculation time.

For interurban networks, a different approach is needed. In this case the main importance is avoiding the large congestion. Having a large allowed overlap will result in small differences near the origin and destination, while having no effect on the congested parts of the network. Therefore a low level of allowed overlap is necessary. As roads on the network may vary a lot in travel time, the number of iterations should be set high to include all different routes. As maximum overlap is already low, the route set will have a limited number of routes.

As our network includes both urban and interurban parts, none of the methods supplied satisfying results. Therefore two Monte Carlo simulations were combined to create one route set. The first simulation would result in a set that was suitable for the urban area and the second simulation for the interurban area. The combined set then had both strengths on interurban and urban level and is used in all strategies. While in some strategies other routes that are not included may be more favorable due to increased travel costs, the advantage of using the same route set for every strategy is that the results become comparable on route level.

5.5.2 Route choice model

Each route is supposed to have a generalized route disutility. This disutility is based on two components, namely travel time and monetary costs. The monetary cost will partially be varying over time.

The travel time component is mainly based on route length and allowed speed, but also the congestion that occurs on the route is important. The monetary cost of a route is largely dependent on the length of the route, making shorter but slower routes more attractive. Route costs can differ per road user (in this case PAYD participant or not) and can differ per link and also be depend on the type of road that is driven, making certain routes more attractive than others, which may give an opposite reaction in accordance to situations in which price is equal for all routes. The route choice cost component can be formulated as followed:

$$c_{mr}^{od}(k) = \beta_m^1 \tau_r^{od}(k) + \beta_m^2 \theta_{mr}^{od}(k) \tag{14}$$

Where:

$c_{mr}^{od}(k) =$ the user group m and route r specific disutility per OD pair o, d for departure time period k

$\tau_r^{od}(k) =$ the travel time for route r for OD pair o, d for departure time period k

$\theta_{mr}^{od}(k) =$ the monetary costs for route r, user group m, OD pair o, d and departure time period k. Fuel costs are not included in the model.

The m denotes whether the drivers from the user group are PAYD participants or not. For the user group of non-participants, $\theta_{mr}^{od}(k) = 0$, as the drivers pay a fixed premium and route cost and therefore choice are not affected by insurance costs. If the drivers from the user group are participants however, $\theta_{mr}^{od}(k) > 0$, as driving will add additional costs to the disutility function. From these last two statements it can be concluded that non-participants will always have a lower trip cost per OD relation on the same departure time and route.

β_m^1 and β_m^2 are user group related disutility parameters for travel time and costs. Making the assumption that the random unobserved cost components $\varepsilon_{mr}^{od}(k)$ are independently extreme value type I distributed over all routes, the trip fractions per routes are calculated using the multinomial logit model (McFadden, 1976):

$$\psi_{mr}^{od}(k) = \Pr(c_{mr}^{od}(k) \le c_{mr'}^{od}(k), \forall r') = \frac{e^{(-\mu_1 c_{mr}^{od}(k))}}{\sum_{r'} e^{(-\mu_1 c_{mr}^{od}(k))}} \tag{15}$$

Where μ_1 is a scaling parameter (inversely related to the variance of the random unobserved component). Multiplying this percentage by the total number of cars drivers from o to d at time k, $D_m^{od}(k)$, leads to the route flows $f_{mr}^{od}(k)$

$$f_{mr}^{od}(k) = \psi_{mr}^{od}(k) D_m^{od}(k) \tag{16}$$

The dynamic traffic demand, $D_m^{od}(k)$, depends on the departure time choice.

5.5.3 Dynamic network loading model

The dynamic network loading (DNL) model finally assigns the route flows to the network, taking into account the maximum capacity of the road and the speeds that follow from the flow and capacity. This model simulates traffic propagating over routes and time. For more information on INDY and the DNL model, see (Bliemer et al, 2004). As both user groups use the same network, reactions of one group may lead to opposite reactions of the other group. If, for example, PAYD participants are forced pay an additional cost per kilometer, shorter routes will be chosen. This way there will be less congestion on the motorway, so that non-participants are more likely to choose the motorway.

The model does not include blocking back. This means that not all travel times will be correct and that drivers will react in accordance with the new travel times. Also no intersection delays are taken into account. This will mainly have effect on interurban and urban roads, underestimating travel times.

Output of the dynamic network loading model are the link flows, speeds and travel times. These will be recalculated to route costs and travel times, which are used for the next iteration of the route choice model.

5.6 Traffic safety model

The traffic safety model in the study is split into two different components, one on network level and the other on route level. Each of these components has its own method of calculating safety for a specific strategy.

5.6.1 Network level safety model

On network level traffic safety is calculated by the link flows and safety values of different road categories. These safety values are increased for nighttime driving. See Figure 20.

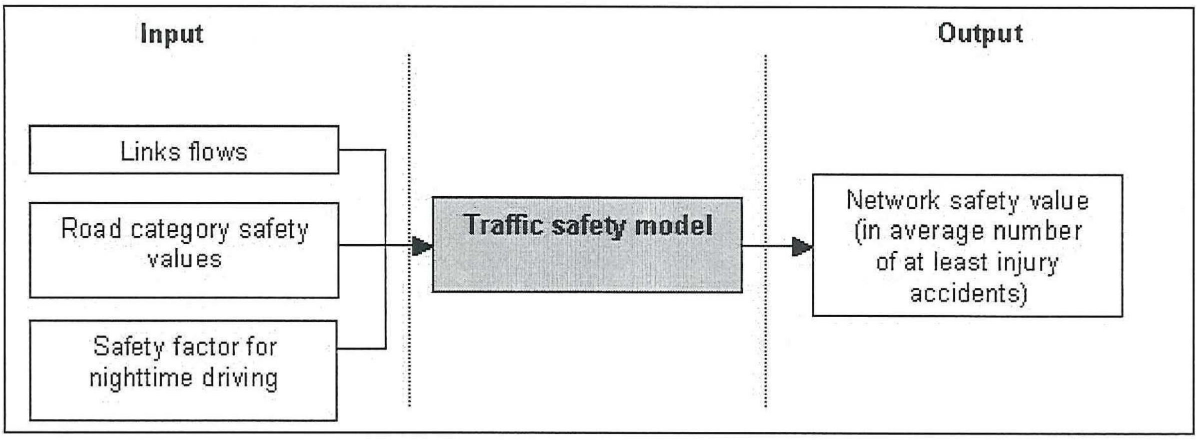

Figure 20 Network safety model structure

The link flows for the safety model are taken from the transportation model results. From the network the road categories are known. The safety values for different road categories have been used after information from the SWOV in such way that they were applicable for our network model (Janssen, 2005). These values are listed below in Table 6.

Road category	Unsafety (traffic injuries per million car kilometers)
Motorway	0,06
Interurban road	0,22

Interurban road for all traffic	0,43
Urban road	1,10

Table 25 Road category unsafety values for the premium structure

The increased unsafety for nighttime driving has been described in section 2.2.4. The value that was found for the increase of unsafety during nighttime driving was found as 1.7. This value is used as the safety factor for nighttime driving.

Multiplying the link flows with the corresponding factors will lead to the network safety level, which is better when lower, as it corresponds to the average number of traffic injuries during the morning peak that is simulated.

The reduction in traffic injuries can give an indication of the reduction of traffic injuries that yearly occur in the Netherlands. In this study the assumption is made that the effects on safety during the rest of the day and year are the same as in this specific morning peak. For the road category safety data, the data averaged for 1997-1999 are used. For consistency the data about the number of traffic injuries will be used for these years as well(Janssen, 2005), see Table 26.

Crash type	Number
Injury accidents	18952
Fatalities	1106

Table 26 Yearly numbers of injury accidents and fatalities in the Netherlands

From these data total reductions in injury accidents and fatalities can be calculated. If these reductions are multiplied with the overall cost for crashes, see Table 21 (AVV, 2006), a part of the savings of the PAYD strategy can be expressed in money. This value will then be compared with the estimated costs of implementing and running a PAYD strategy.

Crash type	Cost (2003)
Fatal	€ 2,653,462
At least injury accident	€ 280,442

Table 27 Cost of a crash in the Netherlands, 2003

5.6.2 Route safety level

For the evaluation of safety on route level, 7 OD relations have been selected on the basis of the following criteria:

- At least 100 trips on the OD relation
- At least 3 different routes possible
- At least 1 route that uses the motorway for a large part of the trip
- At least 1 route that does not use the motorway

For each of these OD relations safety values will be calculated for each route that leads between the origin and destination. This will be done on the basis of at least injuries per million kilometers per road category and the distances on each road category in each route. From this the safest route that has been found can be determined. This route will be given a safety index of hundred, the relatively unsafe routes will have indexes lower than hundred, depending on the difference in safety between the routes. See formula (17).

$$I_{rs}^{od} = \frac{S_s^{od}}{S_r^{od}} * 100 \qquad (17)$$

Where:

I_{rs}^{od} = the route r safety index for relation o, d

S_s^{od} = the safety value of the safest route in the route set for relation o, d

S_r^{od} = the safety value of route r for relation o, d

As the route flows are available from the transportation model, a match can be made between the level of the safest route and the amount of traffic choosing that route. A diagram is presented in Figure 21.

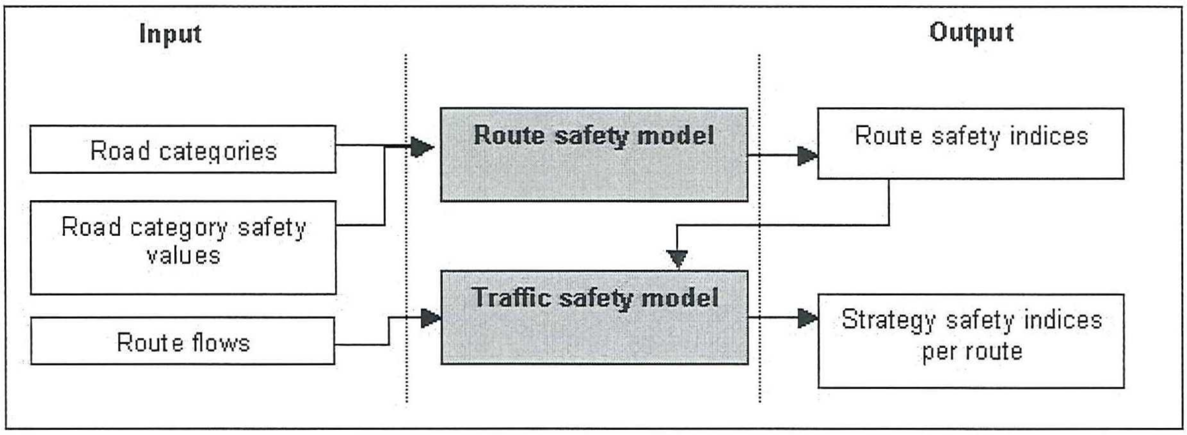

Figure 21 Route safety model

The road category safety values are equal to those used in the network safety model (Table 6 of the previous section). The road category lengths depend on the route. Route safety indices are equal for all strategies, as the route set does not change over different strategies. Route flows are likely to change, however, so the strategy safety indices can be compared per route. The OD safety indices are determined as the flow weighted average of the route safety indices. See formula (18).

$$I_s^{od} = \frac{\sum_r f_r^{od} * I_{rs}^{od}}{\sum_r f_r^{od}} \qquad (18)$$

Where:

f_r^{od} = the flow on route r for relation o, d

I_s^{od} = the weighted OD safety index for relation o, d

From this the strategy safety index can be calculated as the average OD safety index.

6 Case study: Region of Haaglanden

The chapter before the modeling framework was discussed. In this chapter we give an explanation of the case study in which this modeling framework will be applied. In the next chapter the results of the model will be presented.

This chapter starts with the model setup and follows with the description on participant creation. The chapter ends with the description of the reference situation.

6.1 Model setup

The model setup is split into three parts. The first part holds the transportation model network description, followed by the information about the travel demand. Finally this section concludes with the model parameters that have been used.

6.1.1 Network description

The network of the model consists of the study area located in the western part of the Netherlands. The study area is northbound by the city of Leiden, eastbound by Gouda, southbound by Rotterdam and westbound by the North Sea. See Figure 22.

Figure 22 Model study area

All main roads have been incorporated in the model. These roads consist of the three main motorways (A4, A12 and A13, for location see once again Figure 22), all provincial roads and most urban roads as well. Home zone streets, however, are not taken into account at all. This is no problem as often Home zone streets come to a dead end or speed-reducing measures are taken to make through routes less useful. As the PAYD program should run throughout the country, this area shows only a part of the effects of PAYD. It will, however, give a strong indication of the effects of PAYD on traffic safety.

For all road elements in the network, its characteristics need to be described (maximum speed, capacity, number of lanes, etc). For the nodes in the network, no information is needed, as delays at intersections are not taken into account. About the centroids in the network information must be given of the number of trips departing to each other centroid. These centroids are based on postal 4-code areas. The Origin – Destination matrix is given for this specific network. The network itself is shown in Figure 23.

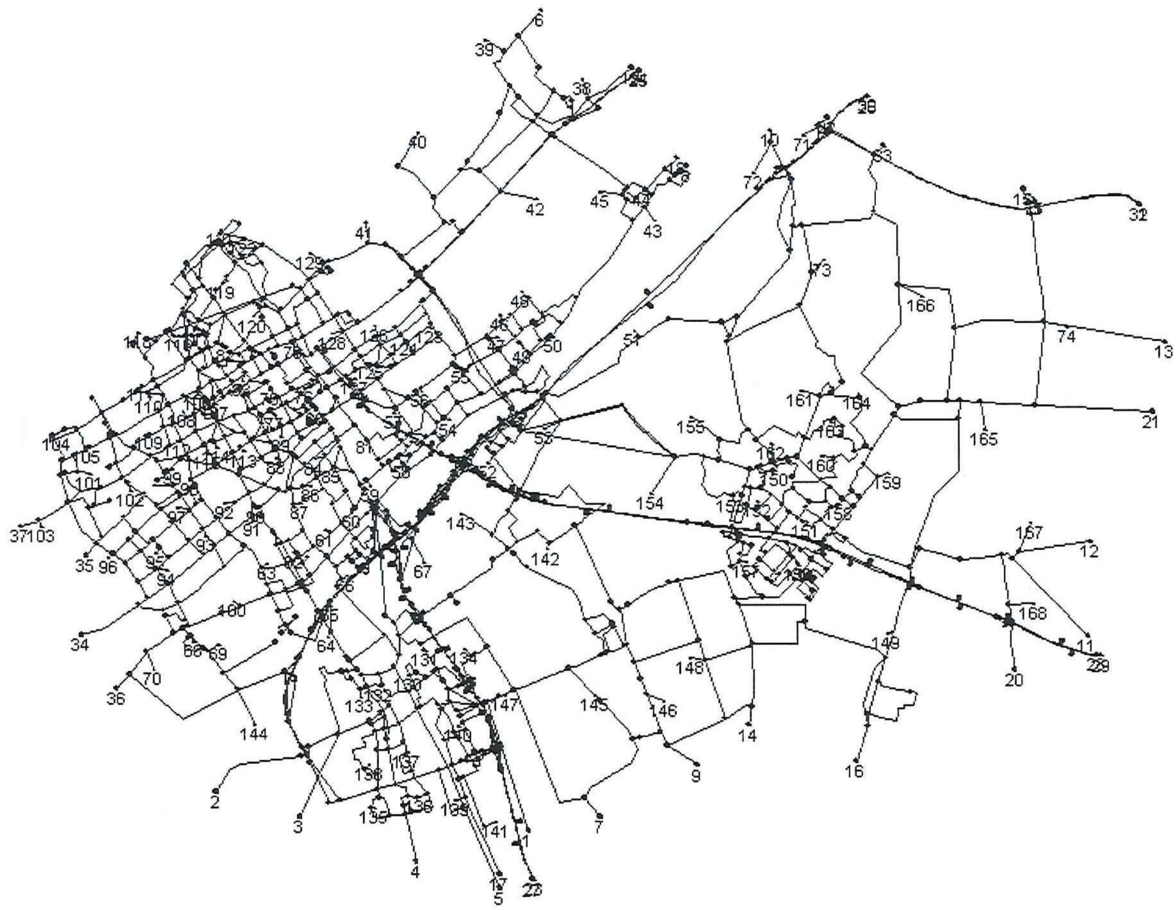

Figure 23 The network model in OmniTRANS

The simulation period of the transportation model is limited to the morning peak. The morning peak that is important for out research runs from half past six to half past ten. Some time is needed, however, to fill and empty the network before and after the research period. Therefore the simulation period is defined as follows:

1:	6:00 – 6:30	starting of the model and filling of the network
2:	6:30 – 10:30	simulation period
3:	10:30 – 11:30	emptying of the network before end of simulation

6.1.2 Travel demand

The network travel demand was a parameter of calibration. To calibrate the travel demand, data from the Regiolab of the traffic counts on the motorways was available. See Figure 24.

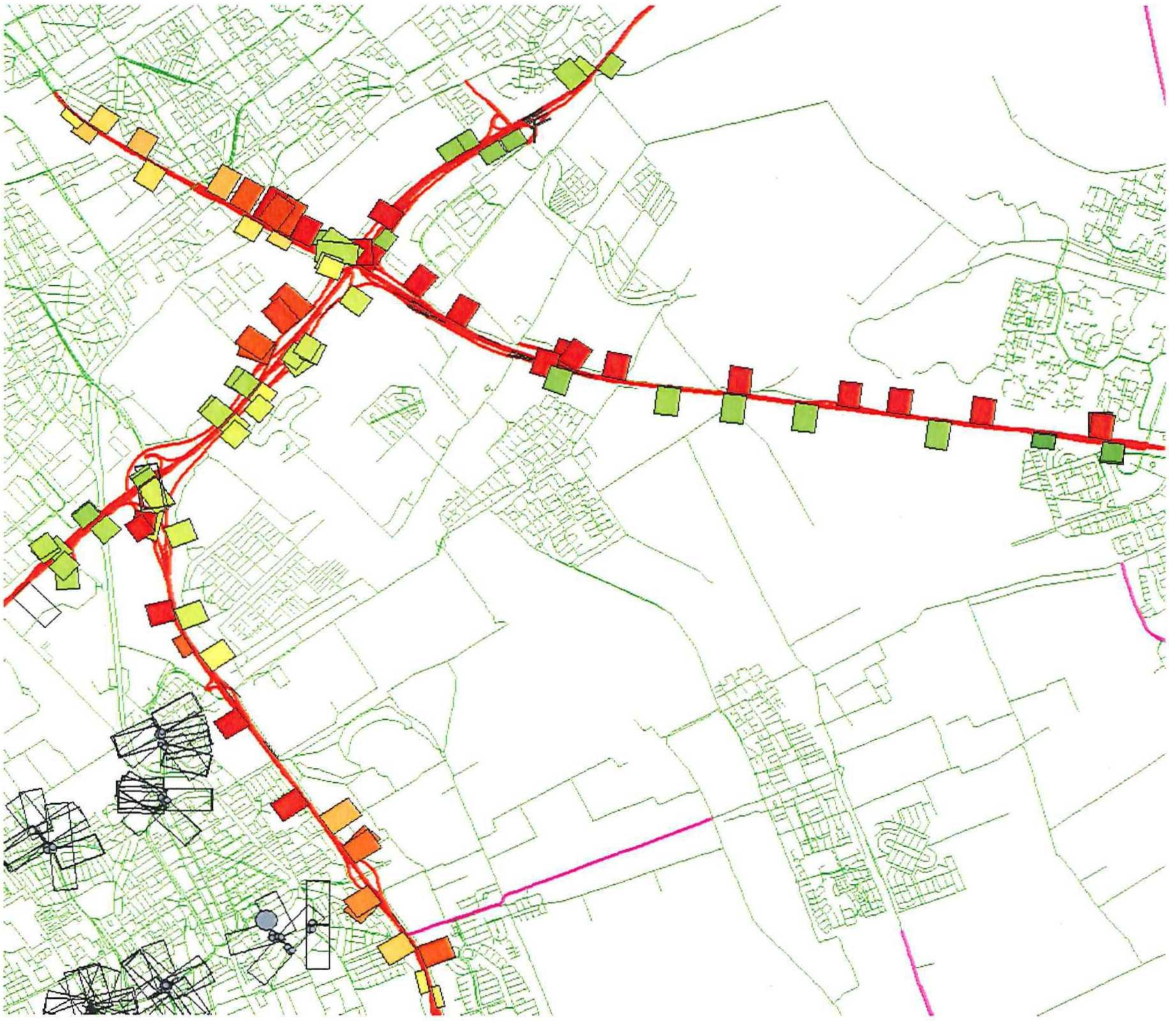

Figure 24 Detection loops from the Regiolab Delft area

These counts consisted of both the number of vehicles passing and the harmonious speed of vehicles passing during the time interval. The locations of the loop detectors were found using Google Earth, and matched with the links on the network, see Figure 25.

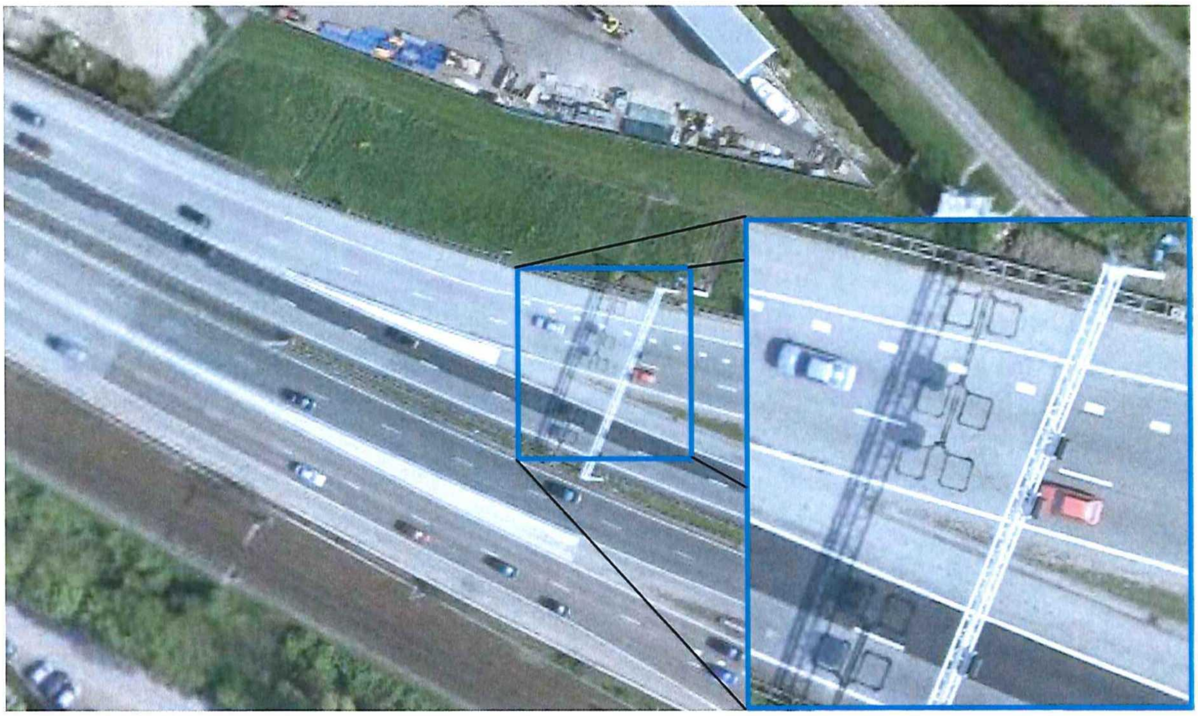

Figure 25 Locating loop detectors with Google Earth

The Regiolab data viewer, which is used for extracting the loop data, does not only retrieve and clean data, but is also capable of creating trajectories and calculating travel times. For the network calibration, an "average" morning peak has been used. The morning peak that has been selected is from April 4th 2006. The trajectories and travel times from Gouda to The Hague over the A12 are shown in Figure 26.

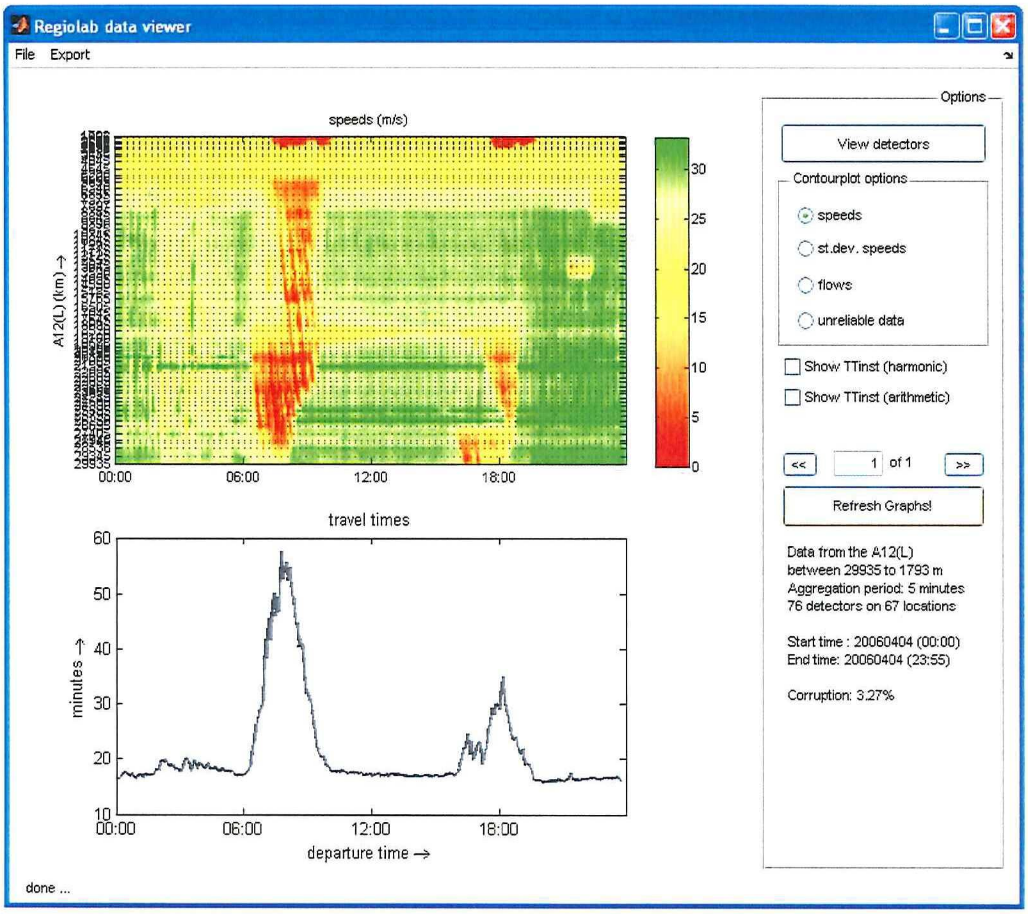

Figure 26 A12 from Gouda to The Hague in the Regiolab viewer

With the data from the Regiolab, the total number of vehicles could be calibrated. This mainly meant changing the level of demand for different OD relations. By changing the preferred arrival time pattern of the drivers the shape of the flow over time periods could be changed. The final shape of the flow curve is shown in Figure 27. This curve is made after all other calibration presented below is completed as well.

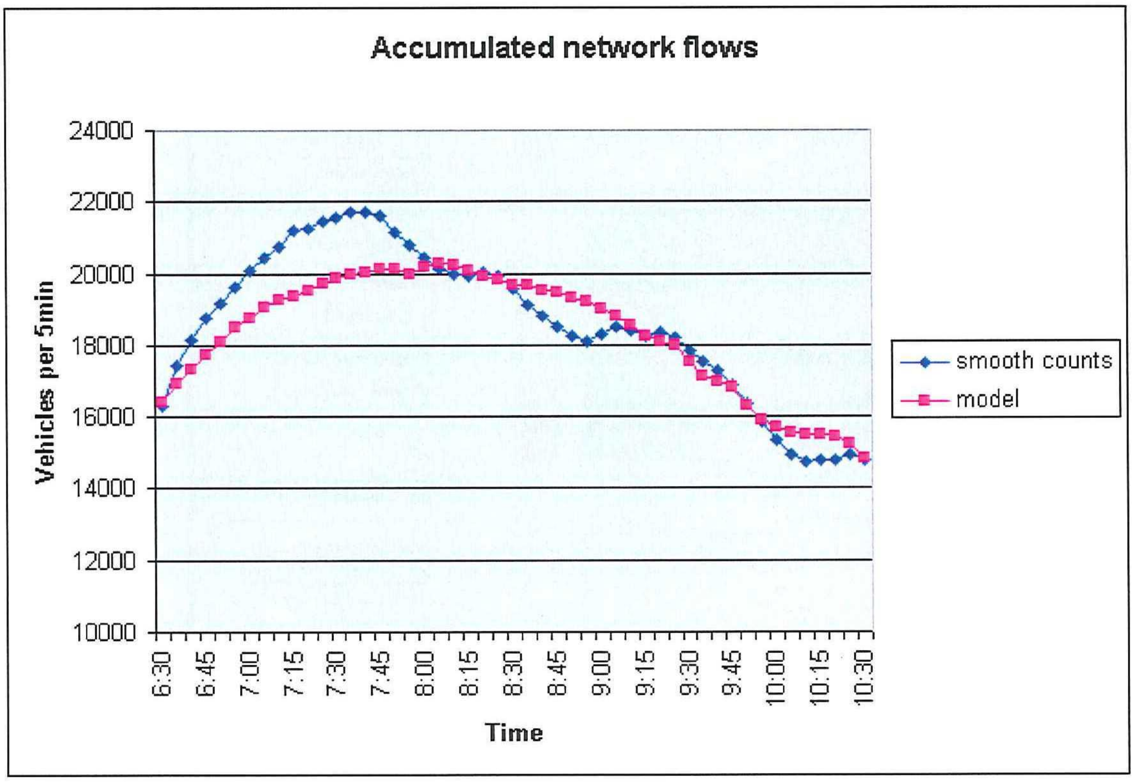

Figure 27 Accumulated traffic flow on the network after calibration

The preferred departure time is dependent on the preferred arrival time, which is a parameter of calibration. The preferred departure time is determined on the basis of the free flow travel times in the network and subtracted from the preferred arrival times. See Figure 28.

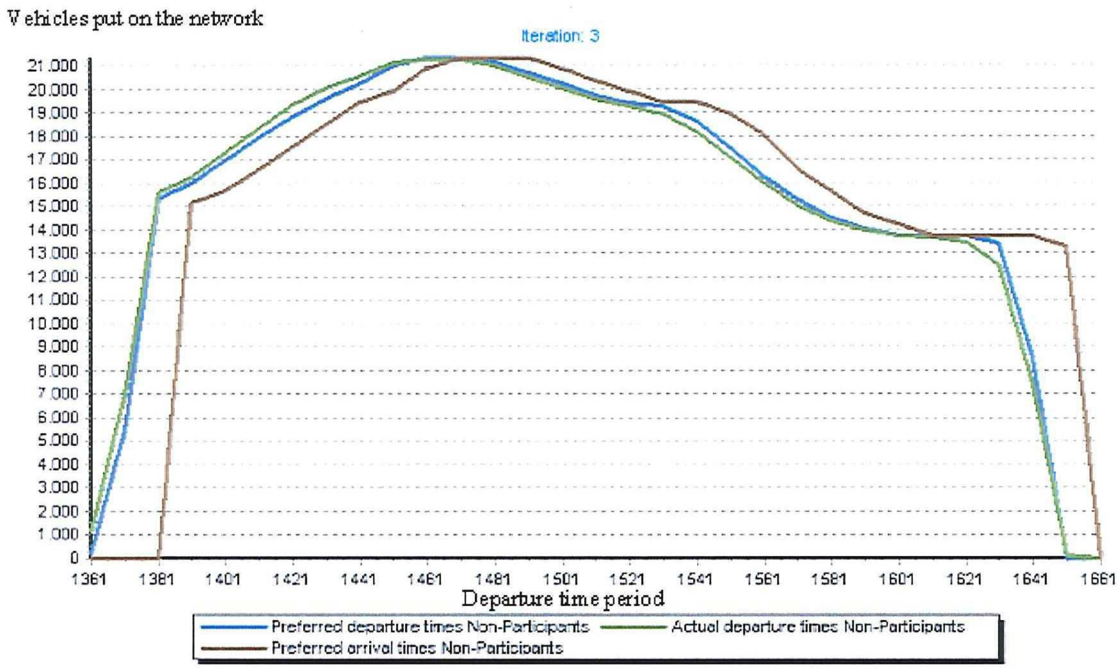

Figure 28 Preferred departure time, preferred arrival time and actual departure time in the Reference situation

Actual departure time is updated in the departure time choice model (see section 5.4) to include extra travel time due to congestion. Preferred arrival time is shifted to bring the flows and densities closer to the data available.

6.1.3 Model parameters

After the total flow, many other parameters had to be calibrated, such as link specific parameters like the maximum capacities and speeds of the roads, and network specific parameters as the minimum speed and maximum density. Density is defined as the total number of vehicles per kilometer. The sum of all densities of the traffic counts on the network has been calibrated towards, resulting in a fairly accurate congestion pattern. The density graph is displayed in Figure 29.

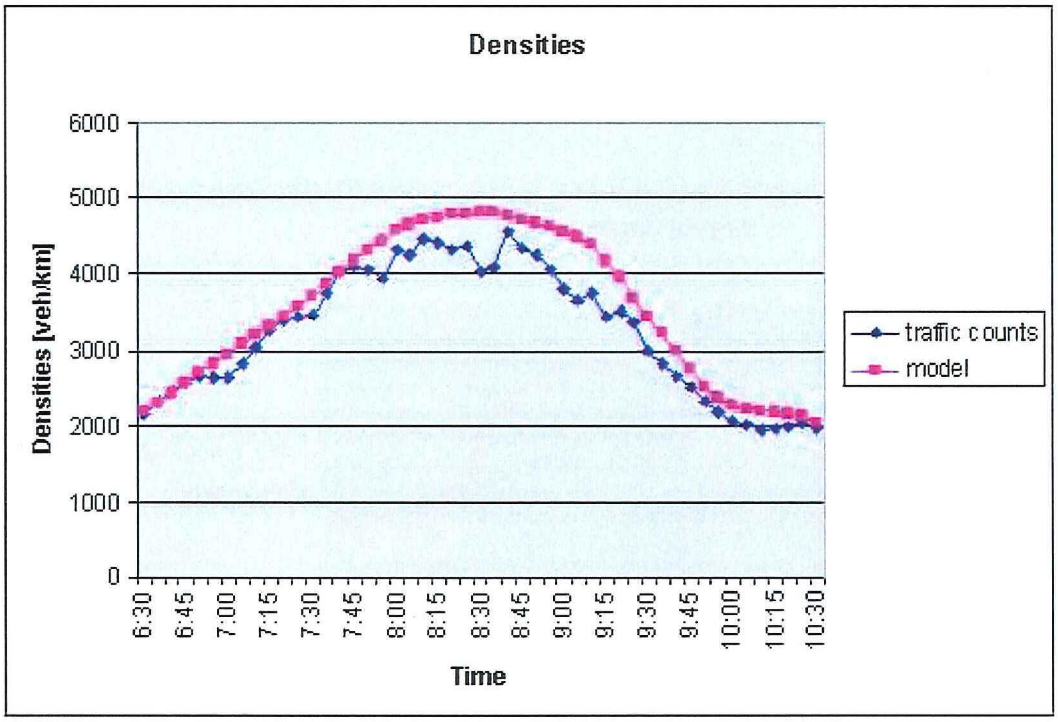

Figure 29 Densities

With the densities are accurate enough, the travel times on the various motorways can be calibrated. Optimizing the values of capacity, speed, etc for individual links accomplishes this. Examples of travel time graphs are shown below. As no blocking back is taken into account in the model, more then one bottleneck is simulated. This way the maximum travel time and free flow travel time will be equal to the reference situation, but on the edges of the peak hour travel times are too high.

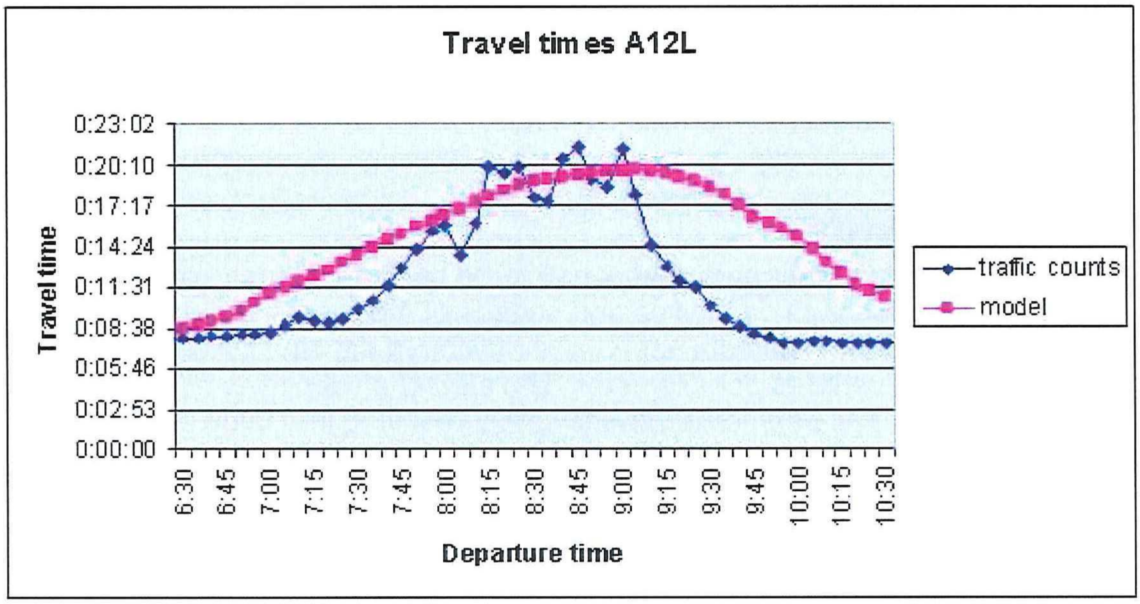

Figure 30 Travel times on the A12 from Zoetermeer to The Hague

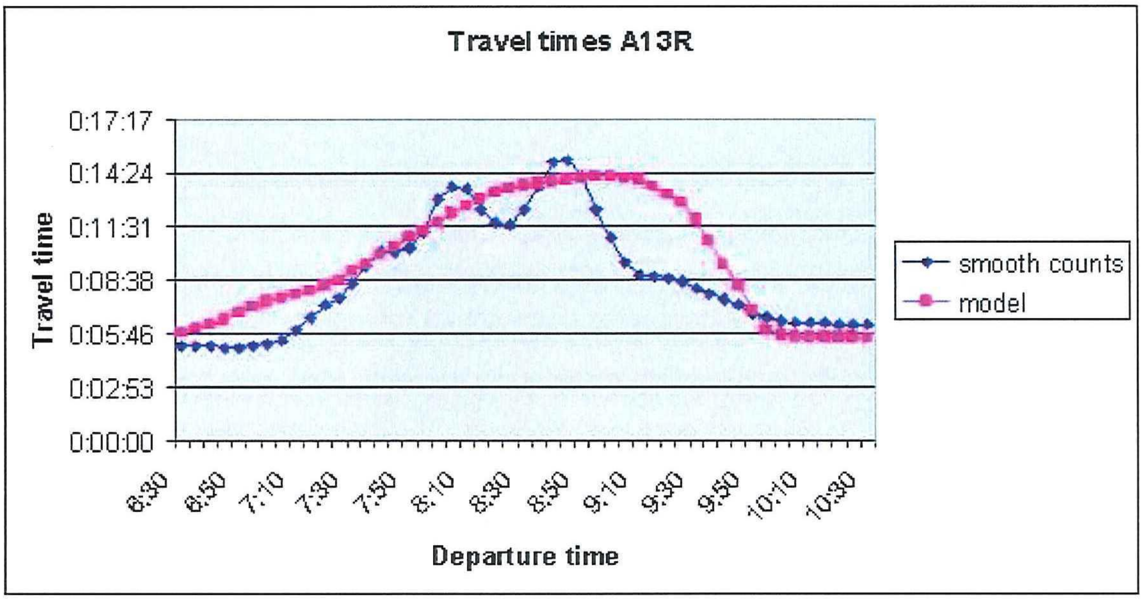

Figure 31 Travel times on the A13 from The Hague to Rotterdam

In the model the choice functions for departure time and elastic demand have a number of choice parameters. Most of the parameters have been taken from the MD-PIT research program. For the utility elasticity no parameter has been found, so instead of using an utility elasticity, a cost elasticity is used. The cost elasticity for the average driver is set at -0,3(Ubbels, 2006; Rietveld, Vervoort, 2005). Except for the young drivers, it is estimated that the participants have the same behavioral parameters as the non-participants, as the groups of participants are relatively large. For the young drivers a different set of parameters will be used, as young drivers are, for one, more influenced by monetary controls due to the fact that they have less money. Parameters for the young drivers once again come from the MD-PIT research and the elasticity from the research of Ubbels (Ubbels, 2006). The user group specific parameters used in this study can be found in Table 28.

Parameter	(Non-)participant	Young driver
Travel Time	-0.0247	-0.1600
Travel Cost	-0.1158	-0.0243
Departure Early	-0.0162	-0.0205
Departure Late	-0.0791	-0.0413
Arrival Early	-0.0292	-0.0519
Arrival Late	-0.0339	0*
Cost elasticity	-0.3	-0.5

Table 28 Model choice parameters for departure time estimation and elastic demand

* The choice parameter for young drivers for arriving late was not significant and is set to zero for this study.

Several other network wide parameters for INDY have been estimated or used. These parameters include:

- Time step, this is the time step that is used during simulation in which traffic is distributed along the network. In our model this has been set to 2 seconds.
- Spread, this parameter reflects the imperfect knowledge of the driver for which route is fastest. In our model this parameter is set at 0.07.
- Jam speed, this is the minimum speed on each road. This parameter is used to set the curve of the Smulders function in INDY (Romph, 1994). When a link has reached its jam density, new drivers will have this speed. In our model this parameter is set at 14 km/h.
- Jam density, the maximum number of vehicles per kilometer in the network. This parameter is used to set the curve of the Smulders function in INDY, which is used to calculate speed from flow. In our model this parameter is set to 130 vehicles per kilometer.
- Value of time (VOT), this parameter represents the willingness to pay for a certain reduction in travel time. It will influence the route choice of drivers and is set to €10 per hour for all user groups.

Mu, this is the spread parameter for the departure time choice model, indicating the imperfect knowledge of the drivers. In our model this parameter is set at 4.

6.1.4 Assumptions

In the model, some assumptions have been made. These assumptions will have to be regarded when interpreting the results. The assumptions can be grouped in three different kinds of assumptions, general assumptions, transportation model assumptions and safety model assumptions. A list of the assumptions is shown below.

General assumptions:

- No individual cars are identified, meaning that differentiation is limited to the groups which are defined within the model
  - In the young drivers scenario, young drivers are determined throughout the network, in the other scenarios the age of all drivers is ignored;
  - Insurance premium is set at an equal level for all PAYD users;
  - No vehicle weight classes are set in the model;
  - No difference is made in driver crash history;
  - Driver living location in this study is estimated to give a relatively higher premium in relation with the national average, as all drivers are in a more or less urbanized area. The annual premium per driver is set at €600;
  - In the young drivers scenario, the annual insurance premium is set at €800, to give weight to the increased safety risk and insurance premium of young drivers.
- Freight traffic is not taken into account. As PAYD is only for the individual road user, the effects on freight traffic are estimated to be minimal;
- Two-wheeled motor traffic is not taken into account in the model. These drivers are a specific risk group however, with a risk nineteen times as high as that of car drivers (SWOV, 2001).

Transportation model assumptions:

- In the model, home zones and home zone streets are not identified. However, the implications for the modeling results will be minimal, as on this level there will be little possibility for route choice and the driven distances on these roads are small;
- Due to wanting to limitations on calculation time, only a limited number of iterations are performed, and the assumption is made that equilibrium is reached;
- Due to calculation times, the number of routes per OD pair is taken at a relatively low level (3-4 routes per OD pair on average) than would be preferable (8-10 routes per OD pair);
- Nighttime and daytime driving have the same distribution of vehicle kilometers among road categories as the distribution of vehicle kilometers over the entire day;
- Delays at intersections are not taken into account;
- Blocking back is not taken into account, resulting in travel times that are not precisely equal to the measured travel times;
- Because no blocking back is done, the bottlenecks are taken on the links on which congestion occurs in reality. This is, however, not the real bottleneck, but the effect of the real bottleneck downstream.

Safety model assumptions:

- Nighttime is set from sundown to sunup, which is averaged over the year, setting sunrise at 7 am and sunset at 7 pm. Modeling only the morning peak shows night from start to 7 am and day from 7 am till the end of simulation;
- Relative risk for nighttime driving is averaged for all drivers, no matter their driving behavior.

6.2 Participant creation

In several of the strategies in the case study, different user groups are defined for PAYD participants and non-PAYD participants. In this section participant creation will be explained.

6.2.1 50% participation rate

In the case that there is no legislation forcing drivers to have PAYD, it is estimated that about 50% of the drivers will join PAYD freely in time (Todd Litman, 2006). These 50% of the drivers are, however, not uniformly distributed over all different kilometrages. In the model these 50% participants will have to be specified in order to model their behavior. It is unlikely that drivers with a high kilometrage will choose PAYD, as total yearly insurance premium will increase. Lower kilometrage drivers, on the other hand, will be more likely to choose PAYD. The trip length of the drivers in the model has been chosen as indication for the driver's kilometrage. The distribution of distance driven in the model is shown below (Figure 32)

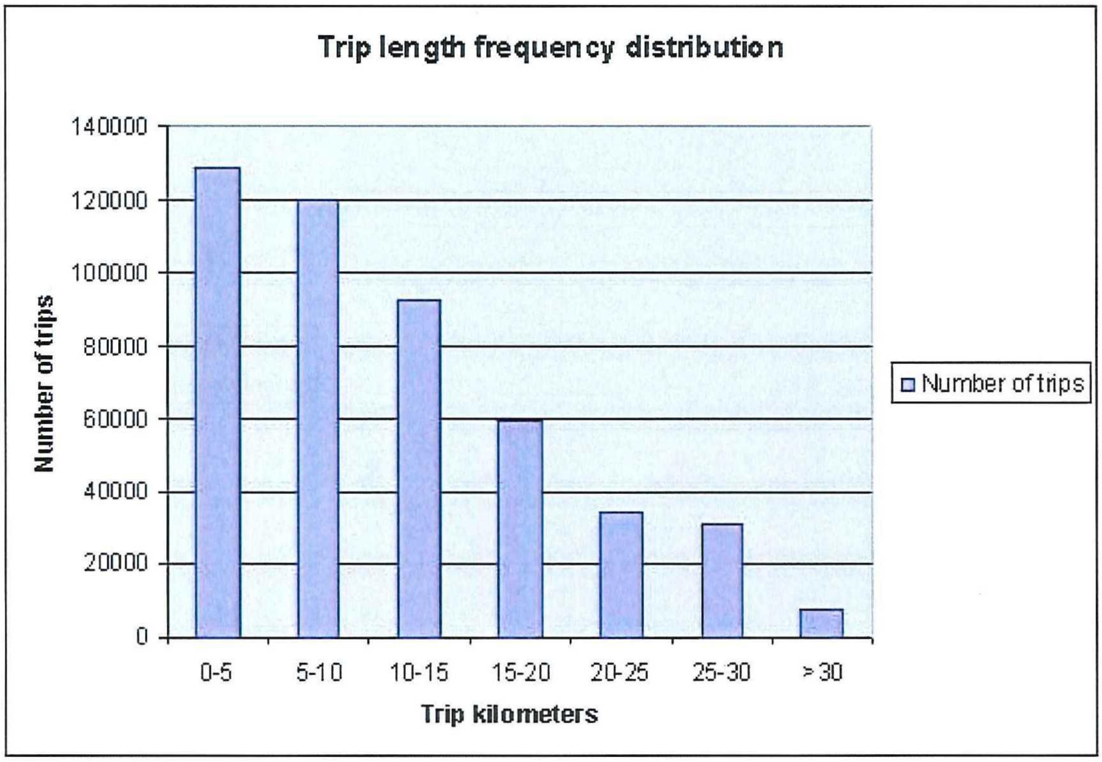

Figure 32 Trip length frequency distribution within the transportation model

As the network model has certain boundaries, not all trips are simulated completely. Therefore, a number of trips will actually be longer than shown in the model simulation. These trips mainly exist in the lower categories of the trip distribution. The percentages of participation are shown in Table 29.

Trip length	0-5	5-10	10-15	15-20	20-25	25-30	>30	Total
Percentages	40%	70%	60%	50%	30%	20%	10%	
PAYD participants	51615	83677	55359	29929	10329	6184	781	237877
non-participants	77422	35861	36906	29929	24102	24738	7031	235992

Table 29 Level of participation

The percentages of participants are for that reason adjusted downwards for the lowest category (0-5 km). As high kilometrage drivers are less likely to join PAYD, the amount of participants is limited in the higher kilometrage categories. The distribution of participants is shown in Figure 33.

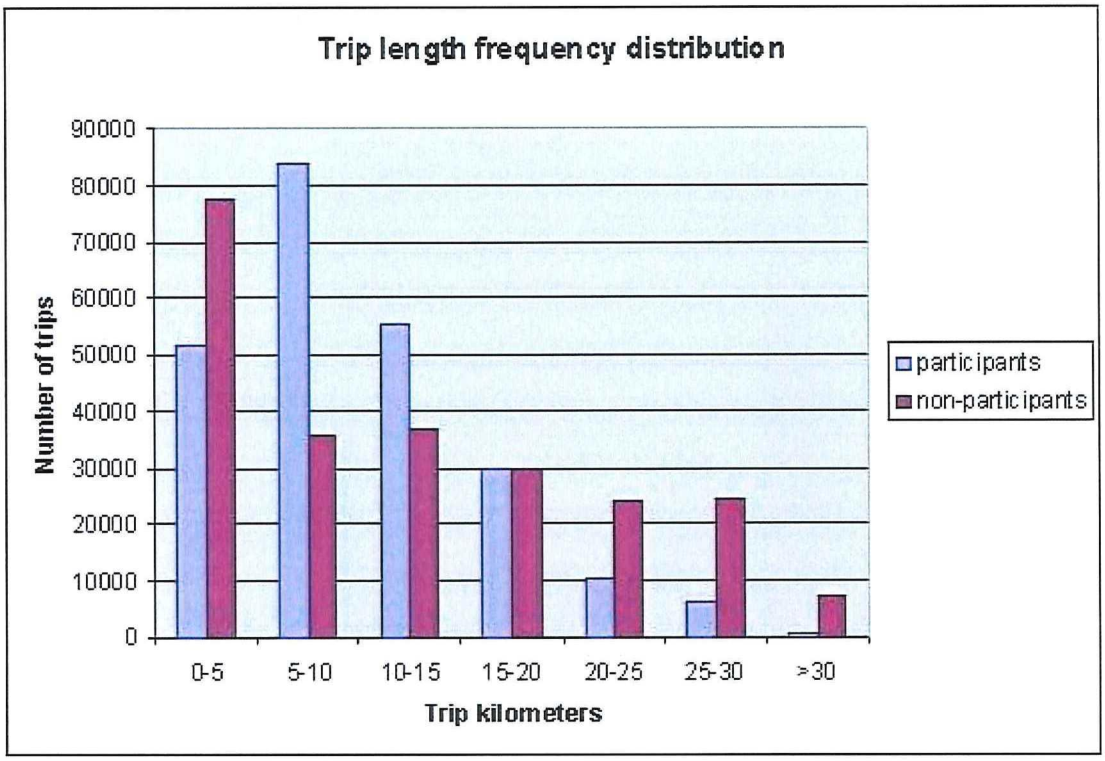

Figure 33 Trip length frequency distribution for participants and non-participants

As visible, most participants are from the 5-10 kilometer category. These drivers kilometrage should allow them to quite easily make a saving on premium if they do not make the trip every day. Changing mode, route or departure time will allow participants to increase their savings further.

6.2.2 Young drivers

For the last scenario, the only drivers who will be having PAYD insurance are the young drivers. As young drivers have a relatively higher crash risk than older drivers, their insurance premium is usually higher as well. Having on average less money than older drivers, young drivers will be more sensitive to pricing measures and are more likely to react by changing driving behavior. In this scenario the young drivers in the model will have to be determined as a specific user group.

To determine the young drivers in the model two steps are taken. At first, demographic information from the NRM (NRM, 2006) is combined with the total trip data in the model, to determine the possible young drivers in a zone. Secondly, the average trip distribution for young drivers is matched with the trip distribution in the model.

Step 1
In the first step the data from the NRM is analyzed. From this data, the population, split in age groups and gender, can be analyzed. This data is added up per postal-four code area, which reflect the centroids of the network model. Next to this data, from the MON, estimations of driving behavior can be made. These result in trip estimations for young drivers (25 and below) and other drivers (over 25), divided by gender. With the knowledge of the age and gender of the zone inhabitants, the percentage of trips from that zone which would be made by a young driver can be calculated. An overview of the results is given in the table below. The calculations can be found in appendix 1.

Age group	Male	Female
18-25 (Participants)	0.15	0.125
15-34 (Young Drivers)	0.60	0.50
35-64 (Older Drivers)	0.80	0.50

Table 30 The average number of trips per morning peak

The boundaries of the model are not as easily estimated, as they are not linked to a specific postal area from the NRM. As the biggest boundary zones are all motorway connections, the effect of non-motorway zones is set at the same level as the motorway zones. The percentage originating from boundary zones is set at the motorway value of 5% (Goudappel Coffeng BV, 1997). The average for other zones lays around 9% young drivers.

Step 2
Secondly, as young drivers have a different trip distance distribution than older drivers, an estimation is made on how many trips a young driver will make on a certain OD relation. A difficulty with this lies in the fact that many trips in the model cross the boundaries (170 thousand of the 470 thousand trips), thus of a third of the trips, the trip length is underestimated. As the main trip category for young drivers is between 10 and 15 kilometers, the weights for trip distribution are shifted to the left, causing lower kilometrage trips to be more common than higher kilometrage trips. See Table 31.

Trip length (km)	0-5	5-10	10-15	15-20	20-30	>30
Factor	1.3	1.1	0.9	0.8	0.7	0.5

Table 31 Weights for kilometrage class

As trips by young drivers are only a percentage of the total number of trips from a zone, the factor of young drivers on a certain OD relation is higher than 1 for short trips. If only step 2 would be taken into account, the percentages of the trip distribution can be calculated. This distribution is shown in Figure 34.

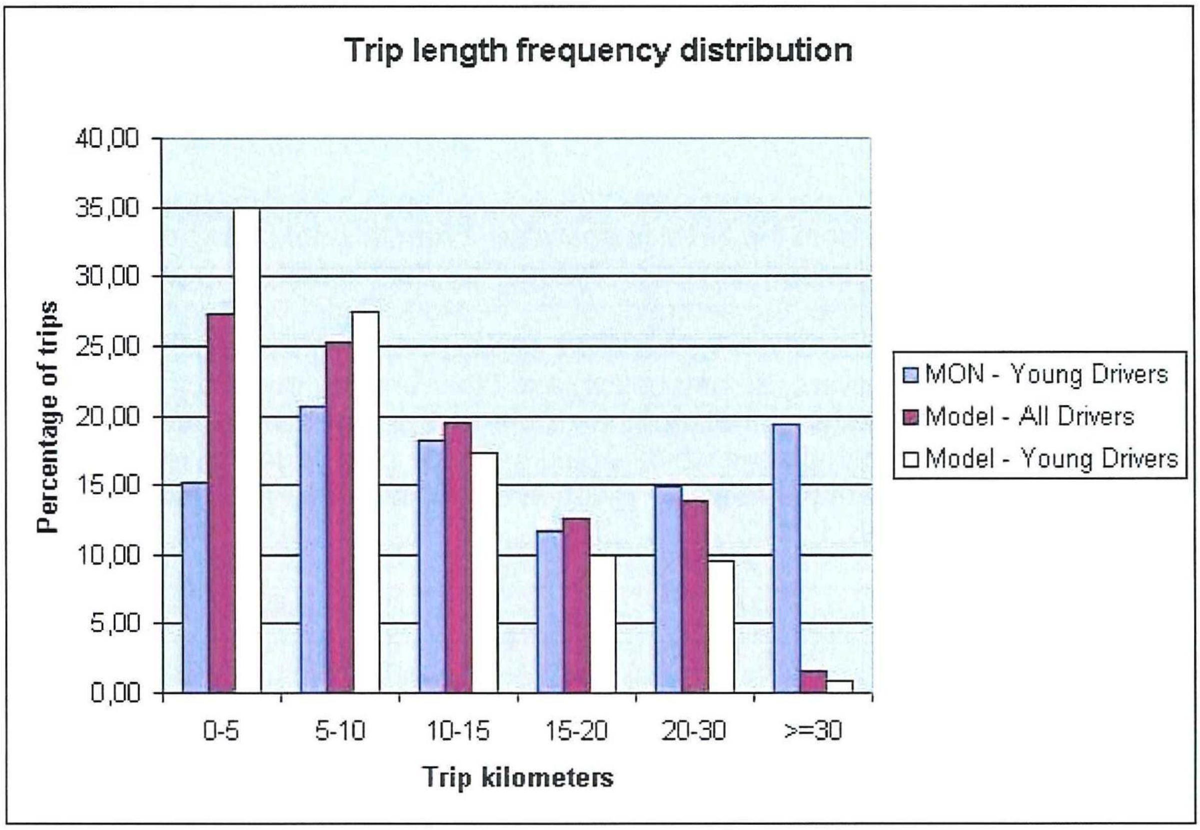

Figure 34 Trip length frequency distribution for young drivers

Combining step 1 and 2 will lead to the estimated trips of the young drivers user group. These drivers are in total about eight percent of the total traffic demand.

6.3 Reference situation

The reference situation is chosen from a specific day of the morning peak in the region 'Haaglanden'. In this morning peak there was average congestion and except for a small event on the A4 motorway, no strange inconsistencies were spotted in the traffic flow. A view of the congestion in the transportation network model is shown in Figure 35.

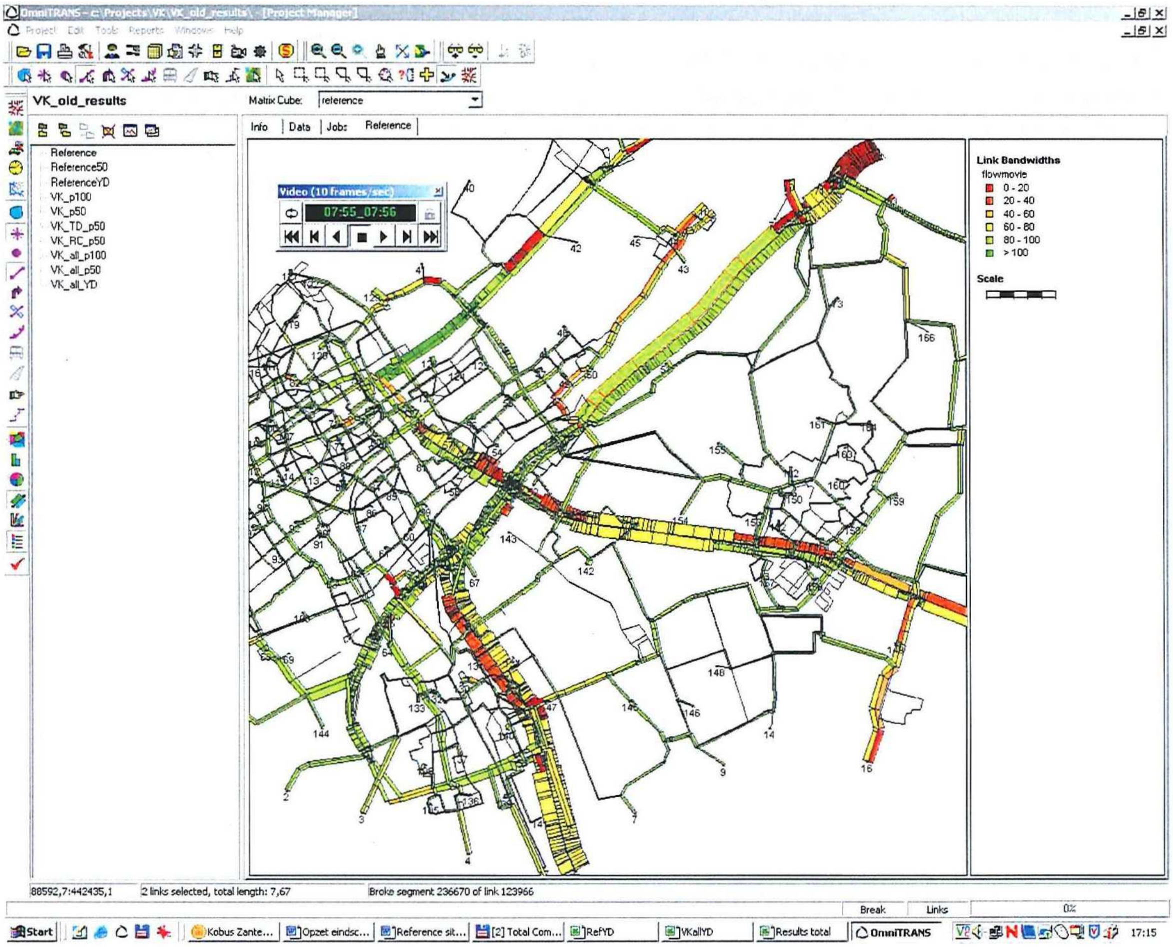

Figure 35 Congested network during the morning peak

The network is currently not capable of distributing the traffic on free flow travel times. From approximately 7:30 am congestion starts building on the A12 near the Prins Clausplein and Zoetermeer. Also on the A13 and A4 congestion occurs. The main traffic streams use the motorways in order to reach their destination. From 9:30 am the congestion quickly decreases and soon after ends.

The reference situation will be the first strategy to be evaluated on the basis of the set evaluation criteria. These criteria have been described in 4.5.

The safety is split in network safety and route safety. After the safety indicators the accessibility aspects are discussed.

Network safety

On network safety level the first aspects that are evaluated are the number of kilometers driven per road category. These kilometers driven are presented in Table 32.

Road category	Motorway	Provincial road	Provincial (all traffic)	Urban road	Total
Total vehicle kilometers	2649650	635513	619650	1233853	5326190

Table 32 Number of vehicle kilometers per road category in Reference situation

Depending on the road category, these kilometers driven relate to safety. After multiplying with the safety parameter for road category, the average number of injury accidents for the strategy is found. This number, combined with other strategy related values, is shown in Table 33.

Number of trips	Total vehicle kilometers	Number of traffic injuries
473869	5326190	2.33

Table 33 Reference related safety factors

Route safety

The route safety value is first of all dependent on the safety of the routes that can be chosen. Next to this value the flow on the routes is of importance for this value. The safety of the routes that can be chosen is displayed below for the OD relation 157 – 130, from Zoetermeer to Delft. Between this origin and destination there are 4 routes available, 1 of which mostly uses the motorway, 2 that uses the provincial roads and 1 that uses some of both. A picture is shown below in Figure 36.

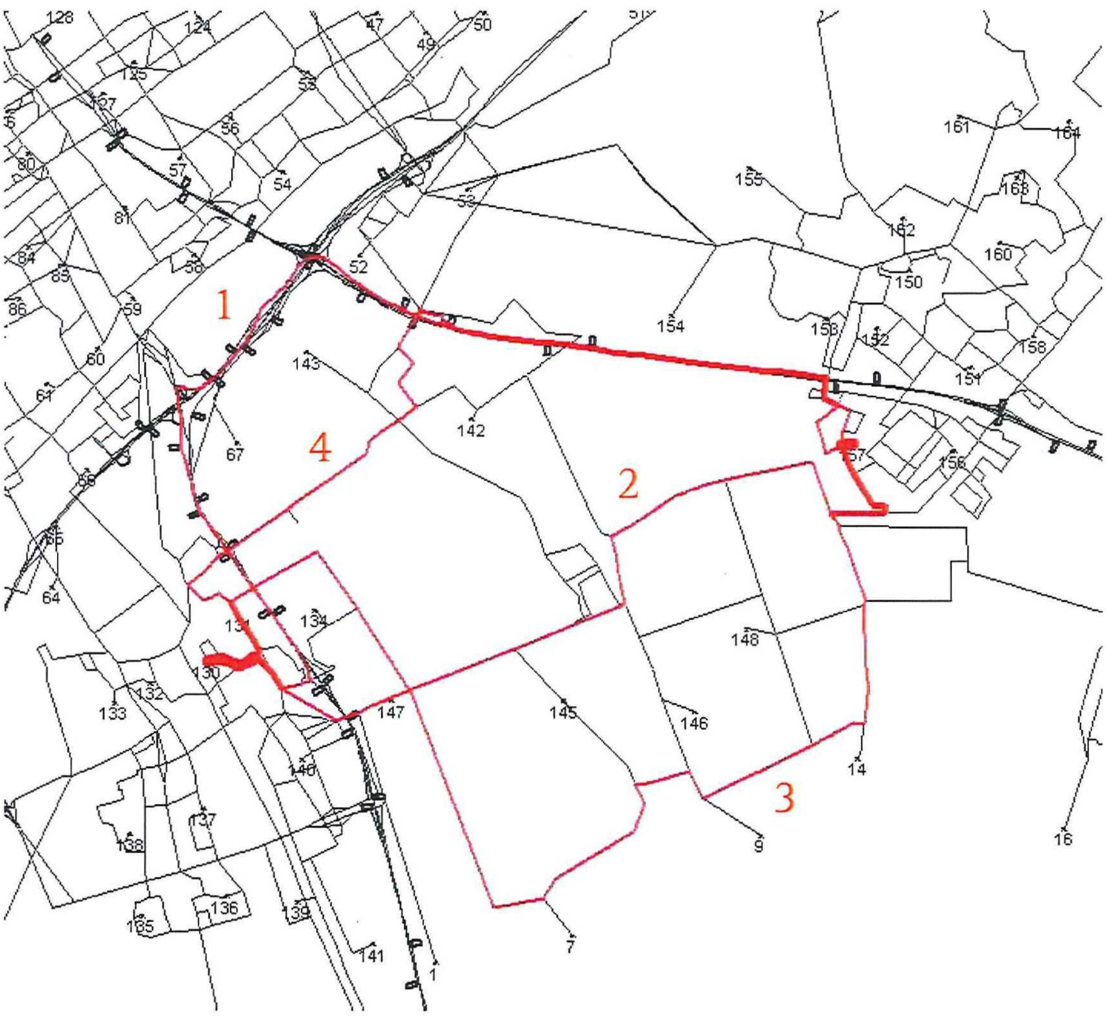

Figure 36 Visualized routes from the route set from Zoetermeer to Delft

For each of these routes, the route safety value can be calculated. This is done using the kilometers of each different road category in the route and multiplying it with the equivalent road category safety factor (example, Table 34). This unsafety factor is the number of traffic injuries due to crashes is the trip is made one million times. Unsafety factors and indices are shown below in Table 34.

Route	1	2	3	4
Unsafety factor	331	551	825	706
Safety index	100	60	40	47

Table 34 Route safety indices for the relation Zoetermeer - Delft

From the model the route shares are available, plotting these shares against the route safety indices can give an impression whether the safest routes are chosen or not. A graph of the routes chosen against the safety of the routes is shown in Figure 37.

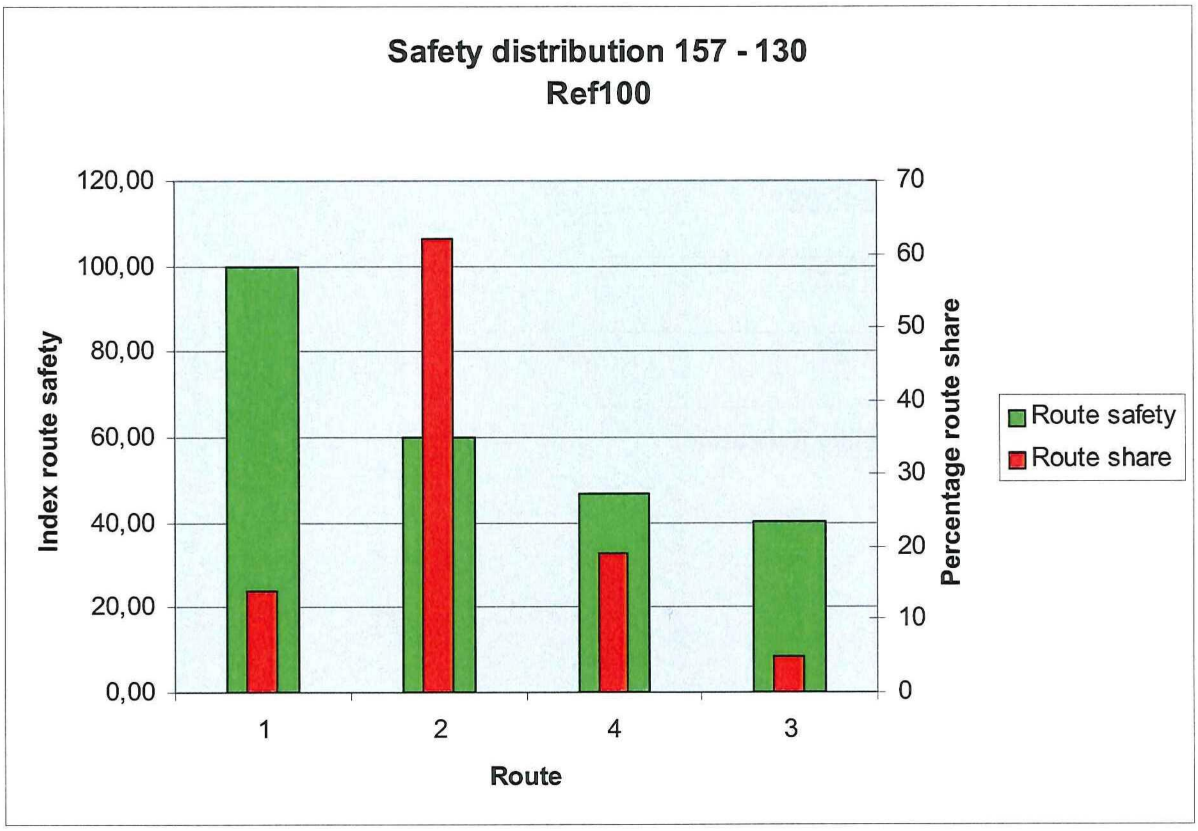

Figure 37 Distribution of route safety and route share for the relation of Zoetermeer and Delft

By multiplying the route shares with the route safety indices, an index can be found for the total OD safety. This way the indices of different PAYD strategies can be more easily compared. The indices for all seven OD relations are shown below in Table 35.

Origin	Destination	Safety Index
157	130	62.08
44	57	54.70
10	156	39.36
30	154	78.66
55	66	84.16
155	127	96.69
140	66	77.26
Total		70,42

Table 35 OD relation safety indices for the reference strategy

Accessibility
For the evaluation of the accessibility in the network several indicators are available. Of main importance are the total number of vehicles that still use the network, the total travel time on the network and the total number of kilometers traveled. The accessibility indicators for the reference strategy are displayed in Table 36.

Indicator	Value
Number of trips	473868
Total travel time	91084
Total number of kilometers traveled	5340221
Average travel time (minutes)	11.53
Average travel distance (km)	11.27

Table 36 Network accessibility indicators

7 Model results

After the case study has been described in chapter 6 and the reference situation has been given, this chapter goes into detail on the model results for the PAYD strategies. Each section holds the results for a different strategy, finally concluding in section 7.8 with the comparison of strategies. The next chapter will go into detail on this studies conclusion.

A remark that needs to be made before going into detail about the modeling results is that an programming error was found in the departure time choice model after the simulation of the different strategies. With little time left this error was corrected and new simulations done. However, with the fixed departure time model, the elastic demand model had far from reached equilibrium after the standard number of iterations and there was no time for new and longer simulations.

Therefore no comparisons are made on the basis of departure time choice and all hypotheses about this subject have not been tested.

7.1 Strategy 1 – Choice for PAYD

In the first strategy – *Choice for PAYD*, drivers are able to choose whether or not they take a PAYD insurance. Only drivers for whom it is financially beneficial are likely to join the PAYD insurance program. These drivers will now pay their premium per kilometer driven, instead of a fixed premium. The price per kilometer will be the average insurance premium (€600) divided by the average kilometrage (15000 km), which leads to 4 cents per kilometer.

7.1.1 Model results

Network safety

The network safety is related to the number of kilometers driven on the network for each different road category. The numbers of kilometers driven per road category is displayed below in Table 37.

Road category	Motorway	Provincial road	Provincial (all traffic)	Urban road	Total
Reference	2649650	635513	619650	1233853	5326190
Choice for PAYD	2602030	620794	609042	1223705	5240167
Change	-1.77%	-2.38%	-1.78%	-0.84%	-1.62%

Table 37 Kilometrages per road category for 'choice for PAYD' in comparison with the reference

It is clear that due to the premium per the total number of kilometers drops. Also, kilometrage on urban roads drops less than average, while other road categories' kilometrages drop more than average. From this may lead that drivers attempt to take shorter routes, to avoid higher premium.

When the 'Choice for PAYD' parameters are split for participants and non-participants, it becomes visible that both groups' kilometrages drop. The effect for participants, however, is much bigger than for non-participants. Again, especially for PAYD participants, it is visible that urban kilometers driven drop less than other kilometers driven. See Table 38. It is strange to see that the kilometrages for the non-participants also change, where traffic conditions should be better. It is estimated that the model has not yet reached equilibrium in the calculation period.

Road category	Motorway	Provincial road	Provincial (all traffic)	Urban road	Total
Non-participants	1601462	328645	311971	577306	2911808
PAYD participants	1000567	292148	297071	646399	2328360
Change Non-participants	-0.28%	-1.11%	-0.60%	-0.07%	-0.37%
Change PAYD participants	-4.07%	-3.78%	-2.98%	-1.52%	-3.14%

Table 38 Kilometrages and changes for participants and non-participants

From the road category kilometrages and safety values the network safety can be calculated. The safety value is presented together with the number of drivers and total kilometrage in Table 39.

	Number of trips	Total vehicle kilometers	Number of traffic injuries
Reference	473869	5326190	2.33
Choice for PAYD	467504	5240168	2.30
Change	-1.34%	-1.62%	-1.14%

Table 39 Changes in traffic safety for 'choice for PAYD' in comparison with Reference

It is notable that the number of traffic injuries in the model decreases less than the total number of trips and the total vehicle kilometers in the network. This means that drivers decide to take relatively unsafe routes. Looking at only kilometrage and the number of trips, it seems confirmed that relatively shorter routes are taken. Looking at safety it is shown that the number of traffic injuries decrease a little more than one percent. Splitting this table for participants and non-participants (Table 40) shows that the effects on trips, kilometers and crashes for PAYD participants are much greater than for non-participants, while earlier statements hold. Also here strange behavior for non-participants in relation with the Reference strategy is found. Where traffic conditions improve and should lead to additional driving, fewer trips are made.

	Number of trips	Total vehicle kilometers	Number of traffic injuries
Non-participants	235376	2911808	1.13
PAYD participants	232128	2328360	1.16

Change Non-participants	-0.21%	-0.37%	-0.20%
Change PAYD participants	-2.46%	-3.14%	-2.03%

Table 40 Traffic safety changes for participants and non-participants in relation with Reference

On the number of traffic injuries from 1997-1999 the reduction of fatalities and injured are calculated and displayed in Table 41. Also the estimated value of statistical life (AVV, 2006) for these crashes is used to calculate benefits from the scheme.

	Crashes old	Reduction (%)	Reduction (Crashes)	Crash cost (€)	Crash cost saved (mln€)
Fatalities	1106	-1.14%	12.6	2,653,462	33.4
Injuries	18952	-1.14%	215.6	280,442	60.5

Table 41 Total crash reduction and value of crash cost saved

In the previous table a monetary value of €93,8 million is given for the total reduction in number of traffic injuries. The benefits are partly for the insurance companies, but furthermore come as a benefit to society. The scheme, however, also costs money. As there is only differentiation to kilometrage, odometer audits are sufficient. With half of the cars insured by PAYD a rough estimation of the costs presented in Table 42

	Number of participants (mln vehicles)	Cost per vehicle (€)	Total cost (mln €)
Implementation costs	3.1	negl	1
Annual costs	3.1	10	31

Table 42 Simple cost calculation for 'choice for PAYD'

If these monetary values were the only costs and benefits involved, it would seem that the yearly benefits outweigh the costs by more than 60 million euros. However, as no cost-benefit analysis is made, it can only be said that this scheme seems profitable for society on basis of investment cost and safety benefits.

Route safety

For route safety the relation between Zoetermeer and Delft is once again taken a closer look at. For the other relations an overview is given. On the relation between Zoetermeer and Delft, it was visible that many drivers did not take the safest route over the motorway, as shown in Figure 38. When looking at Figure 39, a lot more drivers shift to the shortest route, looking at the data, these are mainly PAYD participants.

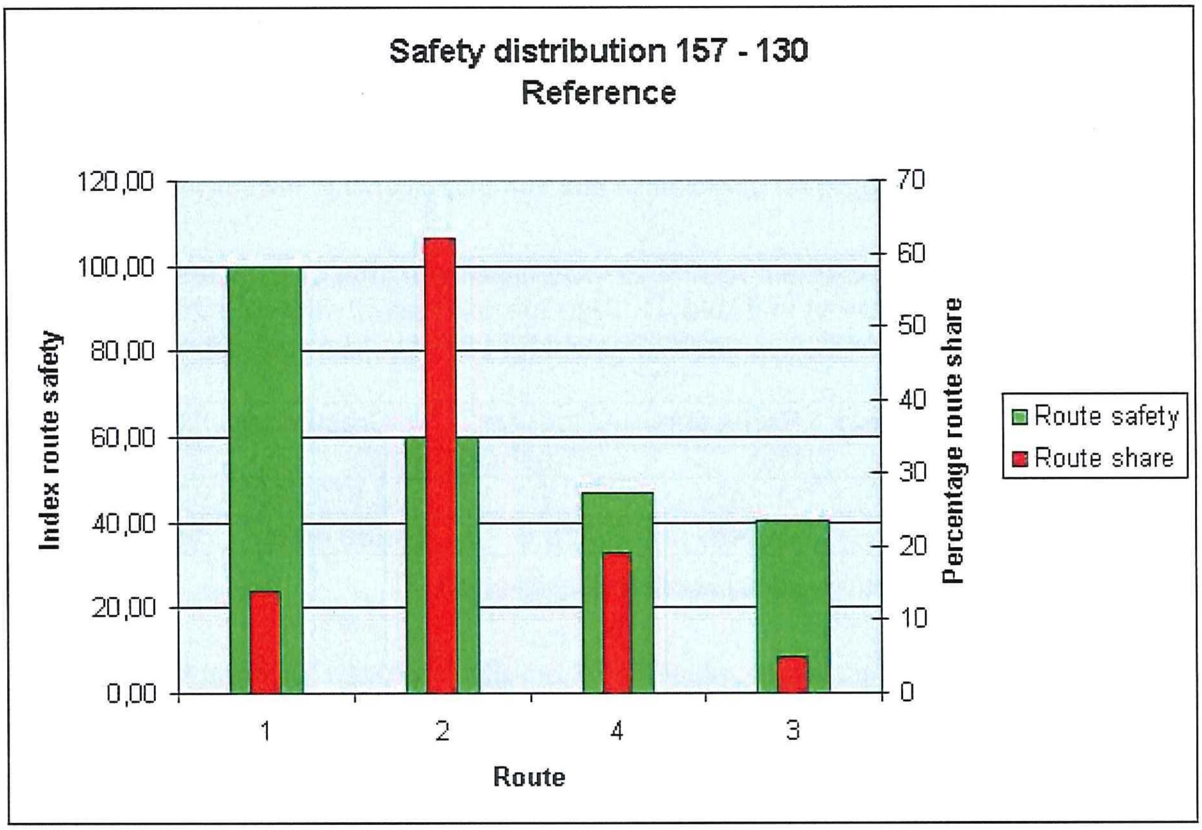

Figure 38 Distribution of route safety and route share for the reference situation

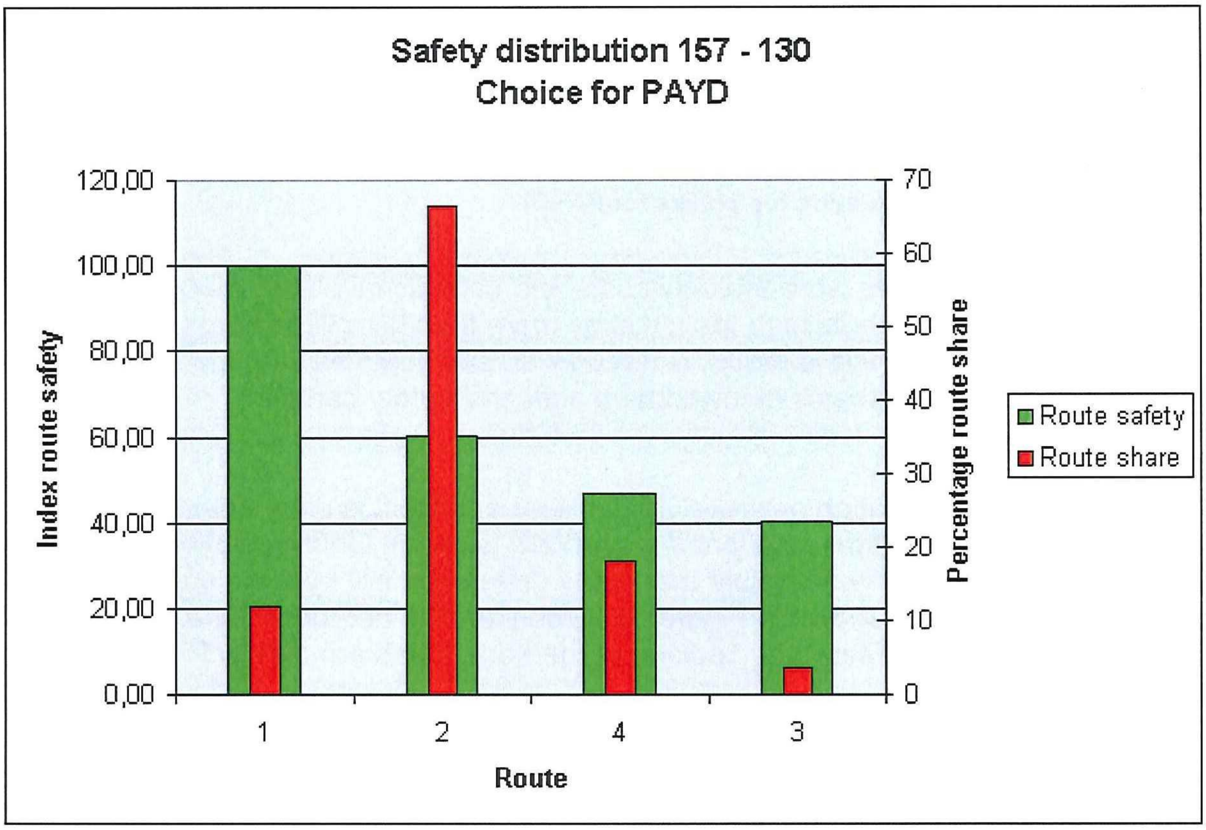

Figure 39 Distribution of route safety and route share

It seems that route 2, the shortest route, is chosen more often than the other routes comparing with the reference strategy. This seems to confirm the statement that drivers tend to take shorter routes when faced with a premium per kilometer. The total safety index decreases a little for the strategy. Overall the 'choice for PAYD' indices are shown below in Table 43.

Origin	Destination	Reference	Choice for PAYD	Change
157	130	62.08	61.73	-0.55%
44	57	54.70	61.20	+11.89%
10	156	39.36	35.76	-9.16%
30	154	78.65	78.11	-0.70%
55	66	84.16	81.42	-3.25%
155	127	96.69	97.12	+0.44%
140	66	77.26	74.18	-3.99%
Total		70,42	69.93	-0.69%

Table 43 Route safety indices compared for Reference and 'Choice for PAYD'

Visible is that the safety of the chosen routes slightly decreases. Only where the shortest route equals the safest route, an increase in traffic safety is seen. But as the total number of trips made decreases (as seen in Table 39), the total level of safety can increase.

Accessibility
For accessibility the number of drivers, number of travel time spent on the network, number of kilometers driven and average travel time and distance are viewed. Comparing 'Choice for PAYD' with the reference situation results are shown in Table 44.

Indicator	Reference	Choice for PAYD	Change
Number of trips	473868	467504	-1.34%
Total travel time	91084	87751	-3.66%
Total number of kilometers traveled	5340221	5253775	-1.62%
Average travel time (minutes)	11.53	11.26	-2.34%
Average travel distance (km)	11.27	11.24	-0.27%

Table 44 Network accessibility indicators

Both average travel time and distance decrease. Where average distance decreases it is clear that shorter routes are taken. As average travel time increases further than average distance, it can be assumed that the level of congestion decreases.

7.1.2 Hypotheses revisited

The hypotheses that were described in section 4.4 are revisited after the model results are described. Short-listed the estimated effects for 'Choice for PAYD' were:
Limited reduction in trips for PAYD participants
Larger reduction of total kilometers driven by PAYD participants, because shorter routes are taken
Non-participants will take the motorway more often
Non-participants will start driving more

The hypotheses for the PAYD participants seem to be confirmed. For the non-participants, however, very little response is seen. However, kilometrages and number of trips for non-participants go down instead of up. Even though the effect is small, this is different than thought beforehand.

7.2 Strategy 2 – PAYD for all drivers

PAYD for all drivers is in many ways equal to the first strategy, only in this case all drivers are forced by legislation to have PAYD insurance for their car. The insurance premium per kilometer is once again 4 cents.

7.2.1 Model results

Network safety
The network safety is related to the number of kilometers driven on the network for each different road category. The numbers of kilometers driven per road category is displayed below in Table 37.

Road category	Motorway	Provincial road	Provincial (all traffic)	Urban road	Total
Reference	2649650	635513	619650	1233853	5326190
PAYD for all drivers	2553143	616985	602855	1218168	5174329
Change	-3.64%	-2.92%	-2.71%	-1.27%	-2.85%

Table 45 Kilometrages per road category for 'PAYD for all drivers' in comparison with the reference

Clear is that the number of kilometers driven greatly drops. Also the kilometrage on urban roads drop less than average, while other road categories' kilometrages drop more than average. This may indicate that drivers attempt to take shorter routes.

From the road category kilometrages and safety values the network safety can be calculated. The safety value is presented together will the number of drivers and total kilometrage in Table 39.

	Number of trips	Total vehicle kilometers	Number of traffic injuries
Reference	473869	5326190	2.33
PAYD for all drivers	463553	5174329	2.29
Change	-2.18%	-2.85%	-1.76%

Table 46 Changes in traffic safety for 'PAYD for all drivers' in comparison with the reference

Total number of traffic injuries decreases less than total number of trips. This indicates that drivers drive on relatively unsafe routes, or at least more unsafe routes than during the reference. As number of vehicle kilometers drops further than number of trips, another sign is found that drivers take shorter routes. As shorter routes often use less safe road categories, it seems likely that drivers are taking shorter routes to avoid paying premium.

From the reduction in crashes the reduction in total fatalities and injuries is calculated. These reductions will than be monetarized by use of the value of statistical life. See Table 47.

	Crashes old	Reduction (%)	Reduction (Crashes)	Crash cost (€)	Crash cost saved (mln€)
Fatalities	1106	-1.76%	19.5	2,653,462	51.8
Injuries	18952	-1.76%	334.5	280,442	93.8

Table 47 Total crash reduction and value of statistical life

The last table shows 145,6 million euros of crash costs are saved by 'PAYD for all drivers'. However, the PAYD scheme implementation also costs money. As only kilometrage is taken into consideration in this scheme, odometer audits would suffice. The costs for such a scheme are displayed in Table 48.

	Number of participants (mln vehicles)	Cost per vehicle (€)	Total cost (mln €)
Implementation costs	6.3	Negl	2
Annual costs	6.3	10	63

Table 48 Simple cost calculation for 'PAYD for all drivers'

Although no full cost-benefit analysis is made, the difference of 80 million euro between the yearly crash savings and scheme costs may give an indication. The main benefits, however, will be for society as a whole and not the insurance companies or the single driver with PAYD.

Route safety

For the analysis of route safety another look is taken at the relation between Zoetermeer and Delft. At first many drivers did not take the safest route but instead of that the shortest route. Displayed below in Figure 40 is the distribution of route safety and route share for 'PAYD for all drivers'.

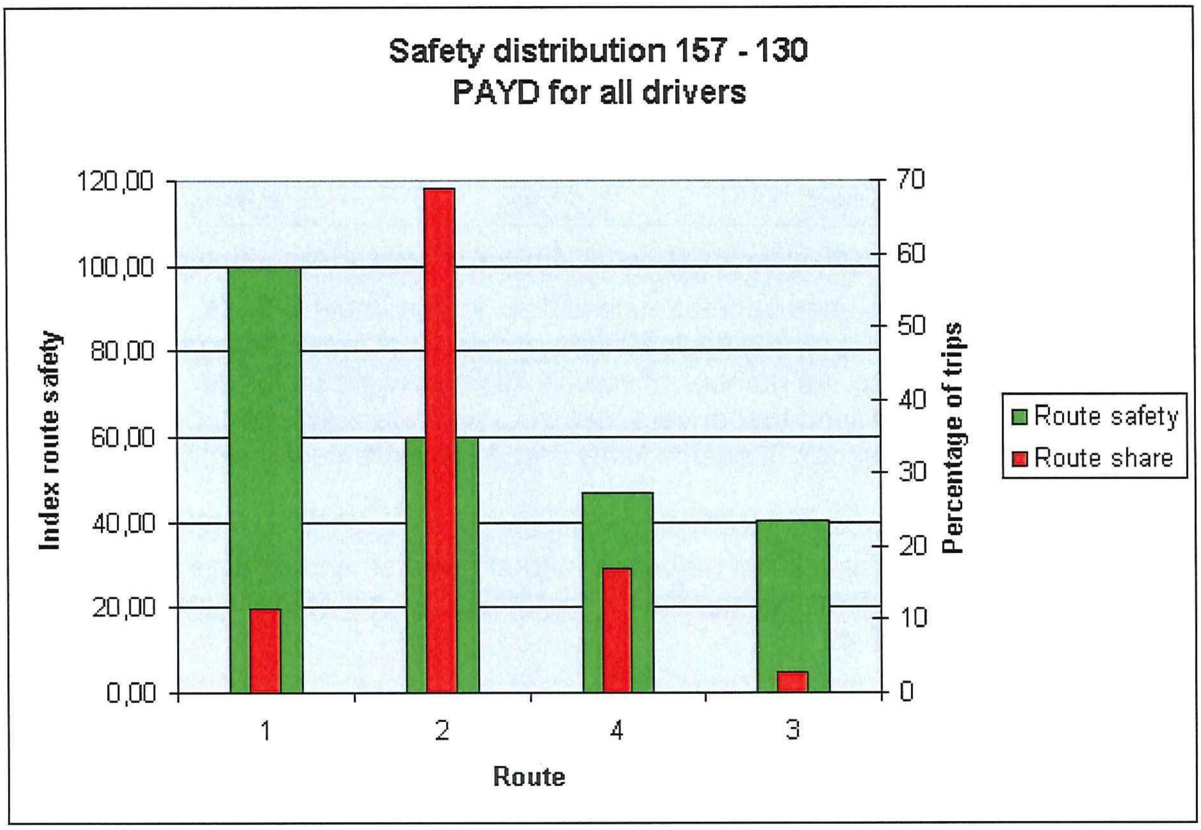

Figure 40 Distribution of route safety and route share

Once more drivers take the shortest, and relatively unsafe, route. This seems to confirm the statement that drivers will take shorter routes in order to avoid premium. The difference with the reference situation is displayed below in Table 49.

Route	1	2	4	3
Route safety	331	551	706	825
Route share Reference	13.81%	62.12%	19.11%	4.96%
Route share 'PAYD for all drivers'	11.4%	68.93%	16.94%	2.73%

Table 49 Route safety and route share for Zoetermeer to Delft

When looking at the other OD relations (Table 50), the overall impression remains that safety per OD relation slightly drops, indicating that drivers take less safe, shorter routes to reach their destination. The total safety index for these relations drops quite much for this strategy, this decrease in route safety will be offset however, by the decrease in number of trips made as showed in the part about 'Network safety' (Table 39).

Origin	Destination	Reference	PAYD for all drivers	Change
157	130	62.07	61.84	-0.37%
44	57	54.70	55.29	+1.09%
10	156	39.36	34.02	-13.56%
30	154	78.65	77.31	-1.71%
55	66	84.15	80.83	-3.94%
155	127	96.69	96.94	+0.26%
140	66	77.25	73.58	-4.76%
Total		70,41	+68.54	-2.65%

Table 50 Route safety indices compared for Reference and 'PAYD for all drivers'

Accessibility
The accessibility indicators for 'PAYD for all drivers' are displayed below in Table 51.

Indicator	Reference	PAYD for all drivers	Change
Number of trips	473868	463553	-2.18%
Total travel time	91084	86692	-4.82%
Total number of kilometers traveled	5340221	5187993	-2.85%
Average travel time (minutes)	11.53	11.22	-2.68%
Average travel distance (km)	11.27	11.19	-0.69%

Table 51 Network accessibility indicators

Once again the resources indicate that shorter routes are taken. This time as the average travel distance decreases slightly. As average travel time decreases further, this would indicate that congestion is alleviated somewhat.

7.2.2 Hypotheses revisited

Here we revisit the hypotheses that were drawn for this strategy and try to explain differences. A short list of the hypotheses:

- Total number of trips will be reduced due to increased costs
- Drivers will take shorter routes, because these are cheaper

Hypotheses of the 'PAYD for all drivers strategy are confirmed. Drivers will start driving less and take shorter routes to avoid the higher premium.

7.3 Strategy 3 – Road category differentiation

Strategies 3 to 5 are all implemented as a consumer option. In strategy 3 – *Road category differentiation*, the kilometer charge is also differentiated towards road category. This means that motorways will become cheaper and urban roads more expensive.

7.3.1 Model results

Network safety

The network safety is related to the number of kilometers driven per road category. For the 'Road category differentiation' strategy the kilometers driven are presented in Table 37 below.

Road category	Motorway	Provincial road	Provincial (all traffic)	Urban road	Total
Reference	2649650	635513	619650	1233853	5326190
Road category differentiation	2707974	633535	596123	1192783	5316754
Change	2.23%	-0.38%	-3.86%	-3.35%	-0.18%

Table 52 Kilometrages per road category for 'Road category differentiation' in comparison with the reference

The first number that catches the eye is the increase in motorway kilometers. While the kilometers driven for all other categories decrease or remain equal, the kilometers driven on the motorway increase. As the motorway in this strategy is the cheapest road category, many more PAYD participants will chose this road. When splitting these numbers for participants and non-participants the following table can be created (Table 53).

Road category	Motorway	Provincial road	Provincial (all traffic)	Urban road	Total
Non-participants	1624725	332056	309581	571687	2930865
PAYD participants	1083249	301479	286542	621096	2385889
Change non-participants	1.17%	-0.08%	-1.36%	-1.05%	0.28%
Change PAYD participants	3.86%	-0.71%	-6.42%	-5.37%	-0.75%

Table 53 kilometrages and changes to reference for participants and non-participants

From this table it is found that PAYD participants start driving slightly less kilometers, while non-participants start driving a little more. For participants a clear route choice towards the motorway from the provincial (all traffic) and urban roads is made. This may indicate that drivers choose a cheaper option by taking the motorway. It is surprising to see that non-participants follow the same behavior. Even though motorways become more crowded, non-participants will start using the motorway more often, as was concluded before, the model has probably not yet reached equilibrium with the current set of iterations, explaining these strange results.

From the road category kilometrages and the safety values the network safety can be calculated. The safety value is presented together with the number of drivers and total kilometrage in Table 39.

	Number of trips	Total vehicle kilometers	Number of traffic injuries
Reference	473869	5326190	2.33
Road category differentiation	470568	5316754	2.26
Change	-0.70%	-0.18%	-2.56%

Table 54 Changes in traffic safety for 'road category differentiation' in comparison with Reference

The main change when aggregated for the entire network is in the number of traffic injuries. The number of trips decreases slightly but the total number of vehicle kilometers is almost equal. This may indicate that drivers take safer routes. Splitting these values per user group results in the values in Table 40.

	Number of trips	Total vehicle kilometers	Number of traffic injuries
Non-participants	236106	2930865	1.14
PAYD participants	234463	2385889	1.13
Change non-participants	0.10%	0.28%	-0.74%
Change PAYD participants	-1.48%	-0.75%	-4.30%

Table 55 Traffic safety changes for participants and non-participants in relation with Reference

It is clear that the reactions from PAYD participants are the most important in reducing the total number of traffic injuries. Once again the number of traffic injuries reduces more than the number of trips or kilometers, indicating safer routes. As the total kilometers drop less than the number of trips, longer routes are taken generally more often. For non-participants, the number of trips increases slightly. And as the kilometers increase a little more, this indicates that the extra trips are mainly longer trips.

When the safety improvements are combined with the old crash data, a reduction in number of traffic injuries can be calculated. Also using the costs of a crash will allow calculating the savings on crash costs.

	Crashes old	Reduction (%)	Reduction (Crashes)	Crash cost (€)	Crash cost saved (mln€)
Fatalities	1106	2.56%	28.3	2,653,462	75.0
Injuries	18952	2.56%	484.3	280,442	135.8

Table 56 Total crash reduction and value of crash cost saved

Reducing on average a total of 28 fatalities and 484 traffic injuries will lead to a welfare saving of 211 million euros. These costs are offset to the costs of implementing and running the 'Road category differentiation' strategy (Table 42). As road category is of importance, the location of the vehicle needs to be known. Therefore GPS is necessary to get all required data.

	Number of participants (mln vehicles)	Cost per vehicle (€)	Total cost (mln €)
Implementation costs	3.1	100	310
Annual costs	3.1	75	236

Table 57 Simple cost calculation for 'Road category differentiation'

Because of the costs of GPS, the costs of the 'road category differentiation' strategy outweigh the annual benefits. Including the implementation costs there will be no benefit. However, no full cost-benefit analysis is made, so no real conclusions can be drawn on the basis of these costs.

Route safety
The relation between Zoetermeer and Delft is once more viewed in detail. Now that the premium is differentiated to road category, it is expected that safest routes are used more often. Looking at Figure 41 and Table 58 show that this is the case. Though there are still more drivers to take the shortest route, drivers have shifted to the safest route.

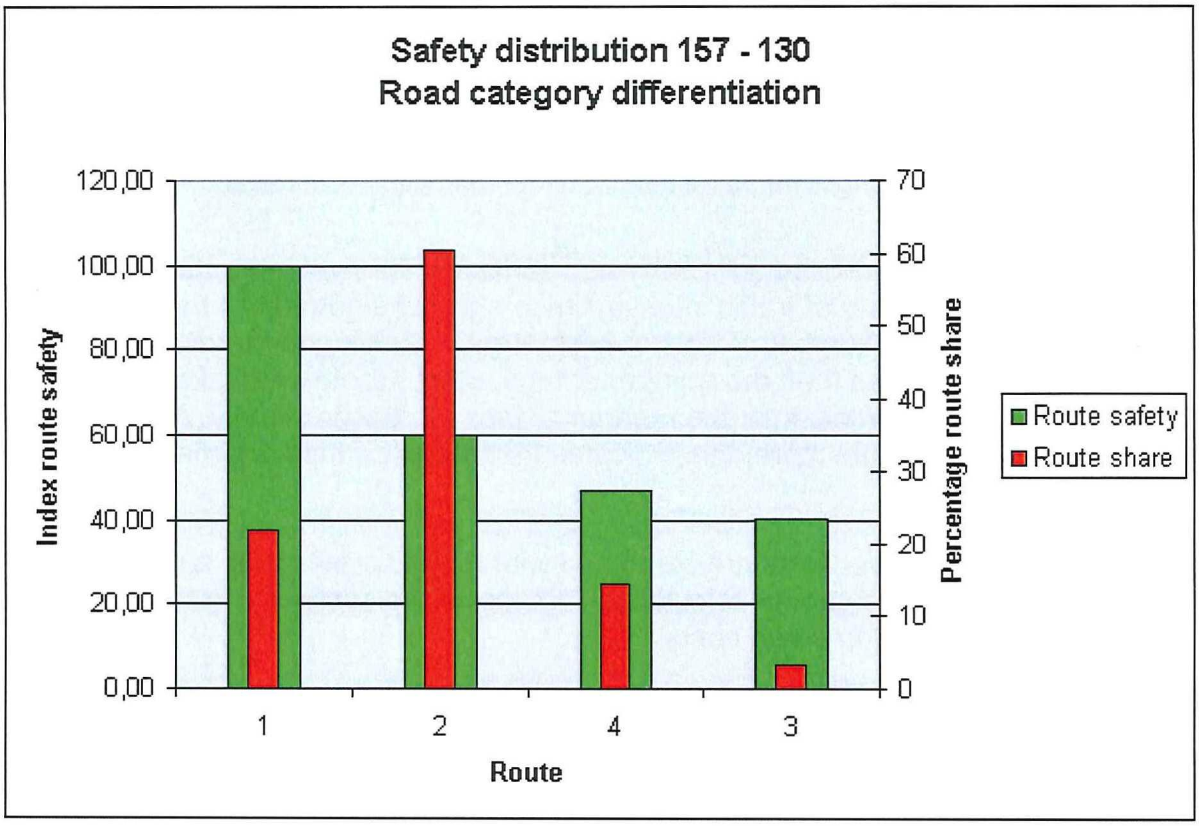

Figure 41 Distribution of route safety and route share

Route	1	2	4	3
Route safety	331	551	706	825
Route share Reference	13.81%	62.12%	19.11%	4.96%
Route share 'Road category differentiation'	21.74%	60.39%	14.5%	3.38%

Table 58 Route safety and route share for Zoetermeer to Delft

The behavior of changing to the safest route should also be visible with the other OD relations that are tested in the network. Results of the safety indices are shown below in Table 43. As the safety indices for all relations increase to some or more extend, it is clear that the safest route is chosen more often throughout the network.

Origin	Destination	Reference	Road category differentiation	Change
157	130	62.08	66.17	+6.60%
44	57	54.70	55.56	+1.58%
10	156	39.36	55.75	+41.64%
30	154	78.65	79.33	+0.86%
55	66	84.16	91.14	+8.30%
155	127	96.69	97.37	+0.70%
140	66	77.26	82.71	+7.05%
Total		70,42	75.43	+7.13%

Table 59 Route safety indices compared for Reference and 'Road category differentiation'

Accessibility
For accessibility the number of drivers, total travel time spent and the number of kilometers driven is viewed. When the 'Road category differentiation' strategy is compared with the Reference, the following results are found (Table 60).

Indicator	Reference	Road category differentiation	Change
Number of trips	473868	470567	-0.70%
Total travel time	91084	91366	+0.31%
Total number of kilometers traveled	5340221	5330728	-0.18%
Average travel time (minutes)	11.53	11.65	+1.04%
Average travel distance (km)	11.27	11.33	+0.52%

Table 60 Network accessibility indicators

In this strategy it is clear by looking at the average travel distance that longer routes are taken. As average travel time increases even more, this would indicate that congestion increases as well.

7.3.2 Hypotheses revisited

Short-listed hypotheses for 'Road category differentiation':

- PAYD participants are more likely to use the motorway instead of other roads
- Total number of trips for PAYD participants will decrease due to increased travel cost
- Non-participants will increase the number of trips
- Non-participants will change routes from the motorway in order to avoid increased congestion.

The model confirms the hypotheses about PAYD participants. For non-participants, however, only the increase of trips is visible. The non-participants are just like the PAYD participants taking the motorway more often.

7.4 Strategy 4 – Time of day differentiation

The *time of day differentiation* strategy involves increased prices for nighttime driving. The price for nighttime driving is multiplied by 1.7 times the daytime pricing.

As no conclusions are drawn for departure time choice, little extra information is expected from this strategy. It will be presented however, to indicate the differences because of another premium per kilometer.

7.4.1 Model results

Network safety

In our network safety model, the input is the number of kilometers that is driver per road category. For the 'Time of day differentiation' strategy, these kilometrages are displayed below (Table 61).

Road category	Motorway	Provincial road	Provincial (all traffic)	Urban road	Total
Reference	2649650	635513	619650	1233853	5326190
Time of day differentiation	2612654	631606	616864	1235054	5282266
Change	-1.37%	-0.68%	-0.52%	0.08%	-0.83%

Table 61 Kilometrages per road category for 'Time of day differentiation' in comparison with the Reference

First of all, it seems the case that drivers are attempting to take shorter routes. This is the result from the motorway kilometers dropping furthest and urban kilometers increasing. More may become clear when results are split for PAYD participants and non-participants (Table 53).

Road category	Motorway	Provincial road	Provincial (all traffic)	Urban road	Total
Non-participants	1600871	332679	314511	579999	2920758
PAYD participants	1011783	298927	302352	655055	2361509
Change Non-participants	-0.32%	+0.11%	+0.21%	+0.39%	-0.06%
Change PAYD participants	-2.99%	-1.55%	-1.26%	-0.20%	-1.76%

Table 62 kilometrages and changes to reference for participants and non-participants

This shows that there is hardly any change in behavior for non-participants. For PAYD participants on the other hand, there is a sharp decrease in total kilometers driven. This is especially the case for the motorway and goes to any reaction for urban roads.

From the road category kilometrages the network safety is calculated. This value is shown in Table 39.

	Number of trips	Total vehicle kilometers	Number of traffic injuries
Reference	473869	5326190	2.33
Time of day differentiation	470955	5282266	2.33
Change	-0.61%	-0.83%	-0.17%

Table 63 Changes in traffic safety for 'time of day differentiation' in comparison with Reference

As total kilometrage decreases more than the number of trips, it seems likely that shorter routes are taken. As shorter routes often use the more dangerous urban roads, this seems confirmed, as the reduction in crashes being smaller than the reduction of trips. Table 40 shows the data split for PAYD participants and non-participants.

	Number of trips	Total vehicle kilometers	Number of traffic injuries
Non-participants	235954	2920758	1.14
PAYD participants	235000	2361509	1.18
Change non-participants	+0.03%	-0.06%	+0.30%
Change PAYD participants	-1.26%	-1.76%	-0.63%

Table 64 Traffic safety changes for participants and non-participants in relation with Reference

For the non-participants there is again little reaction, but even so there is a slight increase in number of trips and crashes. As the total kilometrage goes slightly down, this may be because shorter, less safe routes are chose. The same holds for the PAYD participants. As kilometrage goes down further than number of trips, relatively shorter routes are chosen. And as the number of traffic injuries goes down even less, the routes that are chosen are relatively less safe. The only reason that the number of traffic injuries does go down is likely found because the total number of trips goes down as well.

These safety improvements are once more combined with historic crash data and crash cost to calculate the reduction is crashes and monetary value of these reductions (Table 41).

	Crashes old	Reduction (%)	Reduction (Crashes)	Crash cost (€)	Crash cost saved (mln€)
Fatalities	1106	0.17%	1.9	2,653,462	5.1
Injuries	18952	0.17%	33.0	280,442	9.3

Table 65 Total crash reduction and value of crash cost saved

At is clear that with the small reduction in safety, also the number of reduced crashes and crash cost savings are relatively low. The total savings would mount to 14,4 million euros. Having to implement the scheme will have equal costs to other choice participation levels with GPS. So the costs would amount to 310 million installment costs and 236 million annual costs. Therefore the benefits of the scheme would by far not measure up to the costs. However, no full cost benefit analysis is made in this study.

Route safety
As time of day differentiation has only secondary effects on route choice, it is likely that drivers will mostly behave in reaction to the kilometer price differentiation. This means that mostly the shortest routes will be taken. Looking at Figure 42 and Table 58 this seems indeed the case. Drivers shift from all routes to the shortest route.

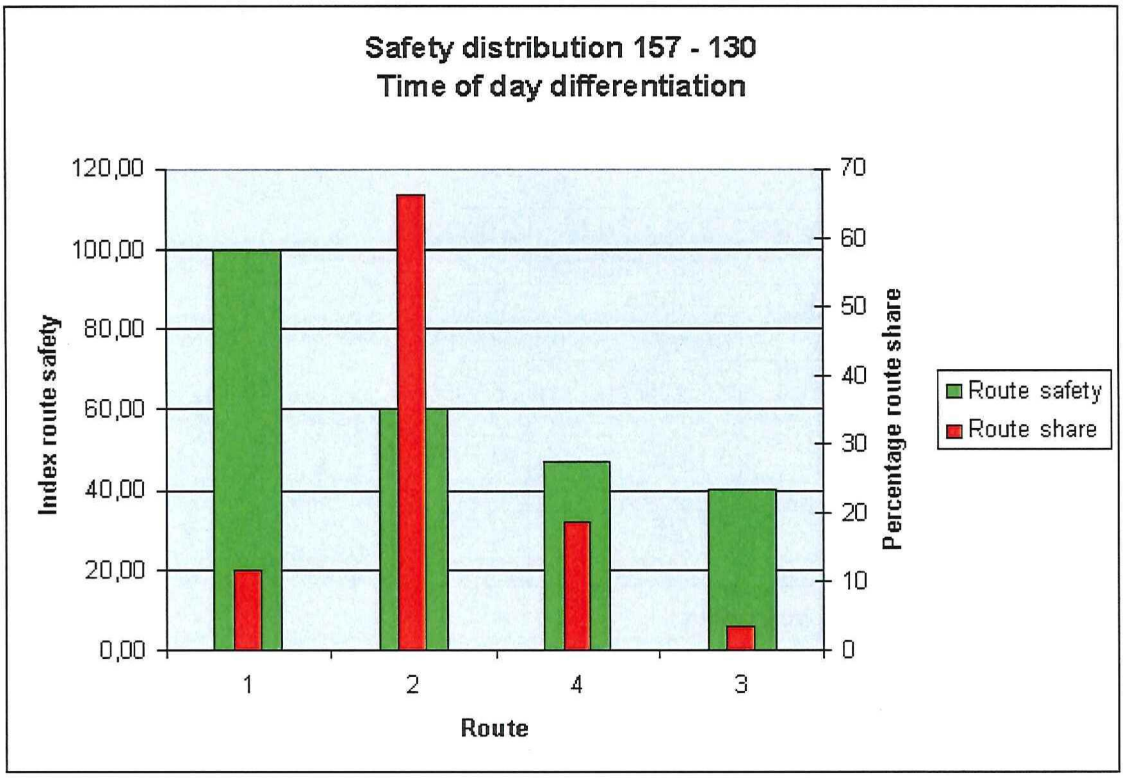

Figure 42 Distribution of route safety and route share

Route	1	2	4	3
Route safety	331	551	706	825
Route share Reference	13.81%	62.12%	19.11%	4.96%
Route share 'Road category differentiation'	11.78%	66.21%	18.49%	3.52%

Table 66 Route safety and route share for Zoetermeer to Delft

When this behavior is tested for other OD relations, the same behavior is found. The responses are displayed in Table 43.

Origin	Destination	Reference	Road category differentiation	Change
157	130	62.08	61.64	-0.71%
44	57	54.70	54.29	-0.76%
10	156	39.36	35.95	-8.67%
30	154	78.65	77.79	-1.10%
55	66	84.16	81.76	-2.86%
155	127	96.69	97.18	+0.50%
140	66	77.26	74.26	-3.88%
Total		70,42	68.98	-2.04%

Table 67 Route safety indices compared for Reference and 'Time of day differentiation'

Accessibility
For accessibility the number of drivers, total travel time spent and the number of kilometers driven is viewed. When the 'Time of day differentiation' strategy is compared with the Reference, the following results are found (Table 68).

Indicator	Reference	Time of day differentiation	Change
Number of trips	473868	470954	-0.61%
Total travel time	91084	90259	-0.91%
Total number of kilometers traveled	5340221	5296028	-0.83%
Average travel time (minutes)	11.53	11.50	-0.27%
Average travel distance (km)	11.27	11.25	-0.22%

Table 68 Network accessibility indicators

It is visible that the average travel time on the network decreases a little more than the average travel distance, this indicates that there is a little less congestion on the network, due to the fact that the motorways are used less.

7.4.2 Hypotheses revisited

As no conclusions are drawn for departure time choice, the only effects that can be measured are the effects on total number of vehicles and route choice. The hypotheses for these were:

- PAYD participants are likely to drive less
- PAYD participants will choose shorter routes to avoid higher premium
- Non-participants may show opposite behavior

From the results it is clear that PAYD participants indeed start driving less and choose shorter routes. Also, non-participants start to drive slightly more than before. On route choice the effects for non-participants are too small to give acquaintance to.

7.5 Strategy 5 – Full differentiation

In the *full differentiation* the price structure is differentiated for all the previously used aspects. This means that the price is differentiated to distance, time and location. It is expected that differentiating the price structure for all these factors will lead to large network effects.

7.5.1 Model results

Network safety

The network safety is related to the number of kilometers driven per road category. For the 'Full differentiation' strategy the kilometers driven are presented in Table 37 below.

Road category	Motorway	Provincial road	Provincial (all traffic)	Urban road	Total
Reference	2649650	635513	619650	1233853	5326190
Full differentiation	2700765	633818	597348	1193122	5311213
Change	+1.95%	-0.34%	-3.66%	-3.32%	-0.29%

Table 69 Kilometrages per full for 'Full differentiation' in comparison with the reference

Special in this strategies result is are the motorway kilometers, which as only road category kilometrage increases. Especially the urban and provincial road (all traffic) kilometers drop much to show a slight overall decrease in vehicle kilometers. Splitting the table for PAYD participants and non-participants will allow going into more detail Table 53).

Road category	Motorway	Provincial road	Provincial (all traffic)	Urban road	Total
Non-participants	1621606	332148	309779	571029	2927266
PAYD participants	1079158	301669	287569	622092	2383948
Change Non-participants	+0.97%	-0.05%	-1.30%	-1.16%	+0.16%
Change PAYD participants	+3.47%	-0.65%	-6.08%	-5.22%	-0.83%

Table 70 kilometrages and changes to reference for participants and non-participants

From this table it is found that PAYD participants start driving slightly less kilometers, while non-participants start driving a little more. For participants a clear route choice towards the motorway from the provincial (all traffic) and urban roads is made. This may indicate that drivers choose a cheaper option by taking the motorway. It is surprising to see that non-participants follow the same behavior. Even though motorways become more crowded, non-participants will start using the motorway more often. Again this is an indication that the model has not completely reached equilibrium.

From the road category kilometrages and the safety values the network safety can be calculated. The safety value is presented together with the number of drivers and total kilometrage in Table 39.

	Number of trips	Total vehicle kilometers	Number of traffic injuries
Reference	473869	5326190	2.33
Full differentiation	470135	5311213	2.27
Change	-0.79%	-0.29%	-2.61%

Table 71 Changes in traffic safety for 'Full differentiation' in comparison with Reference

The main change when aggregated for the entire network is in the number of traffic injuries. The number of trips decreases slightly but the total number of vehicle kilometers is almost equal. This may indicate that drivers take safer routes. Splitting these values per user group results in the values in Table 40.

	Number of trips	Total vehicle kilometers	Number of traffic injuries
Non-participants	235804	2927266	1.13
PAYD participants	234331	2383948	1.14
Change non-participants	-0.03%	+0.16%	-0.86%
Change PAYD participants	-1.54%	-0.83%	-4.28%

Table 72 Traffic safety changes for participants and non-participants in relation with Reference

It is clear that the reactions from PAYD participants are the most important in reducing the total number of traffic injuries. Once again the number of traffic injuries reduces more than the number of trips or kilometers, indicating safer routes. As the total kilometers drop less than the number of trips, longer routes are taken generally more often. For non-participants, the number of trips remains almost equal. And as the kilometers increase a little more, this indicates that the extra trips are mainly longer trips.

In Table 41 the crash reduction is combined with historic data of crashes and the economic cost of a crash. With this the total reduction of crashes and the savings on crash cost are determined.

	Crashes old	Reduction (%)	Reduction (Crashes)	Crash cost (€)	Crash cost saved (mln€)
Fatalities	1106	2.61%	28.8	2,653,462	76.5
Injuries	18952	2.61%	493.7	280,442	138.5

Table 73 Total crash reduction and value of crash cost saved

The reduction of 28 fatalities and 493 traffic injuries will lead to a total saving of 215 million euros. A simple cost calculation for GPS devices for the PAYD strategy results in an implementation cost of 310 million euro and an annual cost of 236 million euro. The benefits shown here are not directly enough to cover the costs of implementation and annual costs, however, no full cost benefit analysis is made, so these values are only an indication of costs and benefits involved.

Route safety

The relation between Zoetermeer and Delft is once more viewed in detail. Now that the premium is differentiated to road category, it is expected that safest routes are used more often. Looking at Figure 41 and Table 58 show that this is the case. Though there are still more drivers to take the shortest route, drivers have shifted to the safest route. Time of day differentiation that is also included is not likely to have primary effects on route choice.

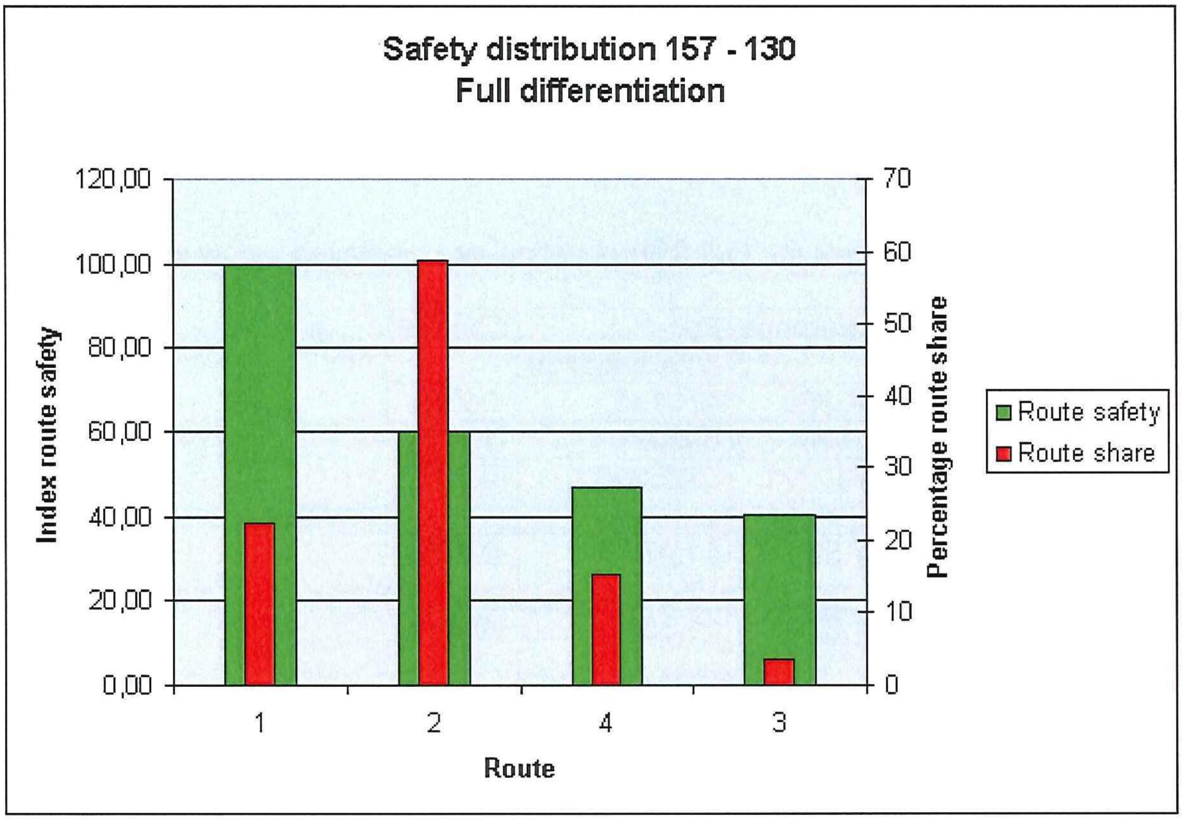

Figure 43 Distribution of route safety and route share

Route	1	2	4	3
Route safety	331	551	706	825
Route share Reference	13.81%	62.12%	19.11%	4.96%
Route share 'Full differentiation'	22.41%	58.8%	15.2%	3.58%

Table 74 Route safety and route share for Zoetermeer to Delft

It is likely that the same behavior of changing routes is visible for other OD relations on the network. The safety indices of all chosen relations are shown below in Table 43. As the safety indices for all relations increase to some or more extend, it is clear that the safest route is chosen more often throughout the network.

Origin	Destination	Reference	Full differentiation	Change
157	130	62.08	66.30	+6.80%
44	57	54.70	57.44	+5.00%
10	156	39.36	56.22	+42.83%
30	154	78.65	79.50	+1.07%
55	66	84.16	90.84	+7.94%
155	127	96.69	97.72	+1.07%
140	66	77.26	80.38	+4.05%
Total		70,42	75.49	+7.20%

Table 75 Route safety indices compared for Reference and 'Full differentiation'

Accessibility
The accessibility indicators for 'Full differentiation' are displayed below in Table 76.

Indicator	Reference	Full differentiation	Change
Number of trips	473868	470135	-0.79%
Total travel time	91084	89902	-1.30%
Total number of kilometers traveled	5340221	5325248	-0.28%
Average travel time (minutes)	11.53	11.47	-0.49%
Average travel distance (km)	11.27	11.33	+0.51%

Table 76 Network accessibility indicators

For this strategy the average travel distance increases, indicating longer routes taken. As the average travel time decreases, it can be estimated that congestion is reduced. Apparently, the chosen longer routes did not have much congestion before the PAYD strategy.

7.5.2 Hypotheses revisited

A short list of the hypotheses for 'Full differentiation' are presented here:

- Fewer trips made by PAYD participants
- PAYD participants will relatively more choose the cheap motorway routes
- Non-participants are likely to show opposite behavior

In total there are fewer trips made by PAYD participants in the network, where the number of trips is reduced by a little less than one percent. Also, the number of vehicle kilometers on the motorway increases, while other vehicle kilometers decrease, which indicates that routes over the motorway are chosen more often.

For non-participants the reactions are less clear. The amount of driving is about the same and for route choice it seems to be that the motorways are used more often, just as with the PAYD participants.

7.6 Strategy 6 – Full differentiation (obligatory)

The sixth strategy – *Full differentiation (obligatory)* – is equal to the fifth strategy, with the only difference being that in this strategy all drivers will have PAYD insurance. This may happen if the government decides on legislation for PAYD. The price structure of this strategy is equal to that of strategy 5.

7.6.1 Model results

Network safety

For the first indication of the network safety the kilometrages per different road category are used. The kilometrages resulting from the 'full differentiation (obligatory)' strategy are shown below in Table 37.

Road category	Motorway	Provincial road	Provincial (all traffic)	Urban road	Total
Reference	2649650	635513	619650	1233853	5326190
Full differentiation (obligatory)	2719696	615971	569664	1149838	5238500
Change	2.64%	-3.08%	-8.07%	-6.81%	-1.65%

Table 77 Kilometrages per road category for 'Full differentiation (obligatory)' in comparison with the reference

It is clear that there is a great reaction to the 'full differentiation (obligatory)' strategy. Both the total kilometrage drops and there seems to be route choice towards the motorway routes. This increase in motorway kilometers comes mostly from the urban roads and provincial (all traffic) roads. That indicates that drivers are taking safer routes in order to avoid higher premium.

From the road category kilometrages and safety values the network safety can be calculated. The safety value is presented together will the number of drivers and total kilometrage in Table 39.

	Number of trips	Total vehicle kilometers	Number of traffic injuries
Reference	473869	5326190	2.33
Full differentiation (obligatory)	462352	5238500	2.20
Change	-2.43%	-1.65%	-5.68%

Table 78 Changes in traffic safety for 'Full differentiation (obligatory)' in comparison with the reference

Here as well great effects are visible. As the number of kilometers driven decreases less than the number of trips, this indicates that the trips that are made are longer. As the number of traffic injuries decrease more than the number of trips, the trips made are safer than before. With a total reduction of more than 5% of the crashes it will be interesting to see the reductions in numbers of crashes, which are displayed in Table 47.

	Crashes old	Reduction (%)	Reduction (Crashes)	Crash cost (€)	Crash cost saved (mln€)
Fatalities	1106	-5.68	62.8	2,653,462	166.6
Injuries	18952	-5.68	1075.6	280,442	301.7

Table 79 Total crash reduction and value of statistical life

With a reduction of on average more than 60 fatalities and more than a 1000 traffic injuries, the total safety value of the scheme sums up to 468 million euros. As the scheme also costs money, these values will be displayed in Table 48. For the implementation of the scheme GPS will be necessary, as driver location will have to be known for the differentiation to road category.

	Number of participants (mln vehicles)	Cost per vehicle (€)	Total cost (mln €)
Implementation costs	6.3	100	630
Annual costs	6.3	75	473

Table 80 Simple cost calculation for 'Full differentiation (obligatory)'

For this simple example of costs and benefits involved, the annual costs are approximately equal to the benefits, however also installment costs are necessary. For more precise information, a full cost-benefit analysis should be made.

Route safety

For the analysis of route safety another look is taken at the relation between Zoetermeer and Delft. At first many drivers did not take the safest route but instead of that the shortest route. Displayed below in Figure 40 is the distribution of route safety and route share for 'Full differentiation (obligatory)'.

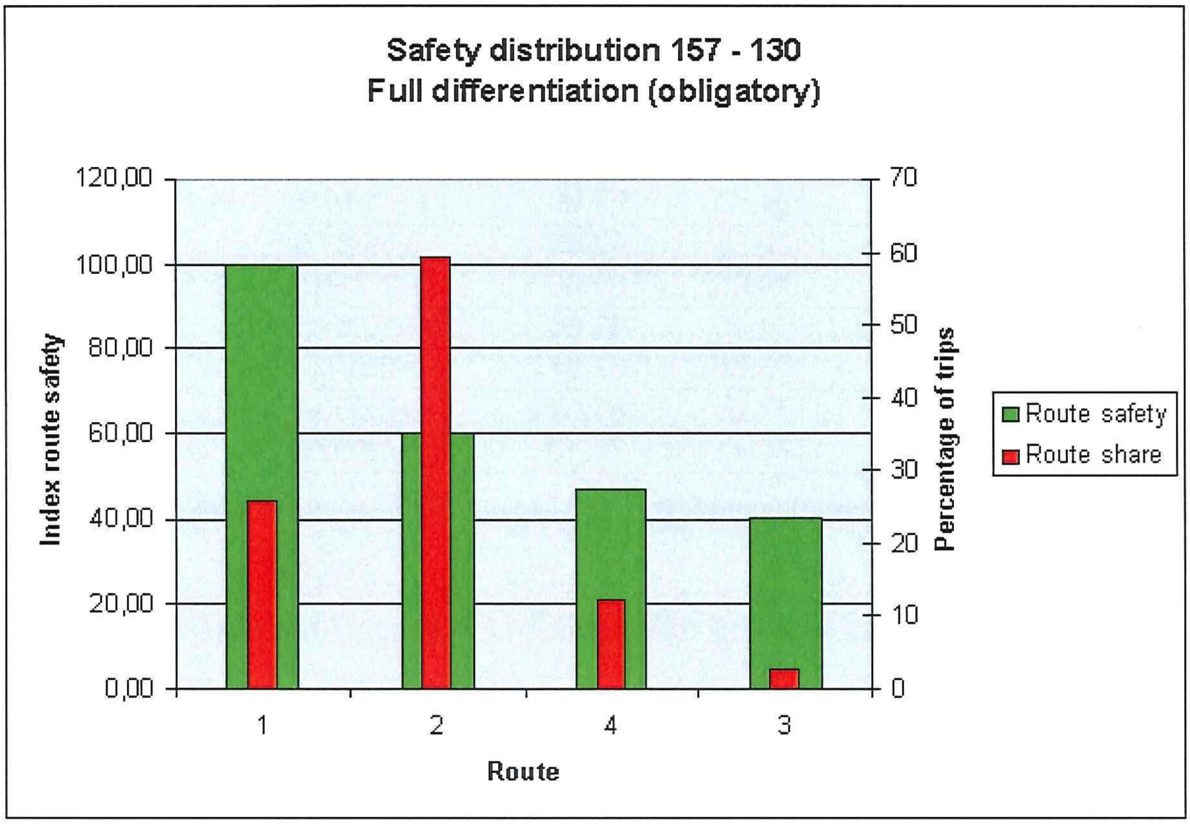

Figure 44 Distribution of route safety and route share

It seems that due to the 'Full differentiation (obligatory)' strategy drivers shift towards the safest route. Looking at Table 49, which compares the strategy with the Reference, this is indeed confirmed.

Route	1	2	4	3
Route safety	331	551	706	825
Route share Reference	13.81%	62.12%	19.11%	4.96%
Route share 'Full differentiation (obligatory)'	25.64%	59.4%	12.21%	2.75%

Table 81 Route safety and route share for Zoetermeer to Delft

When looking at the other OD relations (Table 50), it is shown that safety improves on all selected relations. This indicates that throughout the network, on route level, safer routes are chosen.

Origin	Destination	Reference	Full differentiation (obligatory)	Change
157	130	62.07	68.15	+9.79%
44	57	54.70	60.76	+11.07%
10	156	39.36	62.90	+59.81%
30	154	78.65	80.80	+2.73%
55	66	84.15	92.64	+10.07%
155	127	96.69	97.57	+0.91%
140	66	77.25	83.90	+8.60%
Total		70,41	78.10	+10.92%

Table 82 Route safety indices compared for Reference and 'PAYD for all drivers'

Accessibility
The accessibility indicators for 'Full differentiation (obligatory)' are displayed below in Table 83.

Indicator	Reference	Full differentiation (obligatory)	Change
Number of trips	473868	462351	-2.43%
Total travel time	91084	89423	-1.82%
Total number of kilometers traveled	5340221	5252558	-1.64%
Average travel time (minutes)	11.53	11.60	+0.65%
Average travel distance (km)	11.27	11.36	+0.80%

Table 83 Network accessibility indicators

Both the average travel distance and travel time increase. This indicates that longer routes are chosen in general. As average travel time increases less than average travel distance, this means that there is slightly less congestion.

7.6.2 Hypotheses revisited

Having differentiated insurance as close to safety values as done in this thesis and all drivers having PAYD as insurance is likely to lead to the biggest safety improvement. The hypotheses are listed below:

- Due to increased travel costs, number of trips will decrease
- Drivers change routes to the cheaper motorways
- Effects on departure time choice:
    - Away from the more expensive nighttime hours
    - A secondary shift from the peak hours, as these become more congested

From the transportation model results it is clear that the number of trips decrease due to the 'Full differentiation (obligatory)' PAYD strategy. Also drivers shift towards the motorways to avoid the higher premiums of the other road categories. This leads to a total safety improvement that is relatively large. Due to the error in the departure time model, no conclusions are drawn for those hypotheses.

7.7 Strategy 7 – Young drivers

In the seventh strategy, the only drivers using PAYD as insurance are the young drivers. These drivers have relatively a higher risk and therefore insurance premium. As they also tend to drive less on average per year, insurance per kilometer is increased for this group. Having on average a lower value of time and thus a higher reaction to additional costs, young drivers will quicker change mode, departure time or route in order to minimize costs.

7.7.1 Model results

Network safety

As the network safety is related to the number of kilometers driver per road category, these are displayed first. For the 'Young drivers' strategy, these results are displayed below in Table 37.

Road category	Motorway	Provincial road	Provincial (all traffic)	Urban road	Total
Reference	2649933	635733	619897	1233617	5326619
Young drivers	2685730	636216	604647	1202000	5314797
Change	+1.35%	+0.08%	-2.46%	-2.56%	-0.22%

Table 84 Kilometrages per road category for 'Young drivers' in comparison with the reference

For all drivers a slight change in road categories chosen is visible, from the urban and provincial (all traffic) categories towards the motorways. More results will be visible when this table is split for young drivers and other drivers (non-participants), see Table 53.

Road category	Motorway	Provincial road	Provincial (all traffic)	Urban road	Total
Non-participants	2547172	603125	574177	1117420	5015309
PAYD participants	138558	33091	30471	84580	299488
Change non-participants	1.39%	0.57%	-1.60%	-1.32%	0.28%
Change young drivers	0.72%	-8.14%	-16.23%	-16.47%	-7.94%

Table 85 kilometrages and changes to reference for young drivers and non-participants

Now it is visible that the young drivers are greatly influenced by the PAYD insurance and will start driving a lot less often. Also it seems that the young drivers shift their routes from the expensive provincial and urban roads towards the motorway, showing a large route shift. Non-participants react by starting to drive a little more. As the young drivers drive far less kilometers, the non-participants see improved travel conditions and start driving. However, the roads on which they start driving are strange, as the main increase is on the motorway, for which young drivers also see an increase. This again leads to the conclusion that no equilibrium is reached in the available calculation time. When looking at the number of trips made and the effects on traffic safety (Table 39), it is found that the number of trips and kilometers in the network drop slightly in comparison with the reference. The total number of traffic injuries also drops by the implementation of the 'young drivers' strategy. In Table 40 the changes are displayed per user group in the network, which will allow for further analysis.

	Number of trips	Total vehicle kilometers	Number of traffic injuries
Reference	473869	5326619	2.33
Young drivers	470248	5314797	2.28
Change	-0.76%	-0.22%	-1.99%

Table 86 Changes in traffic safety for 'young drivers' in comparison with Reference

	Number of trips	Total vehicle kilometers	Number of traffic injuries
Non-participants	437369	5015309	2.13
PAYD participants	32879	299488	0.15
Change non-participants	-0.01%	+0.28%	-0.98%
Change PAYD participants	-9.81%	-7.94%	-14.54%

Table 87 Traffic safety changes for participants and non-participants in relation with Reference

Now it is visible that the effect on traffic safety for young drivers is great indeed. With a reduction in crashes of nearly 15 percent, this is the highest safety improvement found so far. As total number of trips for young drivers drop more than the vehicle kilometers, this indicates that longer routes are taken and seeing that the number of traffic injuries decreases more than the number of kilometers and trips, it is found that the routes taken are actually safer as well.

When the safety improvements are combined with the historic crash data and costs of a crash, savings on crashes because of the 'young drivers' strategy can be calculated Table 41.

	Crashes old	Reduction (%)	Reduction (Crashes)	Crash cost (€)	Crash cost saved (mln€)
Fatalities	1106	-1.99%	22.1	2,653,462	58.5
Injuries	18952	-1.99%	378.1	280,442	106.0

Table 88 Total crash reduction and value of crash cost saved

With yearly savings of 22 lives and 378 injured, the reduced social costs mount to 165 million euros. As all young drivers cars need to be equipped with GPS recorders, however, there are also direct costs involved. For Table 42 the assumption is necessary that all young drivers own their car and that it can be equipped with GPS.

	Number of participants (x100.000 vehicles)	Cost per vehicle (€)	Total cost (mln €)
Implementation costs	5.6	100	56
Annual costs	5.6	75	42

Table 89 Simple cost calculation for 'Young drivers'

Looking at these costs and benefits, the scheme should be profitable. However, as no full cost benefit analysis is made, no real conclusions can be drawn here. It seems, however, that the improvement of traffic safety should be enough to cover the costs.

Route safety

For one last time the relation between Zoetermeer and Delft is viewed in detail. Figure 41 and Table 58 display the route shares between Zoetermeer and Delft.

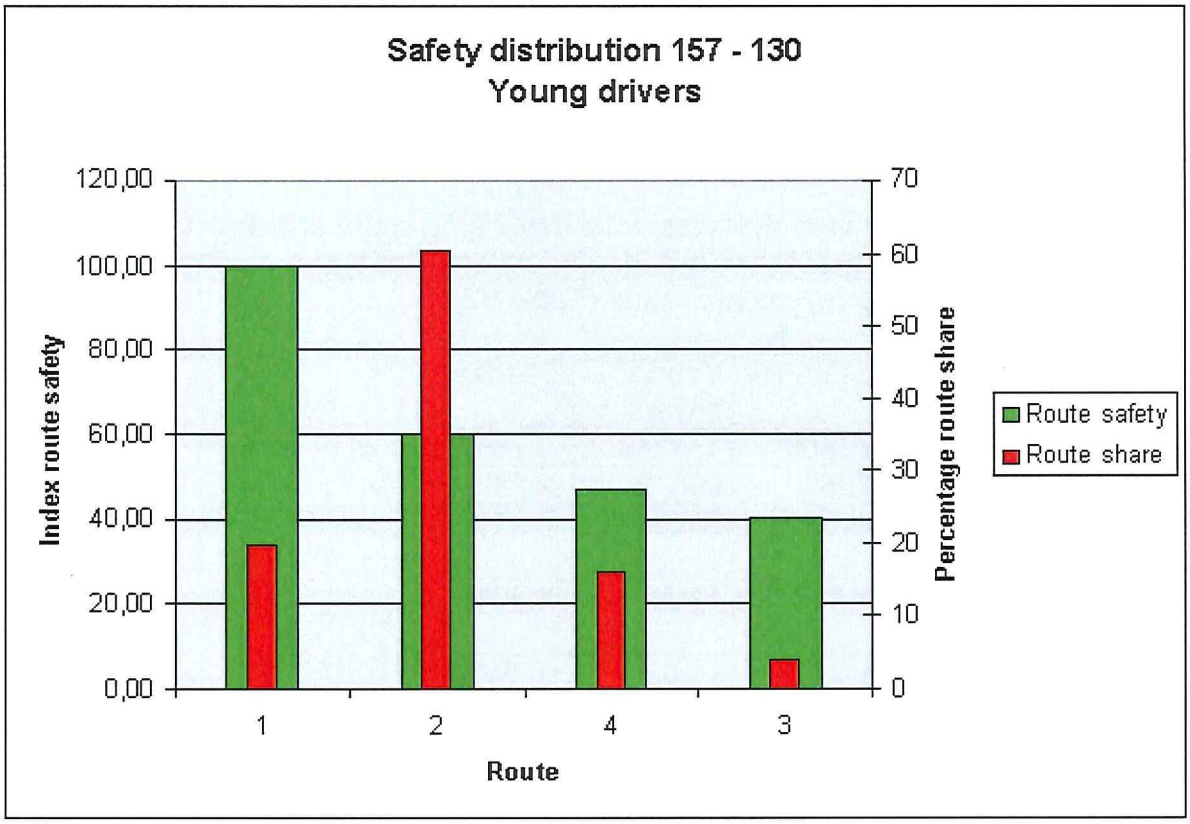

Figure 45 Distribution of route safety and route share

Route	1	2	4	3
Route safety	331	551	706	825
Route share Reference	13.81%	62.12%	19.11%	4.96%
Route share 'Young drivers'	19.71%	60.41%	15.87%	4.01%

Table 90 Route safety and route share for Zoetermeer to Delft

Drivers once more start shifting towards the safest route. Even though the shortest route is still used more often, the total safety index increases. When looking at the other safety indices for different OD relations, the same effect is true for most of the other strategies (Table 43).

Origin	Destination	Reference	Young drivers	Change
157	130	62.08	65.05	+4.79%
44	57	54.70	56.10	+2.55%
10	156	39.36	58.41	+48.39%
30	154	78.65	78.80	+0.19%
55	66	84.16	87.90	+4.45%
155	127	96.69	97.24	+0.57%
140	66	77.26	72.92	-5.61%
Total		70,42	73.77	+4.77%

Table 91 Route safety indices compared for Reference and 'young drivers'

Accessibility
For accessibility the number of drivers, total travel time spent and the number of kilometers driven is viewed. When the 'Young drivers' strategy is compared with the Reference, the following results are found (Table 92).

Indicator	Reference	Young drivers	Change
Number of trips	473868	470248	-0.76%
Total travel time	91084	89072	-2.21%
Total number of kilometers traveled	5340221	5328832	-0.21%
Average travel time (minutes)	11.53	11.37	-1.43%
Average travel distance (km)	11.27	11.33	+0.55%

Table 92 Network accessibility indicators

As the average travel distance increases, longer routes are taken. Average travel time, however, decreases, indicating a reduction in congestion.

7.7.2 Hypotheses revisited

The hypotheses for the 'young drivers' strategy included:

- Trips made by young drivers are expected to reduce by a larger number than found in other strategies
- There will be route choice for young drivers towards the motorways in order to avoid the higher premium
- There will be departure time choice for young drivers to avoid the expensive nighttime driving periods
- Non-participants are likely to start driving more as reaction to improved traffic conditions.

Young drivers in the strategy are indeed starting to drive less than before, with a reduction in kilometrage of nearly 8 percent and nearly 10 percent less trips. The difference between these numbers is the result of young drivers taking the longer motorway routes in order to avoid a higher premium. Also non-participants started driving slightly more than before, because of improved traffic conditions.

7.8 Comparison of strategies

Now that all the strategies results have been discussed, this section will compare the results from the different strategies on the basis of three factors. The three factors are network safety, route safety and accessibility.

Network safety

For network safety the value that is used is the crash reduction for the strategy. This is the calculated crash reduction for the entire strategy and not specifically for the PAYD participants. The crash reductions for the different strategies are displayed in Figure 46.

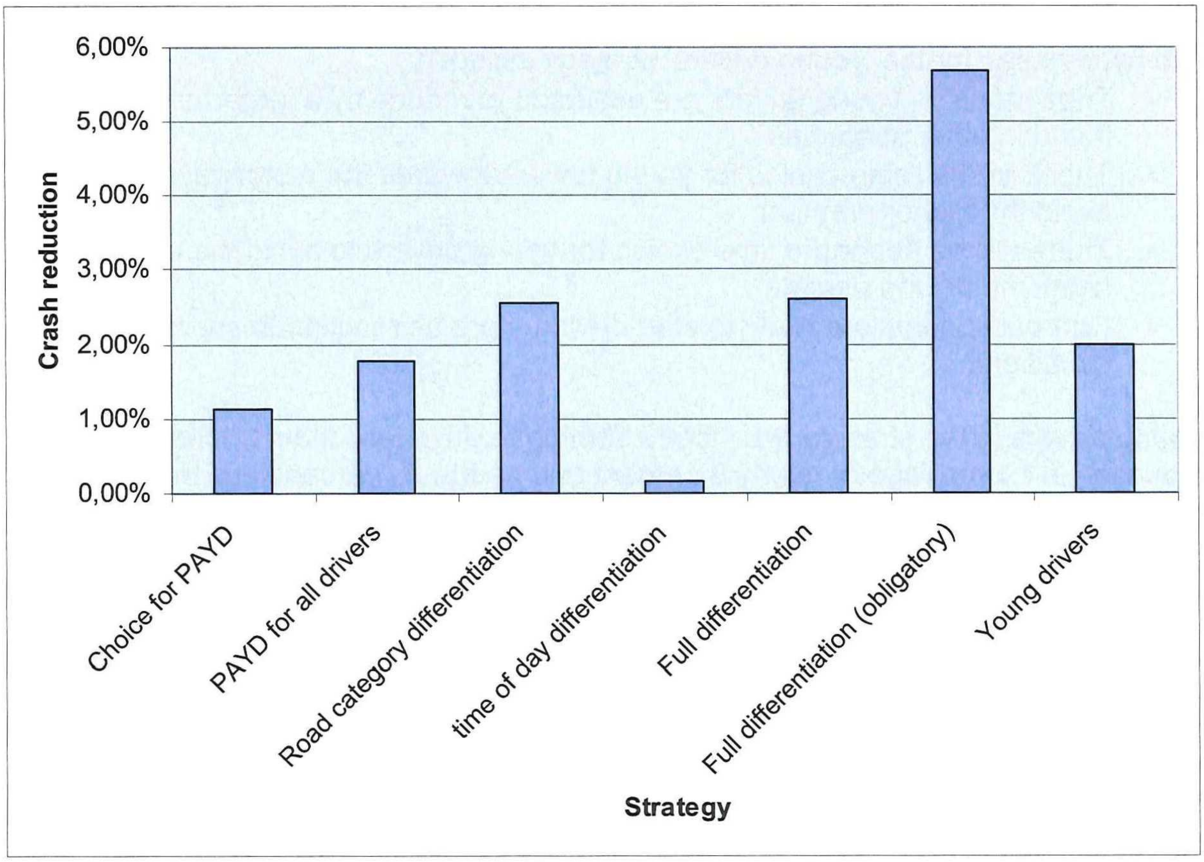

Figure 46 Injury reduction for the different strategies

It is visible that the 'Full differentiation (obligatory)' strategy is most successful in reducing the number of traffic injuries. The next strategies successful in crash reduction would be 'Full differentiation' and 'Road category differentiation' with almost equal results.

Route safety

For route safety, the route safety indices were calculated and combined to result in safety indices per OD relation. The totals over all tested OD relations result in the index totals displayed below in Figure 47. A higher safety index stands for a safer strategy on route level.

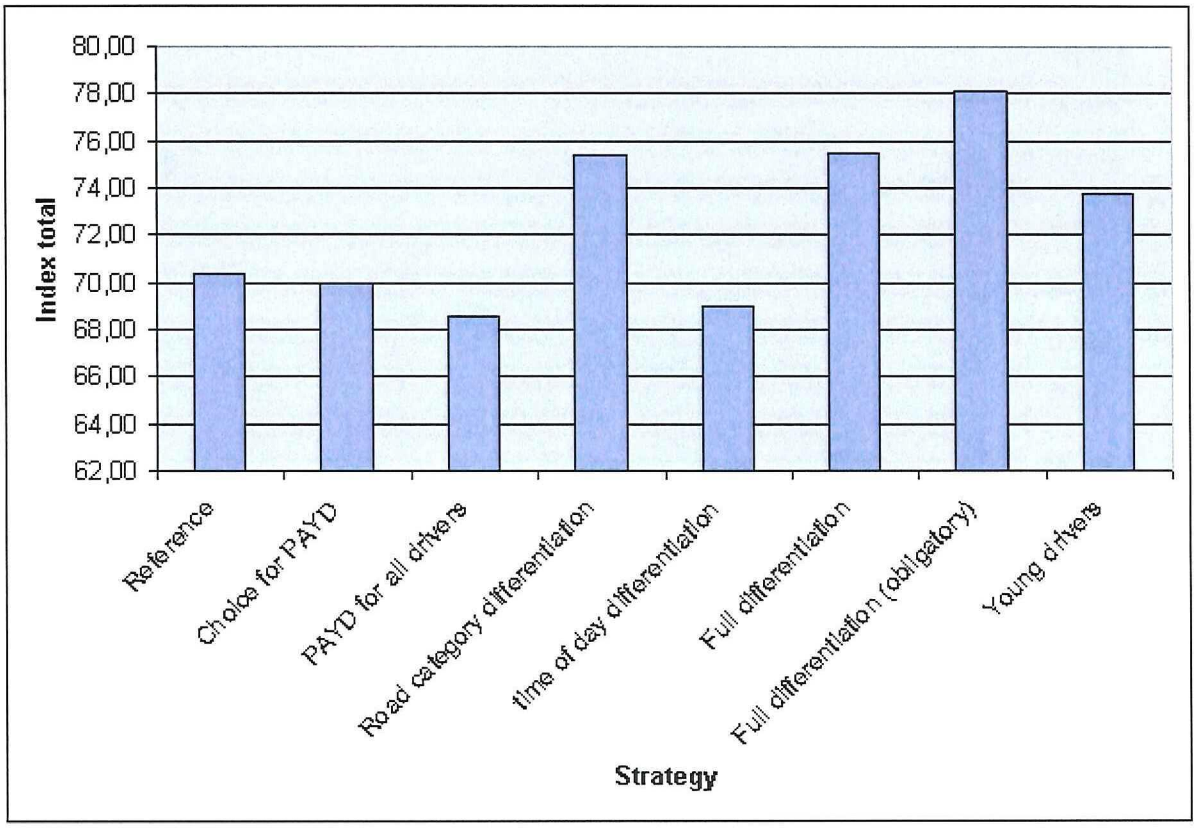

Figure 47 Strategy route safety index totals

It is clear that the 'full differentiation (obligatory)' strategy results in the highest safety value. The strategies following are once more 'full differentiation' and 'road category differentiation'.

Accessibility
For accessibility one values is important, namely:

- Average travel time should be as low as possible

By using the inverse of the travel time, indices are created for which a higher index is better. The average travel time for the reference strategy is set to 100, see Figure 48.

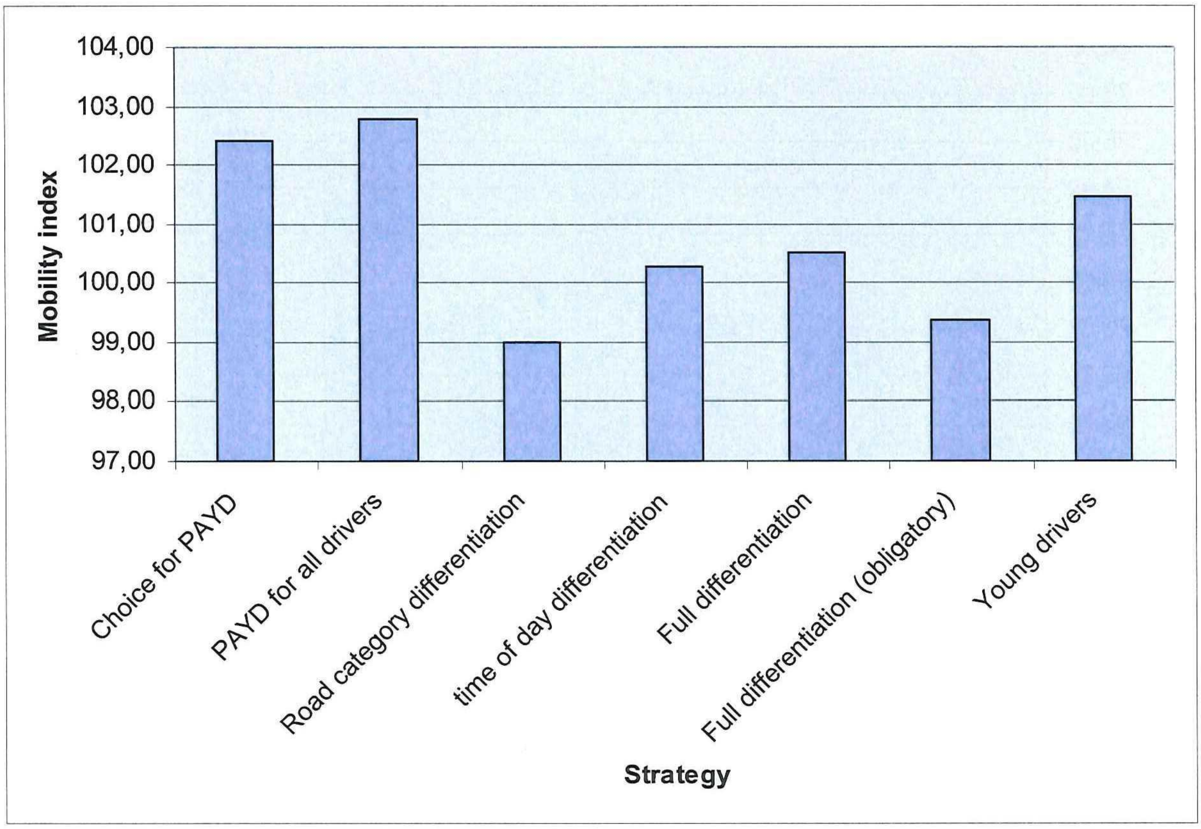

Figure 48 Accessibility indices for all strategies

For accessibility the best strategy would be 'PAYD for all drivers', closely followed by 'Choice for PAYD'. As these strategies avoid the motorways, total congestion in the network is likely to reduce.

Overview

For all strategies network safety (on the basis of crash reduction), route safety and accessibility indices have been determined. With these indices any form of weighing is possible to determine which of the PAYD strategies studied here is the best. For network safety an inverse index will have to be used, as there the lowest value is currently the best and for route safety the index will need to be scaled to have the reference strategy represent an index on 100. In the case that the weighting for all indices is equal the following result is found (Table 93). Whether the weighting of all indices is equal is arbitrarily, however, this table is used as example of a possible weight structure.

Strategy	Reference	Choice for PAYD	PAYD for all drivers	Road categor y different...	time of day different iation	Full different iation	Full different iation (obligat...	Young drivers
Total score	100	100.96	100.64	102.92	99.48	103.46	105.44	102.76

Table 93 Total score for all strategies

For this set of weights the best strategy would be 'full differentiation (obligatory)'. It can be argued, however, that there will be a strong correlation between network safety and route safety. But the 'full differentiation (obligatory)' strategy is the strongest strategy for traffic safety.

Drawbacks of the 'full differentiation (obligator)' could be the costs and acceptability. As with a PAYD scheme there will be drivers for whom the insurance premium will decrease, however, there will also be drivers for whom insurance premium will increase. These drivers will not immediately accept PAYD if it forced by law. As for the 'full differentiation (obligatory)' scheme GPS devices are necessary, the costs of the scheme are high. This also leads to a reduction in acceptability and raises the question who would bear the costs of the scheme. As the benefits of the scheme are not all for the insurers or the insured, the government may have to invest in the scheme as well.

8 Conclusions

In this study a macroscopic dynamic transportation model was used to compare safety and accessibility effects of different PAYD strategies. This study was conducted as part of the TRANSUMO project "Verzekeren per kilometer". In this pilot project, insight was required in the possible large-scale effects of PAYD given the behavioral responses of a limited 300 young participants in the pilot. These three hundred young drivers are not enough to cause network (safety) effects, therefore a model study was performed to assess these impact with higher levels of PAYD market penetration. In this model study seven strategies were tested on the road network of the region of 'Haaglanden' using a macroscopic dynamic transportation model. This model was created to be able to cope with route choice, departure time choice and trip making choice/mode choice.

The model results show that traffic safety can be improved by PAYD. An important finding from this study is however that the level of the safety improvements are highly dependent on the price differentiation of the PAYS strategy. Mainly the differentiation of prices towards road categories lead to higher improvements in traffic safety, see Figure 49 (percentages relative to the reference situation). The downside of differentiating to road category is the increase of motorway kilometers, which may lead to additional congestion on the motorways.

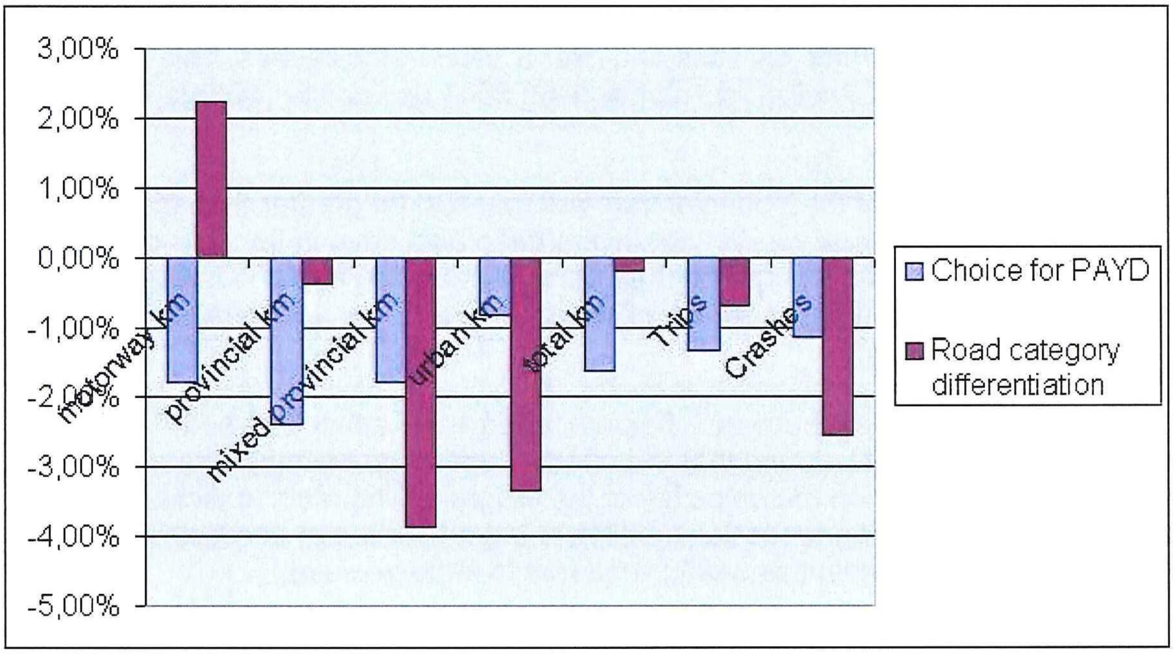

Figure 49 Comparison between strategies 'Choice for PAYD' and 'Road category differentiation'

When looking at the effect of participation level of PAYD, the study results shows that a higher participation level lead to a higher effect on congestion and safety. For the shift from 50% to 100% participation approximately double effects are found for increase in safety and mobility effects, see Figure 50 below.

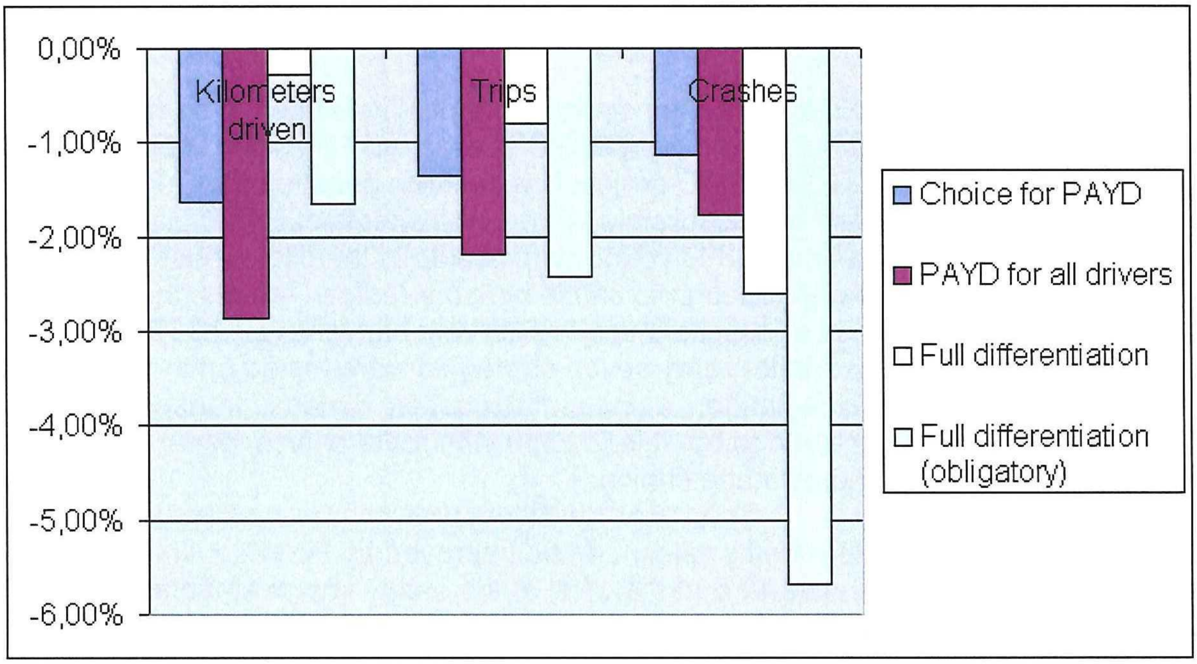

Figure 50 Effects on kilometrage, number of trips and number of crashes relative to reference when increasing participation from 50 to 100 percent

The largest safety effects are found when PAYD is fully differentiated and is applied for all drivers. According to the model this strategy should lead to an average reduction of 62 annual traffic fatalities and over a 1000 traffic injuries. This would save an approximate 470 million euro price level 2003 on economical loss due to crashes.

The behavioral effects of the Young drivers are found to be greater than those of the average participation. However, young drivers often also drive in the cars of their parents, or let their car be insured on their parents name to save on insurance premium. Therefore the total of effects of obligatory PAYD for young drivers cannot be determined.

When looking at difference between kilometer charge (by a flat rate) and PAYD (further differentiated), it is found that the effects depend on the structure and that the structure would depend on the objective of the program. The main objective of kilometer charge would be to reduce mobility in order to improve accessibility. For PAYD the main goal (within this study) would be to improve safety.

When kilometer charge would be differentiated towards road category, a different price per road category would be chosen then with PAYD. It is likely that the motorways would become more expensive then the provincial roads, as the motorways are more congested, where with PAYD this price structure is exactly the opposite, as used in this study.

If PAYD were to be implemented for all drivers, it could be combined with kilometer charge in order to save money on the implementation of these pricing structures, as both kilometer charge and PAYD use GPS for the data transmission.

9 Discussion and recommendations

The transportation model in this study is capable of combining route choice and trip making choice/mode choice. It is also capable of departure time choice, however, an error was found in the departure time choice model, resulting in a departure time choice shift that is too small. This problem has been corrected for, but the new model did not reach equilibrium within twenty-four hours of simulation time. Because of time restrictions of this study, the first model results are used and no conclusions are drawn for departure time changes.

In the first model, some results are found for the non-participants that deviate from our expectations. Even though the road conditions improve as a result of trip reduction by participants, the non-participants reduce their trips as well, rather than the expected increase op trips. These counterintuitive results are the result of a non-equilibrium situation of the model..

The model framework used, is not capable of dealing with speed choice. As the model is a macroscopic model, no individual drivers are distinguished. Also, all drivers entering a certain road section at the same time will have the same speed. Effects on drivers speeding behavior are tested in the pilot, and therefore effects on safety due to a reduction in speeding may be found in the pilot study.

Some other effects that are not modeled perfectly, are that the model does not take into account delays at intersections and secondly blocking back due to congestion is not yet taken into account. Not modeling intersection delays has as drawback that the model will underestimate the level of congestion on urban and sometimes provincial roads. The lack of blocking back in the network has mainly effects on the motorway. To compensate for the omission of blocking back several bottlenecks where modeled in the network, rather than a single bottleneck with spill back. This way congestion will result in travel times that are equally high as normally during the peak hour but are slightly higher on the edges of the peak. Also, by not modeling blocking back, some routes may not come across congestion that would be there in reality.

Route choice, however, does work properly and the model results show that the differentiation to road category leads drivers to take safer routes. The improvement of traffic safety from a reduction of 12 fatalities to a 28 fatalities is found in the model for a level of 50% participation. This indicates the importance of the road category differentiation. This differentiation is therefore recommended to be also implemented in the PAYD pilot or any future pilots that may occur.

For many strategies tested in this study, GPS would be necessary. While GPS is expensive, not all of the uses are applied yet in this study. Insurance premium could also be differentiated to whether or not the driver keeps to the speed limit, as speeding is known to give an increase in average number of traffic injuries. Also other appliances may be connected to a GPS device such as route navigation, parking information or even up to date congestion information. When PAYD is implemented at the same time kilometer charge, the data transmission could be combined in the same box in order to save costs.

For the final results, it has been assumed that PAYD would have the same effect in all other parts of the Netherlands. The question is whether this assumption is valid, as in other parts of the Netherlands the road network is much coarser, leading to less route possibilities for drivers. Also the level of public transport varies over the country, as well as age and level of congestion. All these aspects may have an effect on the reactions to PAYD. A full network study should be done in order to gain more insight for other parts of the Netherlands.

It is recommended that a new and longer model run is done that is able to reach equilibrium. The model should also be expanded to include blocking back, so that travel times match the real life case better. On the interurban and urban routes junction delays should be added to improve the lower level roads in the network.

An extension of the study should include more user group and zone differentiation. Information about level public transport could be made available per zone and age groups could be defined. Safety could also be better calculated on the basis of different age groups instead of an average. With different age groups it could also be found to what groups the scheme is most beneficial.

On the main, PAYD should be introduced in the Netherlands to improve traffic safety. The introduction of PAYD should at least include road category differentiation in order to reach stronger effects on traffic safety. Before implementing PAYD further research is necessary on behavior. The pilot study from TRANSUMO may give information here, but should be differentiated to road category to produce better safety effects.

References

Aarts (2004), Snelheid, spreiding in snelheid en de kans op verkeersongevallen. Leidschendam, SWOV R-2004-9

Aarts & Van Schagen (2005), Driving speed and the risk of road crashes: A review. Elsevier: Accident Analysis and Prevention 38, 215-224

AVV (2006), Kosten verkeersongevallen in Nederland. Rotterdam

Bliemer (2004), INDY model specifications. Working document. Delft University of Technology, Faculty of Civil Engineering and Geosciences, Transport & Planning Section, Delft

Bliemer, M, E. Versteegt, and R. Castenmiller (2004), INDY: A New Analytical Multiclass Dynamic Traffic Assignment Model. In Proceedings of TRISTAN V conference (pp. 1-8). Montreal: CRT.

Brownfield et al. (2003), Congestion and accident risk. London, Road Safety Research Report No. 44, Depertment for Transport

Brühning (1988), Das Unfallgeschehen bei Nacht : Unfallhäufigkeit, Unfallrisiko und Unfallstruktur. Bergisch Gladbach, Bundesanstalt für Strassenwesen BASt, Forschungsberichte der Bundesanstalt für Strassenwesen, Bereich Unfallforschung ; Lfd. Nr. 187

Brühning (1991), Das Unfallgeschehen bei Nacht. Zeitschrift für Verkehrssicherheit 37-1, 17-24

Cirillo (1968), Interstate system crash research; study II, interim report II ?

DGP (2005), Quick-scan knelpuntbeprijzing ?

Fanoy, van Amelsfort & Thijssen (2001) De paradox van de betaalstrook ?

Finch et al. (1994), Speed, speed limits and crashes. Crowthorne, Berkshire, Transport Research Laboratory TRL, Project Report PR 58

Goudappel Coffeng BV (1997), Marktprofiel van de filerijder. Deventer, Goudappel Coffeng BV, AVV105/Bq/ 1616, 970228

Janssen (2005), De Verkeersveiligheidsverkenneer gebruikt in de regio. Leidschendam, SWOV, R-2005-6

Kloeden et al. (2001), Travelling speed and the rate of crash involvement on rural roads. Civic Square, ACT, Australian Transport Safety Bureau A, Report No. CR 204

Litman (2006), Distance-Based Vehicle Insurance: Feasibility, Costs and Benefits. Victoria Transport Policy Institute

Litman (2006), Distance-Based Vehicle Insurance As A TDM Strategy. Victoria Transport Policy Institute

Litman (2006), Converting Vehicle Insurance Premiums Into Use-Based Charges, www.vtpi.org/tdm/tdm79.htm

Nielssen (2003), The AKTA road pricing experiment in Copenhagen. Lucerne, 10th International Conference on travel Behaviour Research

Nilsson et al. (1982), The effects of speed limits on traffic crashes in Sweden. Dublin, Proceedings of the international symposium on the effects of speed limits on traffic crashes and fuel consumption. Organisation for Economy, Co-operation, and Development (OECD), Paris.

OECD (1980), Road safety at night. Paris, Organisation for Economic Co-operation and Development OECD.

Opiela et al. (2003), Driving after dark. FHWA

Polis Direct (2004), De Nederlander & de autoverzekering(premie) http://www.kilometerpolis.nl/media/m23.pdf

Progressive Insurance (2005), Texas Mileage Study: The Relation Between Annual Mileage and Insurance Losses http://www.nctcog.org/trans/air/programs/payd/PhaseI.pdf

Progressive Insurance (2007), Pay As You Drive (PAYD) Insurance Pilot Program: Phase 2 Mid-course Project Report. Prepared by Progressive County Mutual Insurance Company.

Romph (1994), A Dynamic Traffic Assignment Model. http://repository.tudelft.nl/file/257310/201171

RTI (1970), Speed and accidents, Vols. I & II. Research Triangle Institute RTI, Durham, North Carolina.

Santos & Shaffer (2004), Preliminary Results of the London Congestion Charging Scheme. Public Works Management & Policy, Vol. 9, No. 2, 164-181.

Solomon (1964), Accidents on main rural highways related to speed, driver and vehicle. Resource: U.S. Department of Commerce.

SWOV (2002), Tweewielerongevallen. Leidschendam, SWOV, R-2002-05

SWOV (2005), SWOV Factsheet: Puntenstelsels. Leidschendam, SWOV

SWOV (2006), SWOV Factsheet: Jonge beginnende automobilisten. Leidschendam, SWOV

SWOV (2007), SWOV Factsheet: De relatie tussen snelheid en ongevallen. Leidschendam, SWOV

TNO Inro (2003), Pay As You Drive: Mogelijkheden voor een variabele autoverzekeringspremie in Nederland? Delft, 03-7N-190-74010

Ubbels (2006), Road Pricing. VU Amsterdam.

Van der Sar & Baggen (2005), Prijsbeleid op de weg in Nederland : een historisch overzicht. Antwerpen, Paper voor het Colloquium Vervoersplanologisch Speurwerk

Van Schagen et al. (2004), Veilige en geloofwaardige snelheidslimieten. Leidschendam, SWOV, R-2004-12

Vlakveld (2005), Jonge beginnende automobilisten, hun ongevalrisico en maatregelen om dit terug te dringen. Leidschendam, SWOV R-2005-3

Wegman (2003), Verkeersonveiligheid. Leidschendam, SWOV