Pay-As-You-Drive (PAYD): A case study into the safety and accessibility effects of PAYD strategies

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number of words:	6495
number of tables and figures:	4
total number of words:	7495

ABSTRACT
This study compares the safety and accessibility effects of Pay-As-You-Drive (PAYD) strategies, simulated using a transportation model. PAYD is an insurance policy for car owners where, to better reflect crash risk, the insurance premium is paid per kilometer actually driven. With more advanced monitoring technologies, the PAYD insurance premium can be further differentiated to reward safe driving behavior with a lower premium. This more differentiated concept of PAYD is currently being tested in a real life pilot. As part of this pilot a modeling study has been performed in order to assess the possible network (safety) effect of large-scale implementation of PAYD. The setup and results of this modeling study are described in this paper.

Seven PAYD strategies have been investigated with different kilometer-based insurance premium differentiations (road category differentiations, time differentiations, age differentiations). The network effects appear to vary greatly depending on the design of the PAYD strategy. The most common effects found in this model study are mode shifts and trip making (elastic demand effect) and route shifts.

To improve traffic safety, the best strategy would be to differentiate premium to reflect safety, i.e. higher fees for unsafe road categories and nighttime driving, most effectively and apply it to all drivers. This way, drivers optimize towards the lowest cost and highest traffic safety. 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 each year in the Netherlands.

INTRODUCTION TO PAY-AS-YOU-DRIVE

The insurance premium of most current policies is, depending on the insurance company, differentiated by attributes like driver age, gender, car type, self-estimated kilometrage and claim behavior. As the number of insurance claims of a person on average increases with annual kilometers driven, the insurance premium can be affected by risk more realistically if differentiated to actual kilometers driven, see e.g. *(1)* and *(2)*.

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. The PAYD insurance premium can be further differentiated to reward safe driving behavior with a lower premium, by either avoiding driving during nighttime, not exceeding the speed limit, or driving on safe roads. The PAYD principle is based on the hypothesis that travelers will have a direct incentive through variabilizing the cost of traveling to adapt their travel behavior.

It is expected, that higher, possibly involuntary, levels of PAYD participation, may have substantial network level effects on accessibility, safety, and possibly also the environment. This study is part of a Dutch PAYD project (called TRANSUMO "Verzekeren per kilometer"), which involves a pilot study to measure effects of PAYD on individual drivers. A modeling approach is used to assess the network effects of large-scale implementation of PAYD. This paper assesses and compares the safety and accessibility effects of different PAYD strategies simulated with a transportation model.

The model shows that with PAYD insurance traffic safety indeed can be improved. Especially when drivers are made more aware of the risks of provincial and urban roads by a higher premium, they tend to choose safer (cheaper) routes. When differentiating to kilometrage, to road category and to time of day, the model shows a yearly reduction in number of injury accidents of 5.7%. Network travel times can go up or down, depending on the PAYD strategy. When differentiated to road category, there is a likely increase in travel time, as drivers will choose cheaper and safer routes using (congested) freeways.

Types of PAYD

Different variations of PAYD and possible technologies have been developed throughout the years. A concise overview of the different options can been found in *(3)*.

From possible PAYD variations the Mileage Rate Factor (MRF) would be easiest to implement. With MRF, drivers self estimate their annual mileage and pay accordingly. MRF is already used in different insurance premiums. The advantage of this variation of PAYD is that it is easy, and cheap to implement, but the disadvantage is that fraud with MRF is easy. The ease of fraud with MRF is the reason why the amount of premium differentiation between kilometrage levels will be limited and as a result behavioral responses and safety effects will be small.

Another variation of PAYD is to perform car odometer audits at the beginning and end of the insurance policy term. In this case a certified person, reads the odometer results and reports these to the insurance company. To reduce costs, the annual check could, for most cars, be performed together with a regular obligatory check up (SMOG test in the US). Fraud is more difficult as odometers become increasingly tamper resistant and most new cars are equipped with electronic-digital odometers that cannot be reset. Fraud with odometers should be punishable by law, in order to make odometer audits possible.

A third variation of PAYD could be to add the insurance premium to the fuel costs. This Pay-at-the-Pump (PATP) insurance, as proposed by *(3)*, uses a surcharge on vehicle fuel purchase to fund vehicle insurance. All basic coverage is provided and payment will be done per unit fuel consumed. An advantage with this option is that there will be no uninsured driving. One of the downsides of PATP insurance is that people may find this option unacceptable, as they perceive PATP as just another fuel tax, instead of insurance premium. Last, drivers may perceive it an unfair system, in which people that use more fuel pay more than others, while they may not necessarily have more risk. Groups in stop and go traffic will have relatively higher charges, while heavy injury and fatal accidents occur less in these conditions *(4)*.

With more advanced technologies to measure driving behavior, like GPS, even more factors for premium differentiation can be taken into account. For example: driving location, time of travel and exceeding of local speed limits. The disadvantages of GPS are in the cost of the equipment and data storage and transmission. Also privacy issues may arise if the exact location data are transmitted to the insurance company. The latter can be avoided by in-car calculation of premiums that are then transmitted to the insurance company.

Current PAYD Insurance And Studies

There are currently a few PAYD insurances operational on the basis of a price per kilometer, sometimes differentiated to time and location *(5)*. Also several pilot studies are started or have been completed worldwide *(6, 7)*. A few examples of PAYD insurance and pilot projects are given below.

After a successful pilot study in 2003 with 5000 participants, Norwich Union Insurance Company from the United Kingdom fully implemented their PAYD insurance *(8)*. Recording of travel behavior 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 ($102), 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. At these hours, the price per kilometer is £1 ($2.04). 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.

A few years ago, the Polis Direct Insurance Company started with a kilometer polis in the Netherlands, which only takes into account kilometers driven, see *(9)*. The insurance owners report the kilometers driven online from the readings of their odometer. Checks on this are performed by the use of the 'National Car Pass', which registers odometer records every time a car comes for repairs, checkups and taxation. Also, odometer checks are performed 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.

Progressive Insurance Company started its 'Texas Mileage Study' in August 2005, see *(10)*. This study consists of two phases, the first phase researching the relation between speed and crash rate, the second phase including a PAYD pilot study. 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. Only mileage level is considered for the insurance premium during the pilot.

In the Netherlands, a PAYD pilot project has started, and the research described in this paper is part of this project. In the pilot study, approximately 300 young drivers voluntarily participate in which they get discount on their insurance fees when they show safe driving behavior. Their driving behavior is tracked with a GPS device. The less participants drive, the more during daylight, and the more they obey the speed limits, the more they save on insurance fees. Road type differentiation is not taken into account in the pilot study, although the impact of road type specific insurance fees will be analyzed in this paper.

SAFETY FACTORS AND PAYD

As mentioned before, not only amount of kilometers driven determines the safety, but there are more factors involved as well. These factors include road category, time of day, and age of the driver. These factors will be described in more detail below. We would like to point out that other factors are important for safety as well, such as safety-belt usage, alcohol and/or drugs usage, and obeying speed limits. Since in this paper we are analyzing network wide effects using a transport model, it is not possible to include all these safety factors in our analyses. As such, measures to improve safety-belt usage and avoid speeding will not be analyzed in this paper.

Road Category

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 differentiation for road category is used. The relation between road category and safety in the Netherlands has been given by *(11)*, which shows that motorways are the safest roads (on average 0.06 to 0.08 injury accidents per million car kilometers) in contrast to interurban roads that are relatively unsafe (with an injury accident rate of 0.22 to 0.43) and urban roads even more unsafe (1.10 injury accident rate). Also for other countries, including the US, it is found that motorways are relatively safer than interurban roads *(12, 13)*. This implies that the insurance fees for using (inter)urban roads should be higher per kilometer than for using motorways.

Time Of Day

Driving during nighttime is more dangerous 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 *(14)*. This reduced safety of nighttime driving is related to many 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% *(15)*. 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 *(16)*. 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 at night than during the day. This percentage is approximately 33% compared to 13%.

Therefore, nighttime driving should be discouraged. This is accomplished by applying higher kilometer insurance fees for driving during these nighttime hours.

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 *(17, 18)*. 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, introduction of a kilometer based insurance premium may lead to a reduction in the total premium. And as young drivers may not have as much money as older drivers, the cost per kilometer may make them more easily change to a cheaper option than people with more money. This way the insurance company will have less risk of a claim. Overall, the kilometer insurance fee of young drivers should be higher than those for older drivers.

BEHAVIORAL RESPONSES TO PAYD

For drivers, the changed costs per kilometer due to a changed insurance scheme may cause changes in their travel and driving behavior. These changes, depending on the level of differentiation of the premium, may most likely be found in route choice, departure time choice, trip choice and mode choice. This is the basic hypothesis behind PAYD schemes, namely that variabilizing the travel costs is a more effective incentive for travelers to adapt their travel behavior than fixed costs.

As a result of increased variable trip costs people could decide to make fewer trips. In case of a commuter trip for example, workers may decide to go less often to work (e.g. only four days a week instead of five). With recreational trips, the effect may be similar. The driver may decide to skip the recreational trips, make fewer trips, or decide to recreate around the living location.

Instead of making fewer trips by car, the driver may also decide to use another mode for the trip. For commuter trips, it is more common for drivers to choose public transport instead of the car to go to work. Also for other trips this will apply, for example, taking the bike to the shopping center instead of the car.

If the PAYD premium is differentiated towards the time of the day, drivers may shift their departure time in order to avoid the higher pay periods. This choice is likely to be made for commuter trips and even more for recreational trips, as the latter activity can mostly be undertaken at a desired time. Also, if due to a specific PAYD scheme the road conditions change, drivers again may adjust any of their travel decisions.

When a PAYD strategy would increase the cost of a certain route for a trip, drivers would tend to divert to cheaper routes if available. This way they may accept a route with a longer driving time or distance instead of paying the increased premium. The tradeoff that is made is between time and money.

These individual shifts in travel choices may have an impact on network wide traffic patterns, on locations and levels of congestion and as a result the changed network condition may affect travel choices until a new equilibrium is reached.

It is also interesting to see PAYD in the light of road pricing, which has received a lot of interest from researchers worldwide and several real-life implementations exist. Basically, the behavioral responses to PAYD are likely to be very similar to those of road pricing. Especially in the case of kilometer based charging schemes, travelers' behavior is expected to be similar. However, there is much difference in the objectives of PAYD versus road pricing; instead of decreasing congestion or maximizing revenues, PAYD aims to reduce claim behavior of clients such that the insurance companies have to spend less money on claims and increase their margin of profit. Therefore, the structure of (kilometer based) insurance fees will be very different from those of a (kilometer based) congestion charge. For example, while in road pricing one will most likely charge motorways in the morning peak, an insurance fee for improving safety may actually stimulate driving on (safe) motorways during the (safe daylight) morning peak. A further comparison between road pricing and PAYD will not be made in this paper, however it is clear that PAYD may yield very different (opposite) network effects, which is a result of different objectives that cause differences in price differentiation.

METHODOLOGY

As there are many different variations of PAYD, there is a need to identify the effects for different PAYD strategies. In this study an experimental design is used. In this design the different PAYD design factors can be added or removed from various strategies in order to get information about its effects. In order to assess the effects of the different PAYD strategies, a case study approach is chosen. Using a representative and as much as possible real-life environment the different PAYD strategies are tested. The case study is modeled in a transportation model, which simulates travelers' choice behavior and calculates traffic flows, taking into account the different PAYD strategies. These traffic flows are used in order to calculate effects on traffic safety and other network measures (such as congestion or travel time). First, we describe the possible PAYD strategies, then the model framework, and finally the results in a case study.

STRATEGIES

Eight strategies are tested, with their differences in premium structure and level of participation. The PAYD strategies that are tested are described below.

No PAYD - Reference strategy

In the reference strategy, 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 to which the model has been calibrated.

Optional PAYD flat fee

In this strategy drivers are able to choose whether or not to take 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 in the Netherlands) divided by the average kilometrage (approximately 15000 km in the Netherlands), which leads to 4 eurocents per kilometer (9.5 dollar cents per mile).

Obligatory PAYD flat fee

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

Optional PAYD Road Category Differentiation

In this strategy, road category differentiation is added to the previous strategy, in which the kilometer charge is differentiated towards road categories. This means that motorways will become cheaper and (inter)urban roads more expensive. The kilometer price will be set to 0.6 eurocents (1.4 dollar cents per mile) for a motorway, 2.2 eurocents (5.2 dollar cents per mile) for an interurban road (and 4.4 eurocents (10.4 dollar cents per mile) if it is open for all traffic), and 11.2 eurocents (26.5 dollar cents per mile) for an urban road. This is in close relation with safety factors per road category found for the Netherlands *(11)*. For more details on the computation of this price structure we refer to *(19)*.

Optional PAYD Time Of Day Differentiation

This strategy involves increased prices for nighttime driving. The price for nighttime driving is multiplied by 1.7 times the daytime pricing, computed using Dutch figures on the number of fatalities per million kilometers during night (7pm till 7am) and day (7am till 7pm). This factor is comparable with the factor of 1.6 that was found during research in the US *(20)*.

Optional PAYD with time and road type Differentiation

In this 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 substantial network effects.

Obligatory PAYD with time and road type Differentiation

This strategy is equal to the previous strategy, with the only difference being that in this strategy all drivers will have the fully differentiated PAYD insurance. This may happen if the government decides on legislation for PAYD.

Obligatory time and road differentiated PAYD Young Drivers

In this last strategy, all (and only) young drivers have a fully differentiated PAYD insurance. 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 more easily change mode, departure time or route in order to minimize costs.

MODEL FRAMEWORK

In order to forecast the safety and network effects of the PAYD strategies mentioned above, we use a transportation and traffic safety model. As we would like to be able to capture PAYD insurance fees differentiated by road category, time, kilometers traveled, and age, we have to include route choice behavior, departure time choice behavior, trip choice behavior, and also different user-classes for different age groups and/or participation level. We will first describe the transportation model, which aims to model traveler's behavior and simulates traffic on the network. Then we describe the traffic safety model that uses outcomes of the transportation model to calculate safety indicators.

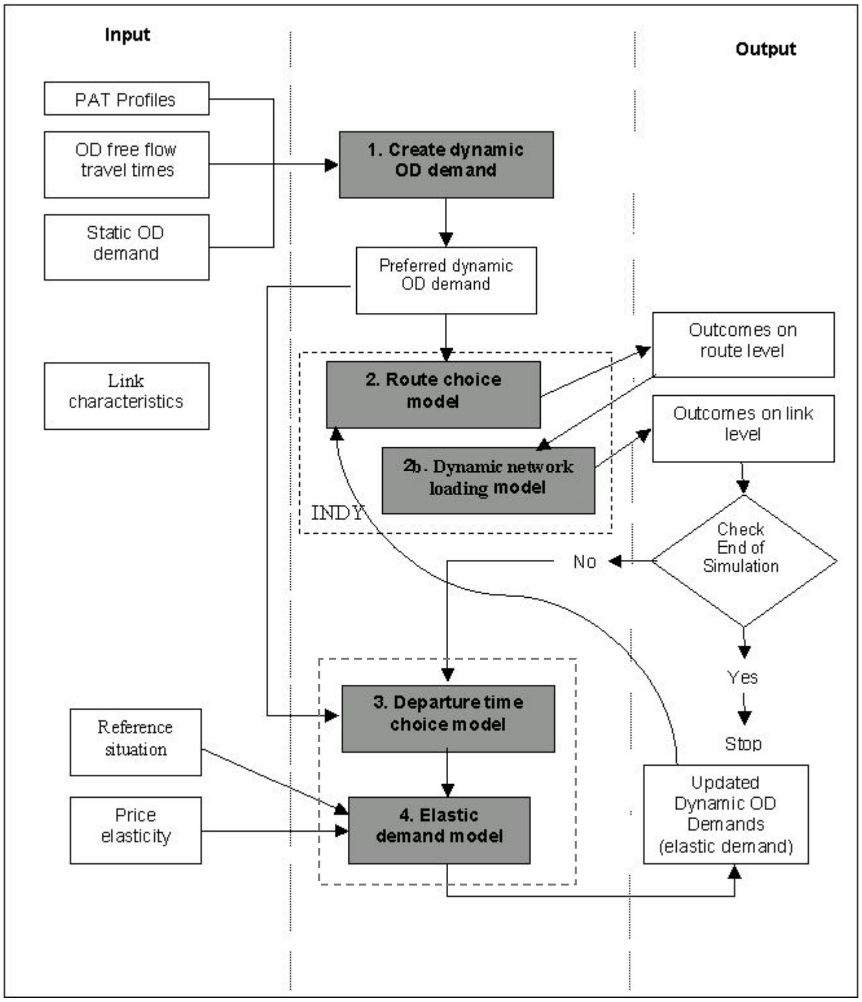

Figure 1: Transportation model framework overview

Transportation Model

The transportation model used in this study is an extended version of the multi user class (MUC) dynamic traffic assignment (DTA) model INDY (Figure 1) *(21)*. INDY dynamically assigns traffic to the network taking only route choice into account. In this study we have extended INDY to incorporate departure time choice and elastic demand (trip choice and mode choice) by creating an additional loop over INDY. This way the previously described behavioral responses are incorporated in the model. The model consists of four sub models, described below.

Elastic demand is implemented in the model to show the effects of increased travel disutility on the change of making the trip by car. The elastic demand sub model covers the trip frequency, trip destination and mode choice adjustments of travelers in an aggregated way. The disutility per origin-destination (OD) pair for each iteration is calculated before departure time choice is applied and the utility is also used during that calculation. This disutility is based on weighted averages of the travel times (including congestion delays), travel costs (including the insurance fees) and deviations from the preferred departure and arrival times. A distribution of preferred arrival times is estimated based on a stated choice experiment. The preferred departure times are set equal to the corresponding preferred arrival times minus the free-flow travel times.

Departure time choice is dependent on the monetary costs of the different departure times (as the insurance fees can be time dependent), the travel times and the deviation from the preferred departure and arrival times. Departure time shifts are calculated with a multinomial logit function on the basis of total travel (dis)utility for each departure time interval.

In the model the calculation of elastic demand and departure time choice is done in the same module. For both the same utility function is used, which is shown below:

$$U_m^{od}(k) = \alpha_m^1 \overline{\tau}_m^{od}(k) + \alpha_m^2 \overline{\theta}_m^{od}(k) + \alpha_m^3 (k - \zeta_m^{od})^- + \alpha_m^4 (k - \zeta_m^{od})^+$$
$$+ \alpha_m^5 (k + \overline{\tau}_m^{od}(k) - \xi_m)^- + \alpha_m^6 (k + \overline{\tau}_m^{od}(k) - \xi_m)^+ + \varepsilon_m^{od}(k)$$

Where:

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

$\overline{\theta}_m^{od}(k) = \frac{\sum_r f_{mr}^{od}(k)\theta_{mr}^{od}(k)}{\sum_r f_{mr}^{od}(k)}$ = 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 $\overline{\tau}_m^{od}(k)$ and $\overline{\theta}_m^{od}(k)$, 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

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

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

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

ξ_m = preferred arrival time for mode m

$\widetilde{t^{od}}$ = 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

Route choice is incorporated within the INDY model structure. For each departure time period, car drivers have several route possibilities, each having route specific attributes like length, travel time, and insurance premium. Car drivers are supposed to choose their optimal route for traveling, based on generalized travel times and costs using a logit model. Route choice sets are generated before the simulation using a stochastic choice set generation procedure, see *(22, 23)*. The drivers cost function is shown below:

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

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.

All parameters in the trip, departure time, and route choice models have been estimated from a large stated choice survey on kilometer charge, see *(24, 25)*. As mentioned before, behavioral changes to a kilometer-based charge are expected to be very similar to behavioral responses to a kilometer-based PAYD insurance fee. The only difference is the objective. Therefore, we believe we can transfer the parameter estimates to our PAYD study. The elasticities for different user groups have been taken from literature *(26, 27)*, but are an approximation, since most the combined elasticity of trip frequency, destination and mode choice is not well known in the Netherlands.

After all trips, departure times, and routes are chosen, the vehicles are simulated on the network in the dynamic network loading (DNL) model. The DNL model propagates the flows on the network, taking into account the road capacities, maximum speeds, etc. For more information on INDY and the DNL model, see *(21)*. As both PAYD participants and non-participants use the same network (and therefore a MUC DTA model is used), reactions of one group may lead to opposite reactions of the other group. If, for example, PAYD participants have to 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. Outputs of the DNL 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, until this converges (the method of successive averages, MSA, is used and the duality gap is used as convergence measure). Similarly, the loop of the departure time choice model and trip choice model also needs to converge. If both have converged, we have reached a dynamic stochastic user equilibrium state in route, departure time, and trip choice.

Traffic Safety Model

The traffic safety model translates link flows to safety values. In order to do this, safety values per road category and time of day are used as described above in the strategies. With these safety factors a value for the total level of safety (measured in crashes and fatalities) is calculated for the reference strategy and each of the PAYD strategies. The change in safety between the reference and the PAYD strategy calculated.

CASE STUDY

We have applied the previously described PAYD strategies on a real-life network consisting of a heavily congested area in the western part of the Netherlands, which includes the city of The Hague and is bounded from the south by Rotterdam, from the north by Leiden, and from the east by Gouda. All main roads have been incorporated in the model. These roads consist of the three main motorways (A4, A12 and A13), all provincial roads and most urban roads as well. In total there are 3387 links, 1300 nodes, and 13603 OD pairs in the network (where each origin and destination is based on the postal 4-code areas). Departure time intervals have a size of 10 minutes, splitting the morning peak (from 06:00 to 11:00) into 31 periods, and the DNL traffic simulation time step is 2 seconds. The total travel demand on the whole network (in the reference strategy) is 473869 travelers. The model is calibrated using dynamic loop detector data on many locations on all three motorways such that model outcomes in the reference strategy (without PAYD) replicate the measured link loads, densities, and travel times with sufficient accuracy.

MODEL RESULTS

The seven PAYD strategies and the references case were all evaluated using the case study network. The different strategies are then compared to assess the impact of different differentiations of PAYD on network conditions and traffic safety.

Safety effects of PAYD

An optional flat kilometer based PAYD premium has the smallest effect on traffic safety (about 1%). As a result of the flat kilometer based premium, participants will reduce the number of trips and choose different routes. While the reduction of trips leads to gains in traffic safety, the route changes do not in this case. The flat premium causes routes that are shorter to become more attractive. These shorter routes tend to contain more lower level roads, which have a higher risk associated with them. If the flat PAYD premium is made obligatory, it seems that the effect on traffic safety is less than double. This would be the case when assuming a linear response to increasing participation, which means that, even more than in the case with optional PAYD, drivers tend to use unsafe routes.

If the PAYD premium is differentiated towards road category, a much larger effect on traffic safety is found (2.5%). In this case drivers respond to the PAYD premium by reducing the number of trips but also by using safer routes. If this PAYD premium is made obligatory, the safety effect more than doubles (to 5.7%). This, larger than double, safety effect is caused by an increase in the congestion on the motorways, which leads to an additional reduction of trips.

Finally the PAYD premium was differentiated towards young drivers. In this case all young drivers are required to have PAYD insurance. A reduction of about 2% in crashes was found in this case. Since young drivers have a lower value of time, they react more strongly to the cost of insurance. So even if the young drivers account for only a proportion of the demand, the safety effect is higher than the case where a flat PAYD insurance is imposed on all drivers. This difference is caused by the different assumptions about choice behavior (elasticity, departure time choice and value of time).

To summarize, the results (see Figure 2) show that the higher the level of differentiation of the PAYD premium towards traffic safety aspects, the higher the traffic safety effects. Since the reduction of trips and safe route choice play a large role in achieving traffic safety effects these effects are presented in more detail.

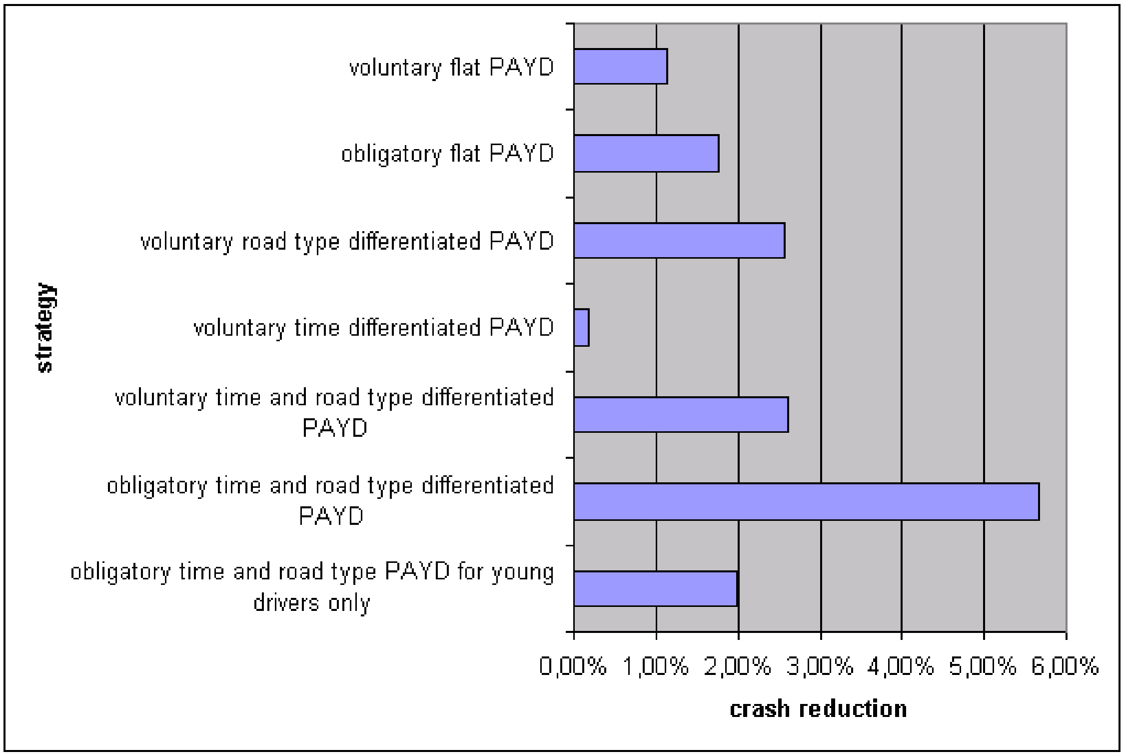

Figure 2: Crash reduction per strategy

For each of the PAYD strategies that were evaluated, Figure 3 shows an example of the route choice effects that occur for an example OD pair. For this OD-pair there are four routes available. For each route a safety indicator was determined, which depends on the road types and volumes of the links in the route. In the figure the routes are ordered towards traffic safety index (the index of the safest found route is set to 100). The lower the index, the less safe the route. From a traffic safety point of view traffic should, as much as possible, use route 1, then route 2 followed by 3 and 4. Without PAYD route 2 is however the most chosen route as it is the fastest route to the destination. When PAYD is differentiated towards road type, the share of route 1 can almost be doubled, at the expense of all other, less safe, routes.

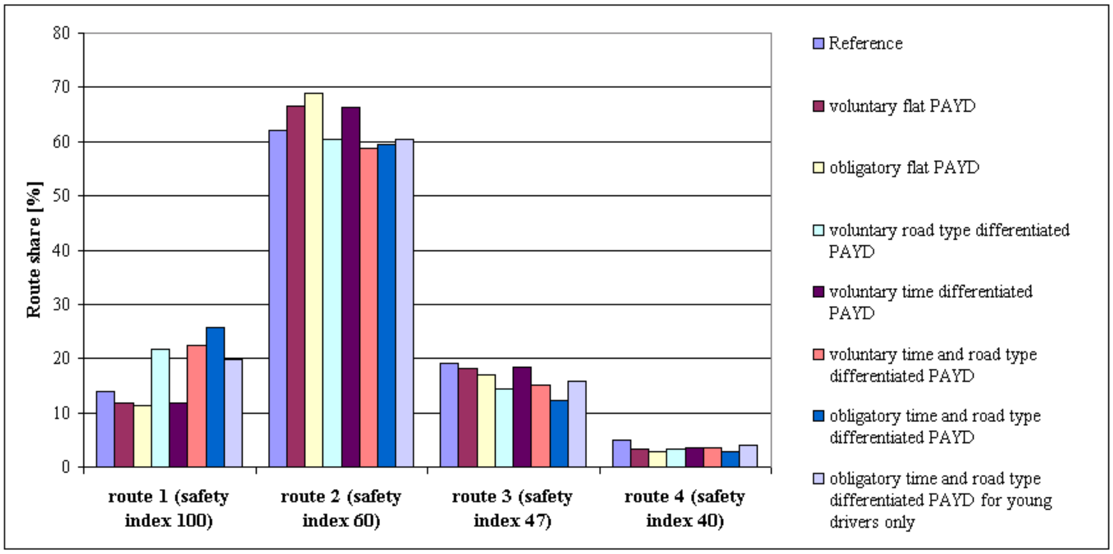

Figure 3: Example of effect of PAYD differentiation on route choice

Effects of PAYD on network performance

Since improving traffic safety is not the only objective of policy makers, the changes in network conditions were analyzed. Figure 4 shows the changes in average travel time for the different PAYD strategies. The results show that when PAYD is differentiated towards road category, the highest traffic safety benefits can be acquired, while as a result the traffic conditions deteriorate when PAYD is obligatory (reaches high participation levels). This is caused by the safer route choice of travelers towards the motorways. In the case study these motorways are already at capacity and the added traffic leads to more congestion. However, the total amount of traffic on the arterials is far lower then the traffic on the main motorway, reducing this effect. Another afterthought is that in the transportation model the junction delays on lower level road were not yet taken into account. This means that the difference between flat and road type differentiated PAYD will in reality be smaller.

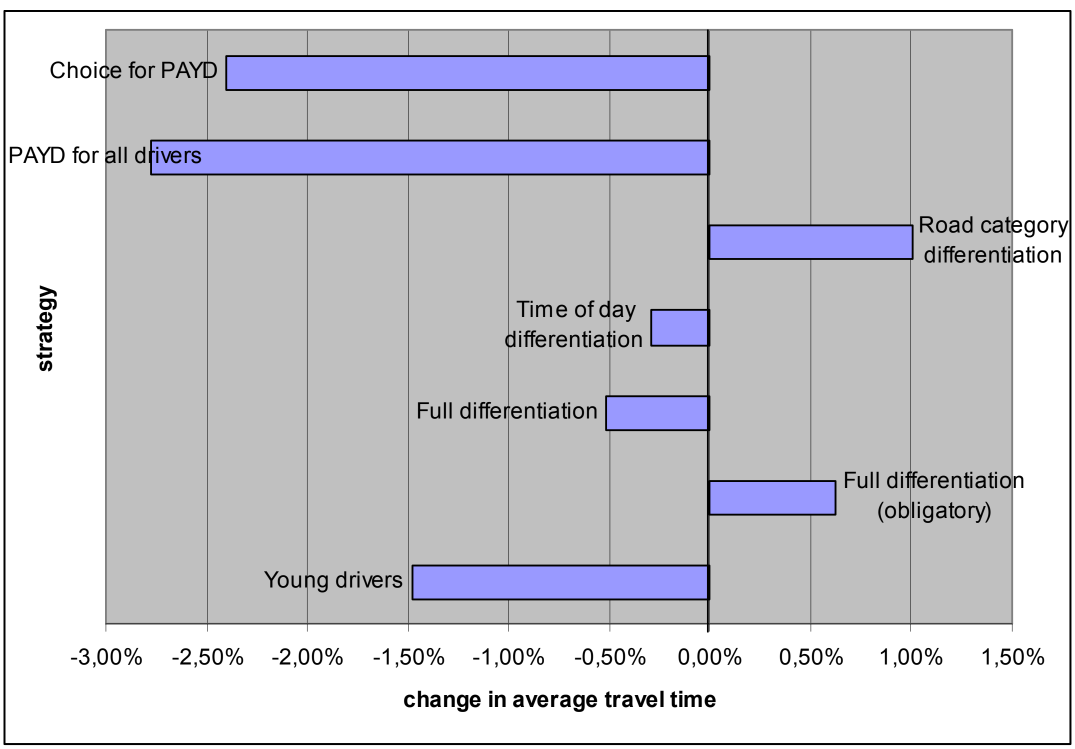

Figure 4: changes in average travel for different PAYD strategies

CONCLUSIONS

The results of the study for the seven PAYD strategies show that system 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 choice (elastic demand effect) and route choice. In mode or trips choice, drivers decide to make fewer trips or to use another mode, to save on insurance premium. With all PAYD strategies, drivers tend to reduce the number of car trips made. With route choice, the PAYD participants attempt to find the route with the lowest generalized cost, taking into account that different road types may have different insurance fees per kilometer. Participation level only has an effect on the level of the network effects and no additional responses are found.

For network effects, the level of mobility 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. Note that the best option to increase safety, i.e. by introducing a road category dependent insurance fee in which motorways are cheapest and (inter)urban roads are most expensive, leads to the worst mobility effects with an increase in the average network travel time.

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.

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

ACKNOWLEDGEMENTS

We are grateful for the funding this research receives from Goudappel Coffeng B.V., the TRANSUMO “Verzekeren per kilometer” research project., and the Next Generation Infrastructures (NGI) research project in the Netherlands. We would also like to thank the anonymous reviewers for their constructive comments.

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