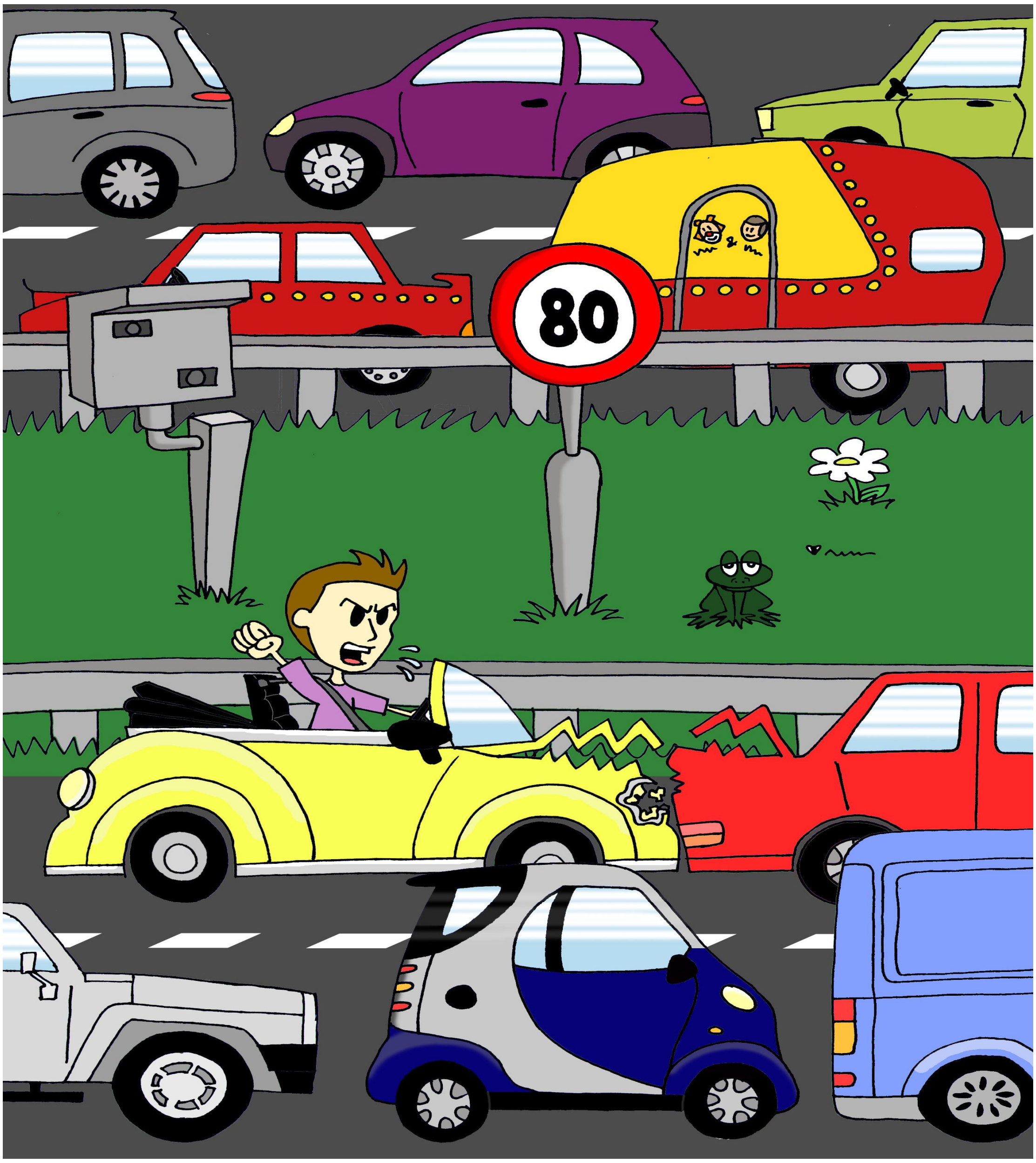
80 Kilometer zones: Safer before or after?

A closer look at the impact of a speed limit reduction on four Dutch motorways



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Abstract

This thesis discusses the combined impact of a reduction from 100 km/h to 80 km/h and permanent speed enforcement on accidents, for four Dutch motorways. Chapter 1 introduces the main question: "What is the impact of the 80 kilometer zones policy on road safety?" and is answered in Chapter 5. Current literature regarding speed, road design and speed enforcement is reviewed and analysed in Chapter 2. The chapter points out the added value of using control groups to correct for trends and regression and two stage least squares analyses to improve statistical validity of the results. Chapter 3 notes that Difference-in-Differences is rejected as a method due to violation of permanent trends assumption and presents regression and two stage least square analysis as valid tools to analyse the relationship between speed and accidents. Chapter 4 presents the results from the regression and two stage least square analysis. The reduction in speed limit reduced the speed and the amount of accidents. An additional effect of enforcement was not found. As speed is a significant factor affecting accidents, Chapter 5 concludes with the final outcome: The introduction of the policy helped reducing speed and accidents and did not cause any spill over effects. Increased speed enforcement help to improve traffic flow, contrary to previous literature, camera's itself did not affect accidents, only speed. Future research could test if the observed results hold in general, irrespective of road type and surrounding.

Executive Summary

Chapter 1 describes the 80 kilometer policy introduction and scope. The thesis analyses the relationship between the introduction of the policy, speed and safety and answers the main question: “What is the impact of the 80 kilometer zones policy on road safety?”

Chapter 2 discusses the theoretical background and the current literature about speed, design variables, speed enforcement and accidents. Decreased maximum speeds yield between 0% and 50% less accidents. Traffic and design features like ADT, lane width, road gradient and curvature have a significant effect on accidents too, however, these factors are harder to adjust. Finally speed enforcement has a positive net effect in the reduction of accidents between an average of 20 to 35 percent. This chapter concludes with noting the added value of using control groups and two stage least squares analyses to overcome methodological issues.

Chapter 3 introduces the six hypotheses that are tested in Chapter 4. Next, the selection of control groups, statistical methodology based on characteristics is presented. Difference-in-Differences is rejected as a tool, due to violation of the parallel trends assumption. Regression and two stage least squares analysis are selected as statistical tools. Data is obtained from various sources and limitations like availability, registration rate and regime are discussed. A detailed description of both regression and two stage least squares, the assumptions and limitations is supplied at the end of the chapter.

Chapter 4 presents the results from the regression and two stage least square analysis. Due to symmetrical relationships between the dependent and independent variables, instead of regression, two stage least square analyses, is used. A test for the instruments of posted speed reduction and enforcements yields a significant reduction in speed due to a lower limit and enforcement. Speed is tested significant in reducing accidents, thus the policy proves effective and enhances safety on the zones. Comparing adjacent motorways accidents to the national trend, no evidence of spill over effects is found.

Chapter 5 answers the main question: “What is the impact of the 80 kilometer zones policy on road safety?” The policy reduces the average speed, reducing accidents and improving safety, without compromising network safety. Accident registration improvement helps improving the validity of the found results. Furthermore another study on more rural and different types of roads could reveal if the results found in this thesis hold in general.

Preface / Voorwoord

For my grandmother, Willy Varwijk / Voor Oma, Willy Varwijk 7/2/1919 – 9/5/2011

Deze scriptie betekent het eind van een hoofdstuk en de start van een nieuw hoofdstuk. Terugkijkend op mijn studie periode kan ik zeggen dat ik er zeer van genoten heb; van start tot einde, van college tot scriptie. Ik heb ook dingen gedaan die ik niet van mijzelf verwacht had: voorzitter worden van een studievereniging, hoe je beeld door iets kan veranderen is enorm. Dit is ook iets wat een studie en alles eromheen moet doen, je beeld veranderen, je breder maken en vooral jezelf eens goed een spiegel voorhouden. Deze scriptie is een voorbeeld van die spiegel, hij reflecteert wat jij in de afgelopen jaren bereikt hebt en hoe je dit invult, dit is ook iets wat bij wetenschap hoort, de continue reflectie van bestaande regels, procedures, aannames en vooral een kritische houding. Voor het tot stand komen van deze scriptie was toch enige hulp nodig. Iedereen die heeft meegeholpen wil ik hiervoor bedanken, maar een aantal mensen in het bijzonder. Vooral de mensen bij de Dienst Verkeer en Scheepvaart wil ik bedanken voor hun opmerkingen, suggesties en in het bijzonder wil ik Joris Kessels, en Henk Stoelhorst bedanken voor hun begeleiding, antwoorden en kritische kanttekeningen. Verder zijn er een aantal mensen, die op de achtergrond vooral morele steun hebben gegeven, ten eerste mijn ouders en broer, die mijn humeur van tijd tot tijd verdragen hebben en mijn vrienden, die ook hun tips en uitleg over stata (Remco bedankt!) hebben gegeven. Ten slotte wil ik mijn begeleiders, Peran van Reeven en Hans van Kippersluis, bedanken voor hun commentaar en hun kritische houding, waardoor ik een betere beschrijving van mijn denkproces heb neergezet. Ze hebben ook van tijd tot tijd mij de nodige hoofdpijn bezorgd met de nodige suggesties, maar ik heb ze met plezier overgenomen. Het resultaat, daar ben ik trots op en hoop ik een bijdrage te leveren in de discussie rondom snelheid en veiligheid op de Nederlandse wegen.

H.G.H. Visser

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Introduction

In November 2005 the Dutch national government instituted four motorway zones with a lowered maximum speed limit from 100 to 80 km/h. A permanent speed enforcement system was added to enforce the reduced speed. The four sections are highlighted with a purple marking on the map.

Map 1: 80 kilometer zones highlighted in purple, created on National Geographics Maps Maker Interactive at *www.education.nationalgeographic.com/education/mapping/interactive-map*

The aim of the lower speedlimit is to reduce the emissions and noise burden caused by traffic. Additionally, the change in policy should not have a negative impact on road safety and congestion. Rijkswaterstaat, the Dutch National Road Directorate, concludes in a 2007 review that the amount of accidents was reduced significantly. (Rijkswaterstaat, 2007) This improvement represents an external cost reduction leading to economic savings.[1] This analysis omits the impact of changing factors, spill over effects and offers no explanation for the observed result. The use of control

[1] Costs for an accident range from minor damage to the car and passenger, accidents leading to hospitalisation (€258.834) or even deadly accidents (€2.528.445) and costs due to time losses (ranging from €5,86 to €41,54 per hour). Source: SWOW, factsheet verkeersongevallen and KPVV, rekenen aan verkeershinder. Both available through their websites, no links due to changing locations.

groups to accounts for a trend in data and applying two stage least squares analyses corrects for a symmetrical relationship between various variables. Finally, spill over effects are analysed, to assess if no shifts of accidents to connected sections has occurred.

The thesis focuses on the impact of the policy on safety and answers the following research question: “What is the impact of the 80 kilometer zones policy on road safety?” An integral approach to safety is applied and includes an analysis of spill over effects. A simple regression is used to explore possible variables and a two stage least square analysis is selected as the statistical method, as it is more robust than regression and accounts for reversed causality between the dependant and independent variable. The method tests which variable is significant and test if the instrument used (Speed reduction) is significant. In the final two chapters, the results are discussed using the current literature as a reference point and conclusions based on the results are drawn.

The thesis contains 5 Chapters and starts with Chapter 1, this introduction. Chapter 2 describes the problem statement, scope and current literature. Chapter 2 concludes with formulating the hypotheses which are tested in Chapter 4. Chapter 3 covers the statistical methodology and starts with illustrating the chosen statistical method and the assumptions which are tested later. Next a description of the data and the characteristics is provided and the impact on the analysis is discussed. Chapter 4 discusses the results and reflects these using Chapter 2. Chapter 5 contains the conclusions and policy recommendations for the policymaker. Finally, suggestions and recommendations for further research are made.

Chapter 2 - Literature review

This chapter describes the current literature and discussion. The last section illustrates why current methods do not reveal the true relationship between speed, road design, enforcement and accidents.

2.1 Changes in speed limits

This section serves as the theoretical base, it discusses current literature and provides the background of subject and analysis. The most recent research from other scholars and institutions is used to examine the relationship between speed, other factors and accidents.

The relationship between speed, design variables and other controllable factors is an important topic reflected by literature. Speed is an important factor contributing to accidents, it determines the probability of involvement and the severity of the accident. (Aarts, 2004) The relationship between speed and accidents is not a 1-on-1 relationship, the actual speed is influenced by the human-vehicle-environment, which is determined by the type of road and (design) characteristics, traffic variables, incidents and other non observable variables (e.g. driver attitude, traffic composition).[2] Various scholars examine the relationship between speed and accidents and the impact of a change in posted maximum speed limit, especially in the USA, parts of Europe and Australia, the issue of safety and speed is well covered. An overview of various studies and their results is described in table 1.

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[2] Suggestion for further reading: Feng (http://safety.fhwa.dot.gov/speedmgt/ref_mats/fhwasa09028/resources/TRR1779-SynthesisofStudies.pdf) and SWOV (2004) Snelheid, spreading in snelheid en de kans op verkeersongevallen, downloadable from the website, www.swov.nl

Table 1: *Overview accident impact of speed changes*

Author	Country	Change km/h (Posted)	Change in accidents	Methodology
Rijkswaterstaat (1989)	NL	+ 20 km/h	- 3 %	Before and after study of entire network
Farmer et al. (1999)	USA	+ 16,1 km/h	+15% to 17%	Before and after study, 12 groups, 18 control groups.
Peltola (2001)	FIN	- 20 km/h	- 14%	Before and after study, only seasonal change.
Rijkswaterstaat (2003) appendix A	NL	- 20 km/h	- 46%	Before and after study, period unclear.
Kloeden (2004)	AUS	- 10 km/h	- 19,7%	Before and after, treated section with control group (all other)
Elihu et al. (2004)	IL	+10 km/h	+24% to +50%	Before and after studies,
Woolley (2005)	AUS (states)	- 10 km/h	0 to – 25,3%	Before and after, same sections
Kockelman (2006)	USA	+ 16,1 km/h	+ 3%	Regression, 35 states, 10 changed speed.
Vejdirektoratet (2008)	DEN	+ 20 km/h	+ 9%	Before and after study. Limited change on urban motorways

Peltola (2001) studied a seasonal change in speed limit and found that a reduction in accidents took place, whereas this could be a temporal change and a possible increase during summer. Rijkswaterstaat (2003) reports a decrease of accidents on the A13 motorway, though the before period covers a larger timeframe than the after period, where in reality a stable or even an increase is the real outcome. Woolley (2005) has different outcomes for different area’s, using only one variable in a before and after study, making interpretation of the results difficult, this could be explained by other non-observed factors. Woolley (2005) and Elihu et al (2004) differentiate between urban and non-urban, and report different outcomes for each level. This difference could be explained by non-observed variable (e.g. driver behaviour) or traffic and design variables. Research from Farmer (1999) and Kockelman (2006) in the USA has different outcomes, partially explained by different selection of treated and control groups. This raises questions if the selection criteria, included variables and techniques used are valid. Kockelman (2006) uses a regression to explore the relationship between the amount of accidents and posted speed limits and other static factors. This approach fails to incorporate the actual speed, which is a better predictor and observes a change in behavior more accurately. Furthermore regression does not address the different initial endowment points and assumes that a linear relationship exists, whereas the real relationship could be exponential. This approach does not correct for possible reversed causality between variables, causing invalid results. Elihu et all. (2004) show a significant increase after the raised speed limit in Israël, therefore raising questions if this is peak in accidents is actually permanent or an outlier. Kloeden (2004) compares the treatment roads with all other non-treated groups, where possible spill over effects as suggested by Elihu et all (2004) are assumed zero, and could lead to faulty conclusions. Finally an increase in speed, from 100 km/h to 120 km/h in The Netherlands has lead, according to Rijkswaterstaat (1989) a reduction in accidents. However, this reduction is relatively small and could be attributed to a longer time trend, rather than policy. The Vejdirektoratet (2008) for example, notes a larger increase, but only analyses a short period of time, omitting trends as well.

One notable observation, found throughout all studies is the actual change in speed of the drivers, is marginally, ranging from 0.5 km/h to 7 km/h. This change reflects a smaller impact on actual speed than expected based on the change in posted speed limit. No explanation is offered for the phenomena in neither study, but indicates that results can partially be attributed to the change in the speed limit.

2.2 Design features and speed enforcement

Speed is one factor influencing the amount of accidents; the road design, weather, location and other characteristics are key factors in explaining accidents. Hadi et al. (1995) examine this relationship using negative binomial Poisson regression for the state of Florida. ADT, lane with, type of median, length and speed limits are noted as significant, whereas median width didn't prove significant. They note that length and speed limits are positively significant, reducing the amount of accidents. This result is not incorporating the actual speed and possibly explains why this relationship is found. Milton and Mannering (1998) analyse data from the Washington metropolitan area, using negative binominal poisson regression, and suggest that section length, gradient, ADT, traffic composition, road width and curves (design) have a significant influence on the amount of accidents. This result is reproduced by Kockelman (2005), linear regression as well, for 30 other states and confirms these factors for other locations within the USA. Milton and Mannering, Kockelman and Hadi et al. only tested design factors however, (human) factors such as: actual speed, homogeneity of traffic and other non-observed factors haven't been tested but affect speed and (in)directly, the amount of accidents. Therefore, these methods might cause over dispersion towards the applied variables, omitting important predictor variables and could suffer from distortions in data like trends. Both forms of regressions do not account for initial endowment and assume a general constant factor.

Furtermore, the introduction of permanent speed enforcement system (trajectcontrole) could have a separate, additional or combined effect as well. Literature regarding speed enforcement is vast, Wilson et al. (2011) conducted a review of existing literature and concluded the following: *All 28 studies found a lower number of crashes in the speed camera areas after implementation of the program. In the vicinity of camera sites, the reductions ranged from 8% to 49% for all crashes, with reductions for most studies in the 14% to 25% range. (...) The studies of longer duration showed that these positive trends were either maintained or improved with time. (..) A reduction in the proportion of speeding vehicles (drivers)* *over the accepted posted speed limit, ranged from 8% to 70% with most countries reporting reductions in the 10 to 35% range.* Speed camera's are suggested to be an instrument to reduce accidents and speed, questions arise if enforcement itself could cause a reduction in accidents, as the effect of the speed reduction could be more significant. Furthermore most of these studies are conducted on different types of roads than urban highways, which have other features and factors influencing accidents and safety, causing different outcomes across the board.

Contrary to Rijkswaterstaat (1989), Farmer (1998), Kockelman (2006), Vejdirektoratet (2008), this thesis uses control groups to account for trends in data. The inclusion of control groups also allows to test if the policy (instrument) had a significant effect on safety. Contrary to all studies, this thesis uses the V85 speed which represents the speed which is respected by 85 percent of the drivers, as this reveals the real change in speed, rather than reduced limit. Usage of the real speed provides a more realistic image of how speed and other variables affect accidents. Regresssion is used by Kockelman (2006) to analyse the relationship between various variables and their impact accidents. Regression assumes that no causal relationship exists between exploratory variables, suspicion arises that some variables do interact. Using two stage least squares analyses corrects for these interaction effects, by the use of instruments. The change in speed limits and speed enforcement are instruments which this thesis uses to correct interaction effects. None of the previous research investigate the possibility of spill over effects, as suggested by Elihu, to adjacent sections, whereas safety as a whole should not decline due changes in speed on the 80 kilometer sections. The accident count on all adjacent roads are plotted and compared to the national trend to investigate if these effects occur. Finally, the author has suspicion that weather and economic variables to influence speed and accidents and are included in the tests. Weather affects speed, therefore is included in the two stage least squares. Economic variables could reveal increased demand for transportation and a reduction in speed due to congestion.

Chapter 3 - Statistical Analysis

Based on the previously discussed literature, hypotheses are formulated to help answering the main question. A description of the selection process for the preferred testing method is given and continues with presenting the data which is used to run the test. In the final section, a detailed description of the statistical tests is given.

3.1 Hypotheses and control group selection

This thesis aims to answer the following main question: “What is the impact of the 80 kilometer zones policy on road safety?” To provide a comprehensible answer, 6 hypotheses, based on the literature, are formulated and tested:

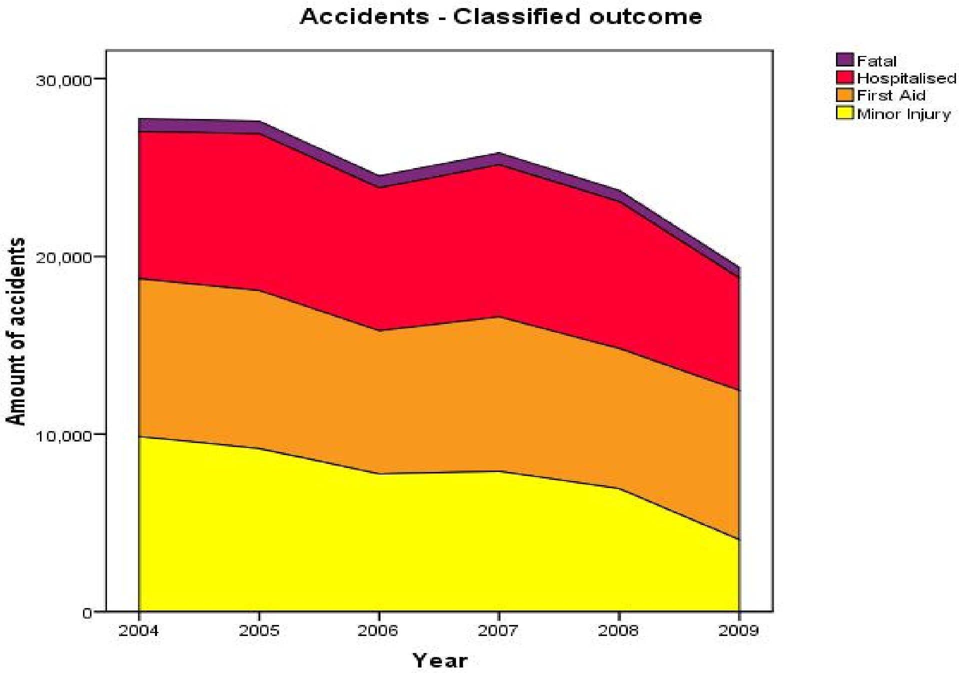
- H1: The introduction of 80 kilometer show a significant reduction in the 85^{th} percentile speed.
- H2: Road- design and characteristics are significant predictors for the amount of accidents.
- H3: Other variables (e.g. GDP and weather) show a significant relationship with accidents.
- H4: The implementation of the 80 kilometer zones shows a significant effect on accidents.
- H5: The implementation of permanent traffic speed monitoring has a significant effect on safety.
- H6: Spill over effects occur.

These hypotheses are tested using variables obtained from various data sources. First, the national trend is presented to understand the setting and assist in further analysis. Figure 1, on the next page illustrates the national trend for the Netherlands from 2004 to 2009 is shown. The total amount shows a steady decline and did so during the last decade.[3]

[3] See CBS and DVS statistics on the next page.

First, the decline can be attributed to increased safety measures, but in section 3.3 it is illustrated that more factors contribute to this decline. Second, note especially minor injuries and first aid accidents show the strongest decline. Finally, the severe accidents (deadly, hospitalized) do not show a decline and accidents with hospitalized victims' shows a small increase relative to all other accidents.

Figure 1: *National accident count – The Netherlands, source: DVS, CBS*



This trend in data causes overestimation in the results obtained by before and after studies like Peltola (2001), Rijkswaterstaat (2003), Elihu et al. (2004), Woolley (2005), Vejdirektoratet (2008) and regression like Kockelman (2006). Using control groups accounts for this pitfall and provides results adjusted for trends in data. Selection of control groups is based on criteria noted in Chapter 2 and include human factors, traffic and design variables. Expert opinions from the staff of DVS confirmed[4] these factors based on previous research and noted that ADT, amount of lanes, ramps, location are determinants on the outcomes. For human factors, traffic and design

[4] The experts where consulted separately and each was asked which criteria they suggest to select control groups

variables, the Randstad area and the city ring of Brabant[5] form the pool of possible control groups. Traffic composition is an important factor and is taken into consideration as well. Based on the selection criteria, expert opinions from DVS, a the final selection is presented below on map 2. A detailed overview is provided in Appendix B.

Map 2: *80 zones and different control groups*

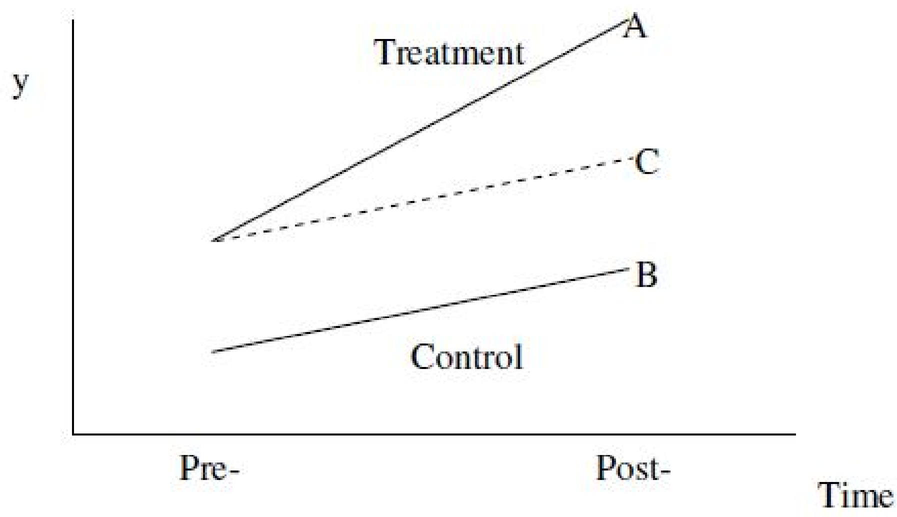
Red: 80 zones Green: Groups without enforcement Purple: Enforcement zones

[5] The Randstad area is roughly the provinces of North and South Holland, Utrecht and part of Gelderland. The city ring of Brabant is the area between Breda and Eindhoven.

3.2 Statistical test selection

The policy introduction can be described as a natural experiment where treatment is given (speed reduction in conjunction with permanent speed enforcement) and compare the result to a control group, which did not receive the treatment. The Difference-in-Differences estimator is a tool to assess the impact of a policy, a drug or any other 'treatment' given to a group or groups, hence it could be a tool to statistically test our hypotheses. However, it only uses one dependent variable and does not incorporate independent variables. Examples of DiD usage include; changes in competition Hastings (2004) and policy by Meyer (1995). Figure 2 illustrates the method graphically. The DiD is calculated by a special form of regression analysis and controls for differences in levels between treatment and control groups[6]. DiD assumes parallel trends through time for both the treatment and control group and a constant treatment effect is assumed.

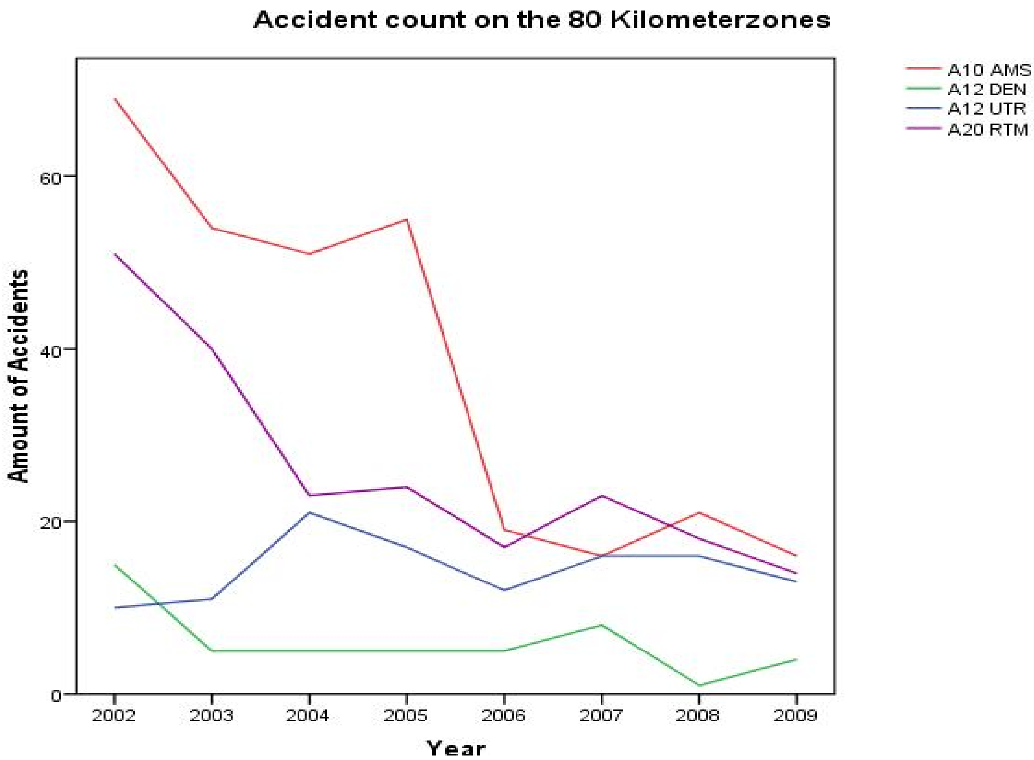
Figure 2: *DiD graphical representation. DiD Estimator is AC*



[6] More about the DiD estimator, see appendix E

First, a test for the assumptions of the DiD estimator is performed. The treatment is constant, the 80 kilometer zones where kept at the designated speed at all times. To test the trend assumption, an overview of the amount of accidents for the 80 kilometer zones is illustrated in graph 3.. Next, the developments in all control groups are illustrated in graph 4 and 5. Due to the timing of the policy, all data has been adjusted to reflect the implementation.[7] The graphs illustrate a much more diverse development through time than initially expected. Some sections show a decline through time, the 80 kilometer zones, A2 Eindhoven, A9 Amstelveen and the A16 Rotterdam. Others show a more erratic development or remain nearly flat. A parallel trend cannot be extrapolated from these observations, violating one of the assumptions of the DiD analysis, making outcomes invalid. Based on the previous, other statistical tests like regression and two stage least squares are more suitable to use.

Figure 3: *80 kilometerzones, group 1 to 4. Appendix B illustrates which number belongs to which road section. Legenda is in ascending order.*



[7] The 80 speed limit started on the 1st of November 2005. Therefore the count for 2005 starts at the 1st of November 2004 till the 31st of October 2005 and so on.

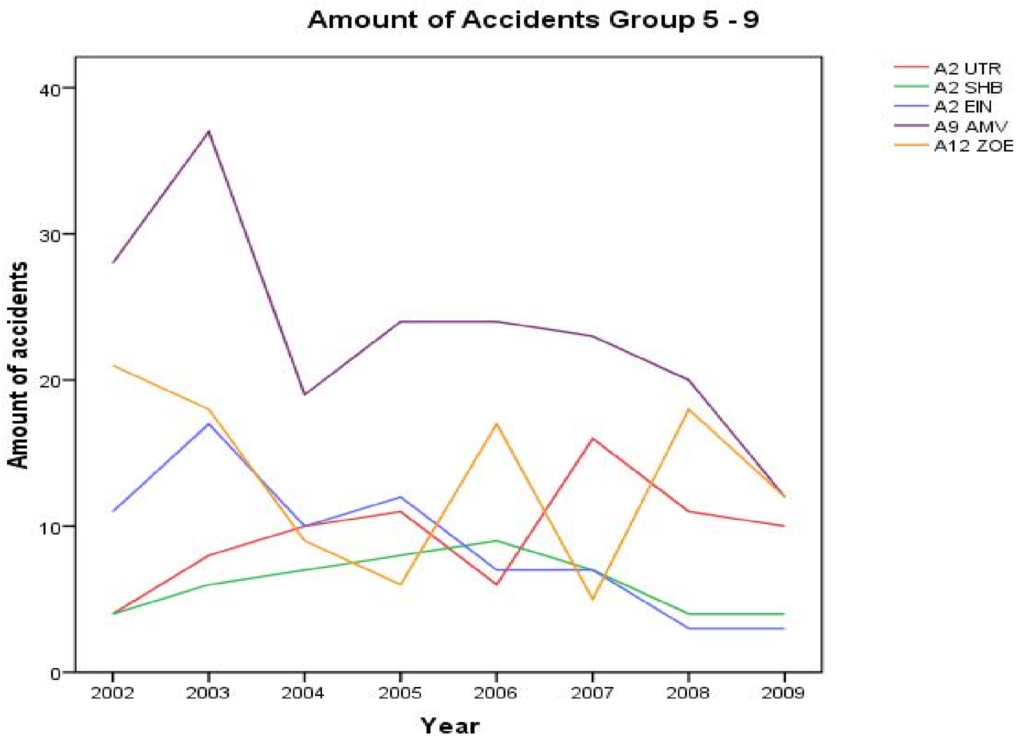
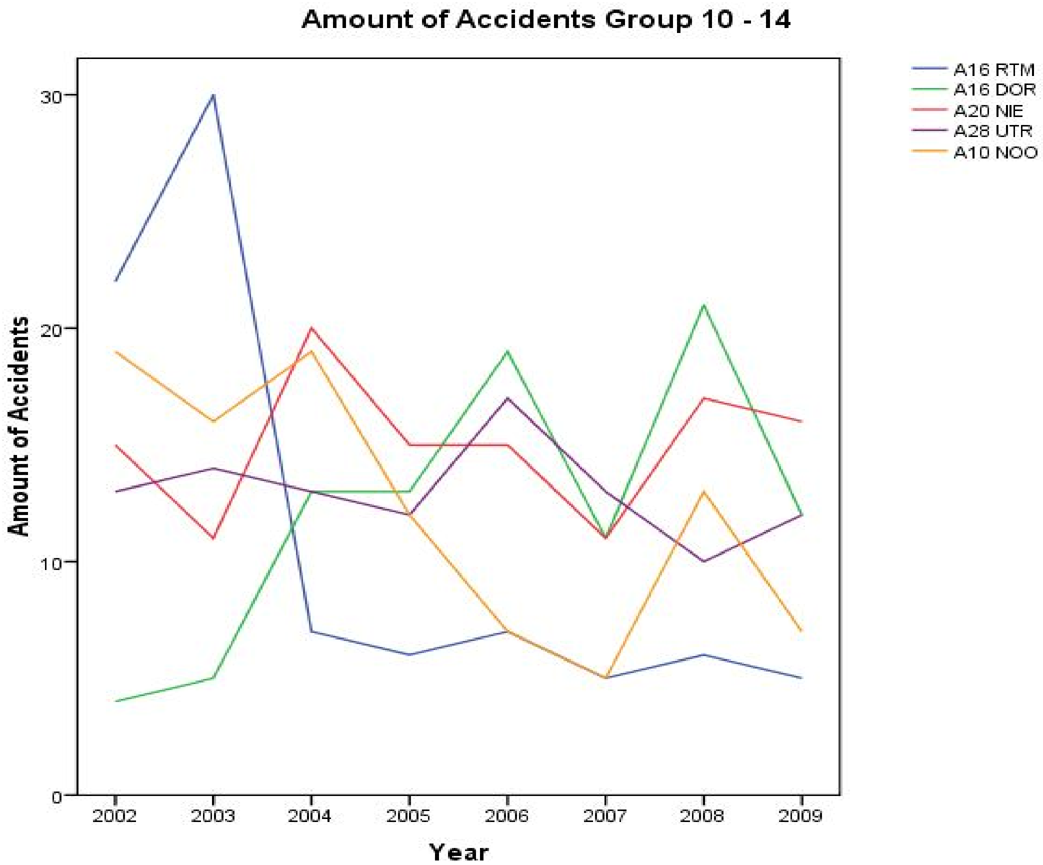


Figure 4 and 5: *Accident count on control groups*



3.3 Variable selection and data description

Based on conclusions from Chapter 2 design, traffic and other variables are selected. Design variables include ramps, length[8], curvature, median width and gradient. Second, other variables could be ADT, average speed and speed violators. Furthermore the economic variable GDP is added as a variable, to capture the increased demand and increased congestion as a result. Finally weather related variables are considered for the models, based on the influence of weather on actual driven speed. Traffic and design variables, based on the data availability, are ADT (INT), average speed (VGmid), length, and ramps. To test if the weather has a significant influence on speed and on accidents, we test various variables like days of rain (RAD), the total amount of rain (RTA), average duration of rain (RDU)and the intensity of rain during a rainy day (RAI). Furthermore we add economic variables like the Gross Domestic product (lnGDP), gasoline (diesel) and fuel prices (euro), which could explain the impact of the costs of driving and increased congestion on speed and accidents. Speed enforcement is noted as Contr. and is a binary variable. Each variable and source is illustrated and the limitations of the data presented, we start with the response variable and continue with the exploratory variables and conclude with data transformation.

The accident data is supplied by the Data ICT Dienst (DID) of Rijkswaterstaat, part of the Ministry of Infrastructure and Milieu. The data is collected by the Dutch police based on the Proces Verbaal (PV)[9] or minutes of the accident registration done by the attending officers. The information from the PV is digitalised, loaded into a central database for accident registration and is available to the DID/DVS. The database contains information about the accident, the time, the location, the severity and the amount of casualties. The dataset however, has limitations. The following apply:

[8] Only length and ramps are used as variables, data on other variables was not available.

[9] The Proces Verbaal is the police document which describes the aspects of the accident, for example, the persons involved, the cars involved, the damage, the casualties, the severity of the injury and a recap of the accident.

- A police PV is needed for an accident to be an ‘official one’, hence accidents without a PV go unregistered.
- Human error could lead to a faulty classification and incomplete data. Incomplete data has been removed and represented < 10% of data for an entire motorway. Accidents from 100 outside the selected groups are added as well, due to a possible error of the noting the wrong hectometer, as the spot where the accident happened.
- Not all deadly accidents are registered as such. For example, if someone drives into a tree and dies (suicide), this is not an official death count. Neither is a murder, this is excluded as well.
- Driving under influence of alcohol or drugs, as stipulated by article 8 of the Dutch Traffic Law and causing an accident is kept separate.
- The reported accidents (deadly, hospitalised) versus the actual accidents are showing a steady decline. For deadly accidents, the reduction is modest, in 2001, 91% of total amount was reported, down to 84% in 2010, this is illustrated in figure 6. For hospitalised, in 2001, 69% was reported, down to 49% in 2009[10]. For less serious incidents, these numbers are unknown. For minor injuries and material damage only, the registration rate is expected to be even lower.[11]

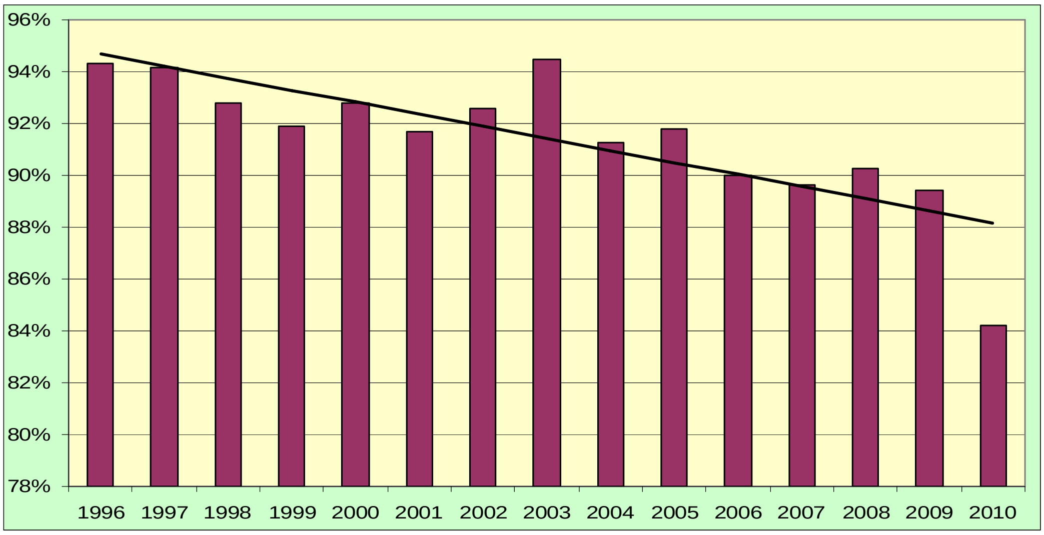


Figure 6: *Registration rate of deadly accidents, presented by M. de Wit and P. Mak; accident registration 20 juni 2011. Based on COGNOS database.*

[10] Source: SWOV COGNOS database
[11] Due to the nature of the accidents, they mostly do not require police assistance and can be dealt with by the involved persons and their insurance company’s. In 2009, nearly 2 million damage reports where filed by the insurance companies in 2009 and less than 10000 are officially reported by the police.

A final and separate note, road works impact the day to day operation of a motorway, causing possible crashes and affecting speed. The author investigated this variable in the dataset, but did not find a relationship between road works and accidents, therefore it is excluded as a variable.

Traffic data like the ADT and Speed is monitored for locations if road loops are present, or for ADT, a manual count is executed and is recorded by the DID. The average speed is based on the V85[12] of September and May[13], excluding seasonal effects. Weather related data is sourced from the KNMI[14], based on the closest observation location to the motorway. Finally, the GDP and fuel/gasoline prices are sourced from the CBS. GDP is recorded yearly, fuel prices monthly.

First the data[15] is transformed into yearly statistics, with a year being the 1st of November of last year the virtual start and the 31st of October of the designated year the last date, reflecting the policy implementation. The transformation to yearly variables is based on the limited amount of accidents per month and improves robustness. All accidents (regardless of type) are counted as one, splitting the accidents into typologies and analyse each separately would be impossible due to low rate of each separate group. Finally the complete set has been transferred to a STATA database and prepared for statistical testing.

[12] The V85, a variable that represents the speed that 85 percent of the drivers do not pass.
[13] If only one month was available, this is used as the average. Individual differences between months where less than 0.2 km/h.
[14] KNMI = The Royal Dutch Meteorological Institute, comparable to the English MET office.
[15] GDP is the only exception to this rule.

3.4 Selected methodology

This section further illustrates the statistical tests and assumptions, starting with regression and continuing with a two stage least squares analyses. The results are reported in Chapter 3. and conclusions and recommendations based on the outcomes are reported in Chapter 4.

We need to establish if the relationship between our variables is valid and assess how they interact with each other, to test this, we run a regression analysis[16]. Regression is a powerful tool to explore the relationship between one dependant variable (response variable, Y) and multiple independent (exploratory variables $U_1..U_i$) with a respective coefficient β and an error term ε. A general regression equation is described as:

$$\mathrm{Y} = \alpha + \beta_1 * U_1 + .. + \beta_i * U_i + \varepsilon \text{ with i = 1 .. v}$$

Regression analysis assumes:

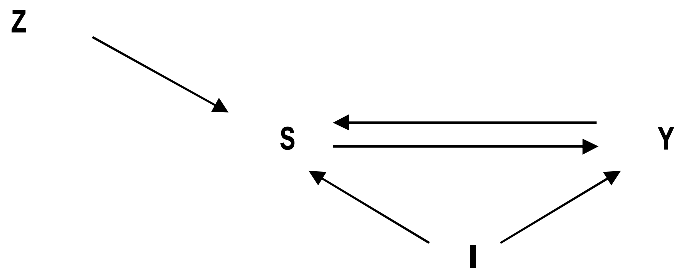
- A linear relationship
- Use of relevant (independent) variables
- Independent variables cannot be highly correlated, this leads to multicollinearity and inaccurate estimators of the coefficient β.
- No heteroscedasticity of the error term; the error term is constant and should not show a particular pattern. This could otherwise lead to insignificant variables to become significant leading to false conclusions. In an optimal situation, the error term is close to 0.

Regression assumes all variables are exogenous and are explained outside the model, except the response variable Y which is endogenous. As noted earlier, speed and accidents have reversed causality, hence making speed and endogenous variable and explained within the model. The introduction of an instrument (or policy) allows

[16] The description in the thesis covers the basics about regression. A (very) detailed description is obtainable at: http://www.law.uchicago.edu/files/files/20.Sykes_.Regression.pdf

to predict the endogenous variable, accounting for the reversed causality and includes the effect of non observed variables on the variable S. The relationship is illustrated in figure 7.

Figure 7: *relation between speed (S), the amount of accidents (Y), the instrument (Z) and a non observed variable (I)*



A two stage least squares regression solves the endogenous relationship by using an instrument(s).[17] In the first stage, U_1 is regressed and the instrument (τ) tested. The results from the first stage, the predicted values for U_1 are used in the second stage together with the other variables to create a regression with Y_1 as a the response variable and produces the respective coefficient (β) for each variable. The process is illustrated below:

The initial regression:

$$Y = \alpha + \beta_1 * X_1 + .. + \beta_i * U_i + \varepsilon_i$$

with *i* = 1 .. v

Is split up into two stages:

$$Y_1 = \alpha + \beta_1 * \hat{U}_1 + .. + \beta_i * U_i + \varepsilon_i$$

$$U_1 = \alpha + \beta_1 * Y_1 + .. + \beta i * \tau + \beta_i * U_i + \eta_i$$

with *i* = 1 .. v

[17] The instrument has to be correlated with the variable of interest for reasons that can be verified an explained. And the instrument has to be uncorrelated with the outcome beyond the variable of interest. For the motorways, the introduction of the 80 kilometer maximum speed combined with permanent speed camera's is our instrument

This is a cross sectional analysis which assumes independent results. We use the same road sections in the panel, hence the observations are dependent. As a correction, we add a time coefficient to the two stage least square function. Furthermore the initial endowment point of each road section is different. To account for this difference, we assume fixed effects. These fixed effects are constant through time and reduces the unobserved variable bias.

After these changes, the relation becomes:

$$Y_{it} = \alpha i + \beta_1 * \hat{U}_{1t} + .. + \beta_i * U_{it} + \varepsilon_{it}$$

$$U_{1t} = \alpha_i + \beta_1 * Y_{it} + .. + \beta i * \tau + \beta_i * U_{it} + \eta_{it}$$

with i = 1 .. v and t = 2002 ... 2009

Due to the fixed effects assumption, the constant, α_i , is excluded, furthermore time invariant variables are assumed to be part of the fixed effects. The assumptions for the two stage, least square analysis are similar to regression:

- A linear relationship
- No heteroscedasticity of the error term; the error term should be constant throughout and not show a particular pattern. This could otherwise lead to insignificant variables to become significant leading to false conclusions. In an optimal situation, the error term is close to 0.
- Endogenity of the variables; only applies to cross sectional two stage least square analysis.
- A valid instrument or instruments need to be applied to correct for the symmetrical relationship.

The instrument also determines if the outcomes are valid, as weak instruments do not fully correct the symmetry, leading to ambiguous results. Furthermore, the methodology does not account for underlying mechanisms and overestimation is a risk. Finally, the results cannot be extrapolated into a general rule of thumb, due to the changes in the underlying relationships.

Chapter 4 – Results and outcomes

This chapter presents the results of the various statistical methods and reflects them. First, the outcomes from the regression are presented and analysed. Second, the two stage least square outcomes are presented and interpreted. Finally, we check if there is any evidence for spill over effects.

4.1 Regressions

First a regression of all selection variables is run, the results are shown in table 2. Next the correlation is estimated and based on this pre-assessment, variables are excluded from further research. A variable is tested using the t-stastic for significance. We use an alpha of 5 percent, a variable is significant if the power is smaller or equal to 0.05. Note that the amount of observations is limited due to data availability, conclusions should be reviewed, taking this into account.

Table 2: *Regression using all variables*

Source	SS	df	MS
Model	6921.93646	11	629.266951
Residual	3799.99211	44	86.3634571
Total	10721.9286	55	194.944156

Number of obs =	56
F(11, 44) =	7.29
Prob > F =	0.0000
R-squared =	0.6456
Adj R-squared =	0.5570
Root MSE =	9.2932

TAC	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnINT	3.05725	7.865862	0.39	0.699	-12.79535	18.90985
euro	-.8934899	.5919175	-1.51	0.138	-2.086421	.2994414
diesel	.9547177	.3999525	2.39	0.021	.1486663	1.760769
lnGDP	-60.42423	45.25503	-1.34	0.189	-151.6298	30.78129
VGmid_02	.2707368	.1703597	1.59	0.119	-.0726007	.6140743
length	-2.099357	1.55315	-1.35	0.183	-5.229526	1.030812
ramps	6.78263	1.193382	5.68	0.000	4.377527	9.187733
RAI	.1037627	.0592249	1.75	0.087	-.0155973	.2231227
RAD	-.4581113	.2022823	-2.26	0.029	-.8657845	-.050438
RDU	1.073997	1.234308	0.87	0.389	-1.413587	3.561582
RTA	.9988949	.6916927	1.44	0.156	-.3951201	2.39291
_cons	819.0859	558.3714	1.47	0.150	-306.2376	1944.41

Table 3: *Correlation between the different variables.*

	TAC	euro	diesel	length	ramps	RAI	RTA	RDU	RAD	lnGDP	lnINT	VGmid_02
TAC	1.0000											
euro	-0.3361	1.0000										
diesel	-0.2910	0.9765	1.0000									
length	0.2480	-0.0000	0.0000	1.0000								
ramps	0.6107	-0.0000	0.0000	0.5672	1.0000							
RAI	0.2772	0.0777	0.0511	0.2330	0.2561	1.0000						
RTA	-0.0315	0.2788	0.2882	-0.0146	0.0585	-0.0743	1.0000					
RDU	-0.0074	0.0299	0.1078	0.1469	0.0552	-0.1281	0.6645	1.0000				
RAD	-0.1130	0.4111	0.4820	0.0655	0.0829	0.0251	0.7491	0.7895	1.0000			
lnGDP	-0.3813	0.9033	0.8581	0.0000	-0.0000	-0.0540	0.1378	-0.0155	0.2233	1.0000		
lnINT	-0.0979	0.0115	0.0135	-0.7633	-0.2968	-0.0934	0.0769	-0.0888	0.0022	0.0277	1.0000	
VGmid_02	-0.0738	-0.2717	-0.2557	0.1915	-0.3795	-0.0317	-0.1457	0.0394	-0.1312	-0.2727	-0.3674	1.0000

Table 2 on the previous page illustrates a regression of the dependent variable TAC, the Total Accident Count and other variables like INT, euro, diesel, lnINT, lnGDP, VGmid RTA, RAD, RDU and RAI. It shows only ramps, diesel and RAD are significant at the five percent level. Speed is not a significant variable, but notably RAD is the only weather significant variable, whereas others are near significant. Other variables like length, RDU, INT show high levels of insignificance. These findings can be influenced by interaction effects. We use correlation to see if these effects occur and regress again with non-interacting variables. A variable has perfect positive (1), or negative (-1) correlation with respect to another, or no correlation at all (0). Any number between is the degree to which variable A and B interact with each other. Table 3 illustrates the correlation coefficients, euro, diesel and GDP show strong signs of correlation with each other. First of all, the prices of fuel are linked to each other, as both are refined oil products. Their strong correlation with the GDP also makes sense, as oil prices tend to follow the economic trend. Based on this logic, we remove the diesel and euro variable due to their mutual correlation and the correlation with the GDP. Weather variables like RAD, RDU and RTA show signs of strong correlation too (>0.6), which can be explained by their nature. If it rains, a certain amount drops in a certain timeframe, as it seems, for a longer period of time, there is a shared average.

Table 4: *Regression of selected variables, corrected for multicollinarity*

Source	SS	df	MS
Model	7354.10959	6	1225.68493
Residual	6500.6956	70	92.8670801
Total	13854.8052	76	182.300068

Number of obs	= 77
F(6, 70)	= 13.20
Prob > F	= 0.0000
R-squared	= 0.5308
Adj R-squared	= 0.4906
Root MSE	= 9.6368

TAC	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnINT	5.51928	5.785699	0.95	0.343	-6.019932	17.05849
lnGDP	-35.69745	13.49173	-2.65	0.010	-62.60585	-8.789054
VGmid_02	.1591793	.1220044	1.30	0.196	-.0841508	.4025094
length	-.4475584	1.162266	-0.39	0.701	-2.765624	1.870507
ramps	5.829512	.9440097	6.18	0.000	3.946744	7.71228
RAI	.0679932	.0543274	1.25	0.215	-.0403595	.1763458
_cons	398.6155	193.0775	2.06	0.043	13.53461	783.6963

In table 4, the outcome of a regression, using the uncorrelated variables is presented. Ramps, lnGDP are the only significant factors, VGmid, RAI and lnINT insignificant and length by an even larger margin. Ramps are significant and have a negative impact on safety, this is reflected by observations in the dataset, accidents tend to happen where users interact. These interactions happen at ramps, junctions and other merging and seperation area's. The natural logarithm of the GDP has a negative impact, thus when GDP increases, a decline in accidents follows, this could point toward an advancing safety in cars.[18] Length is insignificant contrary to expectations, whereas a longer section of road is expected to have more accidents. The ADT does not offer any additional power as well, where we would expect it an increase of traffic to increase the chance of getting into an accidents, due to more interaction moments. Finally, speed is not signficant, in contradiction to what is expected from literature. Hence, there could be other confounding factors, or a relationship between the response variable and exploratory variable. Speed is influenced not only by the driver, but also by weather, accidents and other drivers. To account for this relationship, we start by using a two stage least square analyses in Section 4.2 and discuss the outcomes.

[18] E.g. improved sensors for distance, airbags and construction advancement.

4.2 Two stage Least squares

Table 5: (*cross sectional) two stage least squares analysis outcomes*

Number of obs	= 77
F(7, 69)	= 54.83
Prob > F	= 0.0000
R-squared	= 0.8476
Adj R-squared	= 0.8322
Root MSE	= 6.0548

VGmid_02	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
RAI	-.0016839	.0343984	-0.05	0.961	-.0703068	.066939
lnGDP	-35.14078	8.960636	-3.92	0.000	-53.01676	-17.2648
lnINT	.2173981	3.685553	0.06	0.953	-7.13508	7.569876
length	2.230648	.6832886	3.26	0.002	.8675246	3.593772
ramps	-2.625383	.5240586	-5.01	0.000	-3.670852	-1.579915
Speedmax	.7744654	.077909	9.94	0.000	.6190411	.9298897
Contr	9.118493	1.935945	4.71	0.000	5.256389	12.9806
_cons	465.4411	124.9622	3.72	0.000	216.1482	714.7339

Instrumental variables (2SLS) regression

Number of obs	= 77
Wald chi2(6)	= 86.01
Prob > chi2	= 0.0000
R-squared	= 0.5306
Root MSE	= 9.1906

TAC	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
VGmid_02	.1360396	.1509031	0.90	0.367	-.1597251	.4318042
RAI	.0673575	.0518797	1.30	0.194	-.0343249	.1690398
lnGDP	-36.50308	13.29494	-2.75	0.006	-62.56068	-10.44548
lnINT	5.645754	5.542801	1.02	0.308	-5.217937	16.50944
length	-.3098123	1.247342	-0.25	0.804	-2.754557	2.134933
ramps	5.720198	1.008269	5.67	0.000	3.744026	7.696369
_cons	409.2887	189.3982	2.16	0.031	38.07515	780.5023

Instrumented: VGmid_02
Instruments: RAI lnGDP lnINT length ramps Speedmax Contr

From table 5 note that our instruments, the introduction of a reduced speed limit (Speedmax, the instrument) and permanent speed enforcement (Contr) are significant in the first stage, making them strong instruments which correct the relationship between the various variables. During the second stage ramps is significant as a predictor for accidents. The cross sectional analysis does not account for the dependency of the various observations, as the observations are the same motorway sections during different years. A Woolridge test with a value of 0.1209 confirms autocorrelation between the error term and a variable, based on this test, lnINT is removed as it is correlated to the GDP. The Xtivreg command in stata allows the program to recognise this dependency. The results from this adjustment, using a panel based two stage least square analysis is noted in table 6.

Tabel 6: *(panel) Two stage least squares accounting for dependency, results*

```
Fixed-effects (within) regression               Number of obs      =        92
Group variable: Group                           Number of groups   =        12

R-sq:  within  = 0.5870                         Obs per group: min =         7
       between = 0.6984                                        avg =       7.7
       overall = 0.6652                                        max =         8

                                                F(4,76)            =     27.00
corr(u_i, Xb)  = 0.4861                         Prob > F           =    0.0000
```

VGmid_02	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
RAI	-.0075314	.0118773	-0.63	0.528	-.0311871	.0161242
lnGDP	-18.84583	3.800421	-4.96	0.000	-26.41502	-11.27663
Contr	2.268083	1.186853	1.91	0.060	-.0957396	4.631907
Speedmax	.5435289	.0819975	6.63	0.000	.3802169	.706841
_cons	287.6727	50.7179	5.67	0.000	186.6593	388.6862
sigma_u	9.9858841					
sigma_e	2.5221689					
rho	.94003221	(fraction of variance due to u_i)				

F test that all u_i=0:   F(11, 76) =   66.76   Prob > F = 0.0000

```
Fixed-effects (within) IV regression         Number of obs      =        92
Group variable: Group                        Number of groups   =        12

R-sq:  within  = 0.3304                      Obs per group: min =         7
       between = 0.0392                                     avg =       7.7
       overall = 0.0032                                     max =         8

                                             Wald chi2(4)       =    450.24
corr(u_i, Xb)  = -0.9544                     Prob > chi2        =    0.0000
```

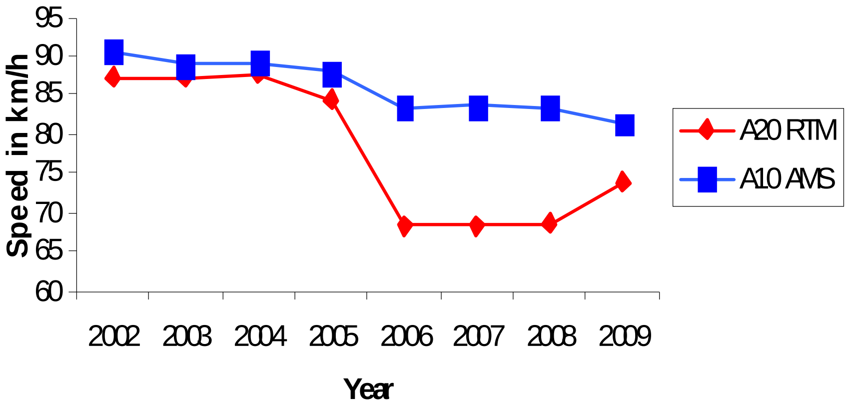
TAC	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
VGmid_02	2.764066	.4723671	5.85	0.000	1.838244	3.689889
RAI	.0322379	.0369315	0.87	0.383	-.0401466	.1046223
lnGDP	28.45887	14.91242	1.91	0.056	-.7689261	57.68667
Contr	-.1707192	3.263224	-0.05	0.958	-6.566521	6.225083
_cons	-624.2691	226.594	-2.76	0.006	-1068.385	-180.153
sigma_u	45.121922					
sigma_e	7.8972541					
rho	.97027832	(fraction of variance due to u_i)				

F test that all u_i=0:   F(11,76) =   13.65   Prob > F   = 0.0000

Instrumented: VGmid_02
Instruments: RAI lnGDP Contr Speedmax

In the first stage, the instrument Speedmax is significant and reduces the actual speed. This confirms the observed reductions in Chapter 2. Speed camera's do not reduce speed as much as a posted reduction, they enforce the maximum and help to limit extremes and do not have an additional effect on accidents when the posted limit is lowered, as observed in the second stage. To fully verify this, an additional instrument needs to be added, testing a speed reduction, without additional speed enforcement, on motorways for the Netherlands. The author examined this option, but concluded that suitable sections and data for this test are lacking. Contrary to earlier studies about speed camera, the camera itself does not reduce accidents, it does however, lower speed and thus accidents. GDP decreases speed, due to increased demand for mobility as GDP rises, leads to increased congestion.

Figure 8: *Speed development on two 80 zones.*



The implementation of the zones reduced the speed on average, by 10 km/h. Comparing this with previous literature, in which reductions ranging from 0.5 to 7 km/h where realised, this reduction is higher. As speed camera's smoothing traffic and, as illustrated in the first stage, increase speed, this difference. Based on these results hypothesis 1 (H1) is not rejected, as the policy reduced the 85th percentile speed, figure 8 illustrates this reduction after implementation of the policy in 2005.

During the second stage, the predicted speed is used and regressed with all variables on the total amount of accidents. First, ramps and length are omitted, as illustrated in Appendix D, this because we use a fixed effects model and as they remain constant over time, they are excluded from this analysis. Based on regression, we do argue that they do contribute to amount of accidents, but due to model assumptions, cannot be further tested. Hypothesis 2 is therefore not rejected, due to the outcomes of regression. Second, RAI and lnGDP are not significant, VGmid is significant, assuming a alpha of 5 percent. The weather, according to this analysis, has no influence on the amount of accidents. An explanation for this phenomena is adjusted driver behaviour, which anticipate better and allow larger margins. GDP is significant in reducing speed, but does not lower accidents by itself, which could be explained by the increased road usage. Therefore Hypothesis 3 is rejected.

Speed is significant with a p-value of 0.000 and (a rounded) coefficient of 3. Based on the literature discussed in Chapter 2, the result confirms earlier findings about the relation between speed, a reduction and the related amount of accidents. Suspicion arises that the factor 3 is overestimated, when compared to the coefficient of the regression and literature. This overestimation might be caused by the limited amount of observations, combined with the range (between 68 km/h and 123 km/h) in which these observations are. Even if overestimated, a reduction maximum allowed speed helps to reduce the amount of accidents on the motorway when compared with various control groups. The overall safety therefore benefits from a reduction in speed. This confirms hypothesis 4, as the introduction of the 80 kilometer zones reduced the speed by 10 km/h, as this reduced the amount of accidents. Hypothesis five is rejected, as permanent enforcement has no effect on speed and thus accidents.

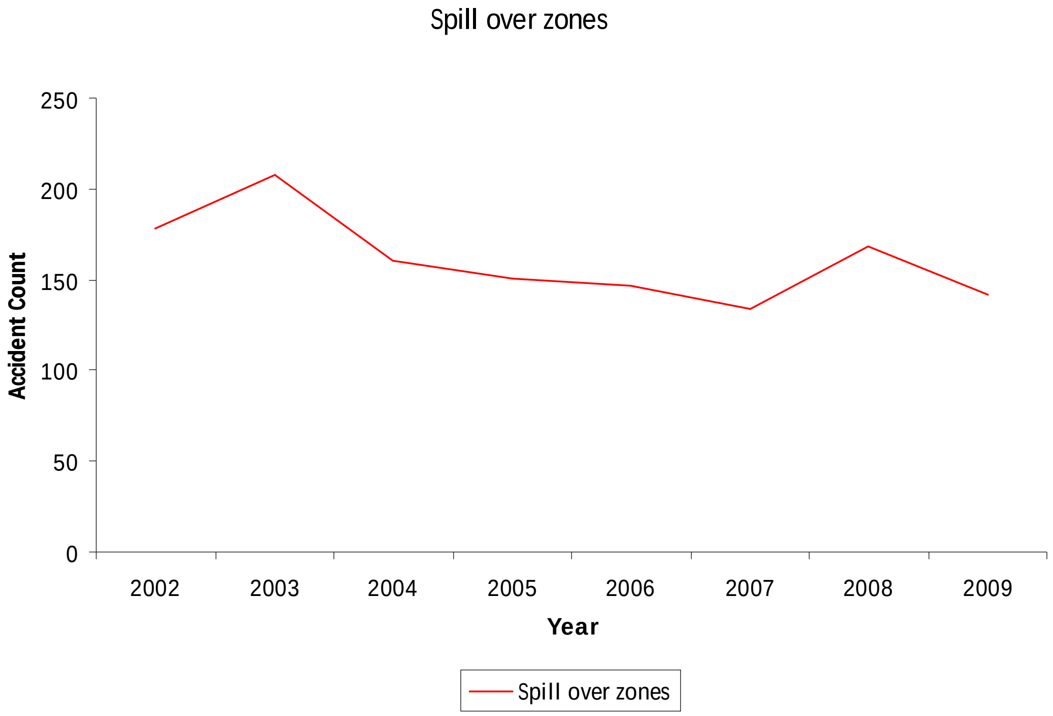
The results need to viewed into the current setting. All groups represent roads with high levels of ADT, short sections, many ramps, motorway features and often urban surroundings. The amount of observations is limited, this could cause a bias, or overestimation, for example, speed as a factor. The underlying mechanisms of the system are not incorporated into the two stage least square analysis and cannot be extrapolated. The analysis does reveal the important factors and points towards an overall positive effect on safety by the implementing a reduced speed on the selected motorways.

This thesis takes an integral approach to safety for network, the next section checks if no spill over effects occur on adjacent motorways.

4.3 Other results and observations

As suggested by Elihu et al. (2004), spill over effects could occur on adjacent road sections of the 80 kilometer zones, reducing overall network safety. This shift in accidents could be caused by changes in behavior and traffic. In figure 8, a plot of the accident count on all adjacent sections to the 80 kilometer zones is displayed. The decline of accidents, in accordance with the trend illustrated in figure 1 on page 14, is observed. After the implementation of the zones in 2005, no increase in accidents is noted, neither a weaker decrease. Though one could argue that the decrease in 2008 is a lagged reaction, this is unlikely due to the immediate correction afterwards. More likely, this is a peak, the same kind of peak measured in 2003 but overall, the declining trend as depicted in figure 1 is still observed. The graph shows no evidence for a partial or a permanent spill over effect, hence hypothesis 6 is rejected. The changes implemented on the 80 kilometer zones have no negative impact on adjacent motorways and the safety of the motorway network as a whole, maintained.

Figure 9: *Accidents on the spill over zones*



Chapter 5 - Conclusions and recommendations

5.1 Conclusions and reflection

The implementation of the 80 kilometer zones on four motorways has external effects, accidents is of them. The (negative) external costs associated with accidents are costs incurred by the general public and translate to an economic loss. This thesis investigates the relationship between the introduction of the policy, speed and safety and answers the main question: "What is the impact of the 80 kilometer zones policy on road safety?" To provide an answer on the main question, the following six hypotheses are formed and tested:

H1: The introduction of 80 kilometer show a significant reduction in the 85^{th} percentile speed.

H2: Road- design and characteristics are significant predictors for the amount of accidents.

H3: Other variables (e.g. GDP and weather) show a significant relationship with accidents.

H4: The implementation of the 80 kilometer zones shows a significant effect on accidents.

H5: The implementation of permanent traffic speed monitoring has a significant effect on safety.

H6: Spill over effects occur.

Hypothesis 1 is not rejected, based on the two stage least square analysis from Chapter 4, which reveals that the implementation of the policy reduced the speed significantly. This confirms earlier results from literature discussed in Chapter 2. Hypothesis 2 is not rejected, based on the regressions from Chapter 3. Due to assumptions for the two stage least square analysis, no further evidence could be found to reject this hypothesis. ADT has been removed due to interaction with GDP as the GDP explains an increase in traffic. Hypothesis 3 is rejected, based on analysis from Chapter 3 as neither proved significant in reducing accidents. GDP however does reduce speed, therefore a partial effect is observed. Hypothesis 4 is not rejected, as the two stage least square analysis reveals that the zone policy is effective in lowering speed and speed a significant factor for accidents, hence the policy reduced the amount of accidents. However, the exact magnitude seems overestimated, when comparing the literature from Chapter 2 and the regression analysis. Still, a significant reduction can be attributed to this policy change. Hypothesis 5 is rejected, contrary to outcomes as reported by Wilson (2011) from various studies regarding speed camera's and accidents. The enforcement is a weaker instrument than a speed reduction, as it does not alter the limit, only enforces it. This implies that a camera does reduce speed, but the camera itself does not directly reduce accidents. Hypothesis 6 is rejected, no evidence of short, or long term spill over effects could be found when comparing them to the trend illustrated in figure 1. The increased safety on the treated motorway section, did not affect adjacent sections negatively. The results need to be viewed in light of the restrictions of the data and chosen methodology. However, the analysis reveals important factors and points towards an overall positive effect on safety by the implementing a reduced speed on the selected motorways.

Now, the main question posed in the introduction is answered: "What is the impact of the 80 kilometer zones policy on road safety?" The implementation of the policy reduced the speed on the zones and through the statistical test, revealed that this speed reduction had a significant negative effect on the amount accidents. The observed lower speed can be attributed to a reduction in maximum speed. Additional effects from permanent enforcement where limited, as they have a stronger effect on speed, rather than accident. The policy implementation did not cause a shift of accidents to other adjacent sections of motorway, the safety of the network as a whole did not deteriorate and increased on the 80 kilometer zones.

5.2 Recommendations and final remarks

The following recommendations are split between the Netherlands and recommendations in general.

For the Netherlands:

- Improved registration of all accidents, including accidents that incur the Dutch article 8 violations, the ‘driver suicides into a tree’ accidents and in general a more precise tracking of the persons involved. Better registration provides a more detailed insight into the actual amount of casualties that eventually die as a result of the accident. This also provides more reliable data, which allows better policy and accident analysis.
- In general, road data is available, but sometimes not logged enough (weather data) or selectively available (speed data), which makes pre-selection of study objects difficult and limits validity. The choice the policymaker needs to make is if this is worth the effort.
- Analyse if a speed reduction without permanent enforcement proves as effective as the 80 kilometer zones. This also provides a better understanding how the speed choice is influenced, either by posted speed, enforced speed or accepted speed relating to the road.
- Policymakers need to assess how the balance between time savings, costs and safety is made. Investments in road safety could lead to long term benefits and should not only be judged by short term costs.

In general:

- An integral approach to safety should be aspired. Analyse if spill over effects occur, the suggestion from Elihu has been reviewed in this thesis and refuted, however, it could hold in other countries and locations due to changing environments.
- If a researcher conducts this type of investigation for his/her country, provide an English summary as well, it makes comparing results easier, reduces any translation errors and provides a better understanding of safety related research, policies and their impact.

- Include the registration rate of accidents in your analysis of safety, as a reduction in accidents could be attributed to a decrease in registration quality instead of policy.
- Future research should focus on which adjustment (in design, speed or other measures) proves most effective in reducing accidents. This allows policymakers to make better assessments on which field they want to invest or improve.
- Additional research towards the change in driver behavior, linked towards the different scenarios. This helps to understand the different attitudes and why behavior changes after policy implementation.
- Another study could test if the observed results hold in general, or if other factors contribute to a different. By using rural motorways and roads as groups, comparing results with this thesis, such results could prove important for making policy decisions about speed and safety.

Finally the author would like to express his gratitude for the cooperation from Rijkswaterstaat in supplying him with the necessary data and background information to perform this analysis, without this cooperation, this thesis would not be realized.

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List of terms used:

ADT: Average Daily Traffic

CBS: Centraal Bureau voor de Statistiek

DiD: Difference-in-Differences

DID: Data ICT Dienst

DVS: Dienst Verkeer en Scheepvaart

GDP: Gross domestic Product

INT: short for the Dutch intensiteiten, translates to ADT

KNMI: Koninklijk Nederlands Meteorologisch Institutuut

PV: Process Verbaal

RWS: Rijkswaterstaat

RAI: Rain Average Intensity, proxy for the average rain per shower, yearly

RAD: Rain Amout of Days, amount of days of rain per year

RDU: Rain Duration, the average during of a rain shower per year

RTA: Rain Total Amount, the total amount of rain per year

SWOV: Stichting Wetenschappelijk Onderzoek Verkeersveiligheid

VGmid: Average speed per year on the motorways.

V85: The speed which 85^{th} percent of the drivers do not cross.

Zone: Instrument, implementation of a speed reduction from 100 km/h to 80 km/h

Appendix A - Results A13 Motorway study Rijkswaterstaat.

Richting	Traject	Aantal ongevallen		Aantal slachtoffers	
		Voor	Na	Voor	Na
Westbaan (Den Haag-Rotterdam)	Stroomopwaarts	75	72	16	11
	Maatregelwegvak	26	16	5	3
	Stroomafwaarts:	111	94	14	18
	- A20 richting Oost	82	74	11	17
	- A20 richting West	29	20	3	1
Oostbaan (Rotterdam-Den Haag)	Stroomopwaarts	118	94	20	15
	- A20 vanuit Oost	56	58	9	8
	- A20 vanuit West	62	36	11	7
	Maatregelwegvak	58	28	8	4
	Stroomafwaarts	60	67	11	31

Tabel 3. Vergelijking aantal ongevallen / slachtoffers in naperiode (2e halfjaar 2002) en voorperiode (dezelfde periode 1997 t/m 2001)

Table from Rijkswaterstaat (2003) p. 27. This table illustrates the Ammount of Accidents (Aantal ongevallen) and Ammount of Victims (Aantal slachtoffers) before (voor) and after (na) the implementation of the of the policy.

Appendix B – Treatment, control and enforcement groups

A2 = Motorway

- X en X = Between section X and section X, (..) group – max speed.

** = 80 kilometer zones, reduction from 100 km/h to 80 km/h*

^ = speed enforcement zones

A2
- Knooppunt Oudenrijn en Everdingen (5) – 100 km/h
- Knooppunt Vught en Knooppunt Hintham (6) --120 km/h
- Knooppunt Batadorp en de Hogt (7) – 100 km/h

A4
- Hoofddorp en Nieuw Vennep (17)^ - 120 km/h

A9
- Knooppunt Badhoevedorp en Holendrecht (8) – 100 km/h

A10
- *de Coentunnel en Knooppunt de Nieuwe Meer* (1)*
- Knooppunt Coenplein tot de Zeeburgertunnel (14) – 100 km/h

A12
- *Voorburg en Den Haag* (2)*
- *Knooppunt Oudenrijn en Knooppunt Lunetten, alleen de paralelbanen* (3)*
- Afslag Zoetermeer Centrum tot Knooppunt Prins Clausplein (9) – 120 km/h
- Afslag De Meern en afslag Woerden (18)^ - 120 km/h
- Knooppunt Velperbroek en Knooppunt Waterberg (15)^ - 100 km/h

A13
- Tussen afrit Berkel en Rodenrijs en Knooppunt Kleinpolderplein (16)^ - 80 km/h

A16
- Drechttunnel en afslag ’s-Gravendeel (10) – 100 km/h
- Afslag IJsselmonde en afslag Kralingen (11)v- 100 km/h

A20
- *Knooppunt Kleinpolderplein en Crooswijk* (4)*
- Knooppunt Terbregseplein en afslag Nieuwekerk aan den IJssel (12) – 120 km/h

A28
- Knooppunt Rijnsweerd en Den Dolder (13) – 100 km/h

Appendix C - DiD estimator

TABLE 1	Before	After	Increase
Treatment group	α	α + γ	γ
Control group	α + β	α + γ + β + δ	γ + δ
Difference	β	δ + β	δ (DiD estimate)

Mathematically the model is the following:

1) Treatment effect is constant over time

$\delta = Y_{1,i} - Y_{0,i}$

2) For the use of a regression model we note the following equation

$Y_i = \alpha + \beta T_i + \gamma t_i + \delta(T_i \cdot t_i) + \varepsilon_i$

3) If we include more covariates into the model, the equation becomes

$Y_i = \alpha + \beta T_i + \gamma t_i + \delta(T_i \cdot t_i) + X_i\lambda + ... + \varepsilon_i$ [19]

The coefficients and variables have the following interpretation for the 80 kilometer zones:

Y_i = The amount of accidents at time i.

α = Constant term over time

β = Treatment group specific effect[20]

T_i = Treatment group is 1, or 0 otherwise

γ = Time trend common to control and treated groups

t_i = Time, 1 for t = 1 and 0 for otherwise

δ = True effect of treatment

X_i = Other observed variables (e.g. average speed)

λ = Effect of other variables

ε = Error term for each unit at each time period

[19] There is also an option to extend the model even more with time and group specific covariates, see Buckley & Shang (2003)

[20] Accounts for average permanent differences between the treatment group and the control group.

Appendix D – Stata output, Fixed effects

Fixed-effects (within) regression — Number of obs = 92
Group variable: Group — Number of groups = 12

R-sq: within = 0.5870 — Obs per group: min = 7
between = 0.6984 — avg = 7.7
overall = 0.6652 — max = 8

F(4,76) = 27.00
corr(u_i, Xb) = 0.4861 — Prob > F = 0.0000

VGmid_02	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
RAI	-.0075314	.0118773	-0.63	0.528	-.0311871	.0161242
lnGDP	-18.84583	3.800421	-4.96	0.000	-26.41502	-11.27663
Contr	2.268083	1.186853	1.91	0.060	-.0957396	4.631907
length	(omitted)					
ramps	(omitted)					
Speedmax	.5435289	.0819975	6.63	0.000	.3802169	.706841
_cons	287.6727	50.7179	5.67	0.000	186.6593	388.6862
sigma_u	9.9858841					
sigma_e	2.5221689					
rho	.94003221	(fraction of variance due to u_i)				

F test that all u_i=0: F(11, 76) = 38.11 Prob > F = 0.0000

Fixed-effects (within) IV regression — Number of obs = 92
Group variable: Group — Number of groups = 12

R-sq: within = 0.3304 — Obs per group: min = 7
between = 0.0392 — avg = 7.7
overall = 0.0032 — max = 8

Wald chi2(4) = 450.24
corr(u_i, Xb) = -0.9544 — Prob > chi2 = 0.0000

TAC	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
VGmid_02	2.764066	.4723671	5.85	0.000	1.838244	3.689889
RAI	.0322379	.0369315	0.87	0.383	-.0401466	.1046223
lnGDP	28.45887	14.91242	1.91	0.056	-.7689261	57.68667
Contr	-.1707192	3.263224	-0.05	0.958	-6.566521	6.225083
length	(omitted)					
ramps	(omitted)					
_cons	-624.2691	226.594	-2.76	0.006	-1068.385	-180.153
sigma_u	45.121922					
sigma_e	7.8972541					
rho	.97027832	(fraction of variance due to u_i)				

F test that all u_i=0: F(11,76) = 6.50 Prob > F = 0.0000

Instrumented: VGmid_02
Instruments: RAI lnGDP Contr length ramps Speedmax