CHALMERS
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The Power Model

A Validation of the Model's Applicability in Sweden

Master's Thesis in the Master's Programme Infrastructure and Environmental Engineering

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ABSTRACT

The Power Model, seen in the equation below, can be used to foresee the number of accidents or people injured after a change in mean speed on a road stretch or road network. The accidents and people injured are also divided into three different categories depending on severity.

$$\frac{Accidents\ after}{Accidents\ before} = \left(\frac{Mean\ speed\ after}{Mean\ speed\ before}\right)^{Exponent}$$

The exponent used can be changed to conform to reality in the most correct way. The model was introduced by Göran Nilsson in 1981 and with the development in car- and safety technology and infrastructure etcetera, several updates have been made to reflect this progress.

The aim of this study was to look into the background and the updates that have been attempted and validate the model with the prevailing traffic environment of today. This was done with a meta-analysis and with a case study on road stretches in Sweden which have had their signposted speed changed between 2006 and 2015. In the study the accidents and people injured after the speed change was compared with the Power Model's prediction. In Sweden the Power Model is mostly used by the Swedish Transport Administration (STA) in socioeconomic calculations to advocate a decrease or increase in speed on a road stretch. Therefore, the exponents used in the case study is the same as the ones used by them.

There has been a number of updates on the Power Model and which exponents to use to generate the most correct predictions. The majority of the updates has led to conclusions that the model's prediction is accurate, even though it is not a hundred percent correct.

In the case study it was found that the model can be consistent for the categories all accidents and all people injured while it becomes more unreliable for the higher degrees of severity for both accidents and people injured. It could also be concluded that having more data included in the analysis, will improve the Power Model's prediction. For single road stretches, the model has inaccurate predictions due to many random events. If the mean speed on a road stretch decreases the model will, with the exponents of the STA, predict a lowering of accidents or injured. This was found to be wrong in around 50% of the cases, where they instead increased.

To use the Power Model in socioeconomic calculations on a macro level may be relevant but to use it in order to advocate a lowering of the speed on single road stretches is questionable.

Key words: The Power Model, traffic accidents, traffic injuries, traffic safety, validation.

Potensmodellen
En validering av modellens tillämplighet i Sverige

Examensarbete inom masterprogrammet Infrastructure and Environmental Engineering

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SAMMANFATTNING

Potensmodellen, som ses i ekvationen nedan, kan användas för att förutse antalet olyckor eller skadade personer efter en förändring i medelhastighet på en vägsträcka eller ett vägnät. Olyckorna och de skadade är också indelade i tre olika kategorier beroende på allvarlighetsgraden.

$$\frac{Antal\ olyckor\ efter}{Antal\ olyckor\ innan} = \left(\frac{Medelhastighet\ efter}{Medelhastighet\ innan}\right)^{Exponent}$$

Exponenten som används kan ändras för att återspegla verkligheten på det mest korrekta sättet. Modellen introducerades av Göran Nilsson 1981 och i och med utvecklingen inom bil- och säkerhetsteknik och infrastruktur med mera, har flera uppdateringar gjorts för att återspegla denna utveckling.

Syftet med denna studie var att undersöka bakgrunden och de uppdateringar som har gjorts och validera modellen utifrån dagens rådande trafikmiljö. Detta gjordes med en metaanalys och med en fallstudie om vägsträckor i Sverige vars skyltade hastighet ändrats mellan 2006 och 2015. I studien jämfördes antalet olyckor och skadade efter hastighetsförändringen med Potensmodellens prediktion. I Sverige används Potensmodellen mestadels av Trafikverket i samhällsekonomiska beräkningar för att förespråka en minskad eller ökad hastighet på en vägsträcka. Därför är exponenterna som används i fallstudien desamma som de som används av dem.

Det har gjorts ett antal uppdateringar av Potensmodellen och vilka exponenter som ska användas för att skapa de mest korrekta förutsägelserna. Majoriteten av uppdateringarna har lett till slutsatser om att modellens prediktion är riktig, trots att den inte är hundra procent korrekt.

I fallstudien visades att modellen kan vara överensstämmande för kategorierna alla olyckor och alla skadade personer medan den blir mer opålitligt för högre allvarlighetsgrader för både olyckor och skadade personer. En ytterligare slutsats är att ju mer data som inkluderas i analysen desto bättre kommer modellens prediktion att bli. För enskilda vägsträckor stämmer modellen dåligt överens med verkligheten på grund av många slumpmässiga händelser. Om medelhastigheten på en vägsträcka minskar, kommer modellen med Trafikverkets exponenter att förutse en sänkning av antalet olyckor eller skadade. Det visade sig vara felaktigt i omkring 50 % av fallen, där de istället ökade.

Att använda Potensmodellen i samhällsekonomiska beräkningar på makronivå kan vara relevant men att använda den för att motivera en sänkning av hastigheten på enskilda vägsträckor kan ifrågasättas.

Nyckelord: Potensmodellen, trafikolyckor, trafikskadade, trafiksäkerhet, validering.

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Equations

Designations

AADT	Annual average daily traffic
ABS	Anti-lock braking system
ATK	Automatic traffic safety control
BAC	Blood alcohol content
E.g.	*“Exemplī grātiā”* - For example
I.e.	*“Id est”* - In other words
STA	Swedish Transport Administration
STRADA	The Swedish Traffic Accident Data Acquisition

Preface

The Power Model - A Validation of the Model's Applicability in Sweden is a master thesis in which the correlation between speed level and accidents and people injured within the road traffic area is evaluated. The thesis have been executed during the spring semester in 2017 and is a 30 credit part of the Civil Engineering Master Programme at Chalmers University of Technology. It has been completed at the Institution of Civil and Environmental Engineering, the Department of Geotechnical Engineering and the Group of Road and Traffic Engineering. The supervisor was Claes Johansson while the examiner was Anders Markstedt.

During the work with this project, the following persons have been very helpful to us and we want to thank:

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André Dennhed & Svante Möller

1 Introduction

The number of kilometres annually driven in Sweden has been increasing continuously since the 1950's. The distance driven has on average increased with around 2% each year and in 2015 the annual driven kilometres was around 80.7 billion vehicle kilometres (Trafikanalys, 2017). The number of fatalities in traffic in actual numbers has varied to a large extent over the years. However, relative to the amount of vehicle kilometres driven, the fatalities per 1 billion kilometres driven have steadily decreased from 115.7 in 1950 to 6.3 in 2004 (Brüde, 2005). In actual numbers for 2004, this corresponds to 473 fatalities and in 2015 this number had decreased even more to 259 fatalities (STRADA, 2006-2015).

Each and every one of these accidents led to some costs for the society, both directly and indirectly. In 2005, the total cost due to road traffic accidents was estimated to approximately 21 billion SEK. The cost for property damage, which is related to repairs that requires labour and material, was estimated to be around 38% of the total cost. The remaining costs are related to medical expenses (13%), administrative costs related to insurance administration and payments of sickness benefits (7%), reduced production in a sense that the involved individual is unable to work, both at work and in the household, and reduced consumption (42%) (Myndigheten för samhällsskydd och beredskap, u.d.).

When the Swedish Transport Administration (STA) plan for infrastructure projects, three main benefits and two drawbacks are evaluated. The benefits are travel time, environment and safety and the drawbacks are investment cost and maintenance costs. To be able to compare these parameters, they are transformed into a monetary unit. The monetary value of a human life is obtained from studies of humans' willingness to pay for increased traffic safety and decreased risk for accidents. In 2008, it was found that a human life was worth 21 million SEK, which corresponds to 22.3 million SEK in 2015. It is important to still have in mind that a human life is invaluable, but in order to perform socioeconomic calculations it is necessary to put numbers on it (Trafikverket; A, 2017).

The STA are continuously working to further reduce the number of accidents and people injured on the Swedish roads (Trafikverket; A, 2014). There is a program, Vision Zero, which has been approved by the Swedish government where the aim is that no one should be killed or seriously injured in road accidents in Sweden. Based on this vision, the STA are adapting roads and vehicles in order to increase the safety. The safety responsibility is shared between the STA who design the road network and the people who use the road network. On the other hand, Vision Zero also points out that it is impossible to prevent all accidents since humans always can make mistakes. Accidents can in some way be accepted but only if no one is severely injured or killed (Trafikverket; B, 2014). As part of the vision a milestone of a maximum of 220 people killed in road accidents in 2020 has been set (Trafikverket; A, 2014).

There are multiple measures that play a vital role in increasing the traffic safety and reduce number of accidents and people injured in the traffic. Examples of measures are technological advances in vehicles that help to avoid accidents, measures connected to the development of safer infrastructure, technical aids to prevent intoxicated people from driving and various speed reduction measures (Trafikverket; B, 2017).

One of the most effective ways of increasing the traffic safety is to reduce the speed (Palholmen & Granholm, 2016). There are several ways of predicting the improved safety of reduced speed on the roads. One of them is the Power Model. The model takes into account the mean speed before and after a change, the number of accidents or people injured before a speed change and a certain exponential factor, in order to predict the number of accidents or people injured that will occur after the change of speed. The main benefit and reason for why the Power Model is used is because of its simplicity (Elvik, 2009). The Power Model formula can be seen in Equation 1.

$$\frac{Accidents\ after}{Accidents\ before} = \left(\frac{Mean\ speed\ after}{Mean\ speed\ before}\right)^{Exponent} \tag{1}$$

To adapt the model to the current circumstances and studied road type the exponent can be modified to give the most accurate result in accordance to reality (Elvik, 2009).

1.1 Purpose

This project is done to gain deepened knowledge within the traffic planning area by going into further detail and looking into the Power Model. The purpose is to evaluate the model's background, its relevance according to today's traffic situation in Sweden and eventual need for changes.

1.2 Objective

The objective of this project is to study the background of the Power Model as well as the parameters used to see if they are relevant related to current knowledge. Is it relevant according to the prediction of number of accidents or people injured and their severity? Should some of the included parameters be changed? And in that case, how?

1.3 Scope

An assessment of the models ability to predict certain types of accident outcomes in the form of fatalities and severity of people injured was performed. Further, an investigation on how the model is applied was included. The evaluation was based on the infrastructural and technical situation in Sweden and Swedish statistics. This due to the great differences in safety standards and statistical availability if a broader area would be evaluated.

The analysis has been limited to rural road stretches due to limited information about the traffic situation in urban areas in form of speed measurements. This due to that the urban roads are operated by individual municipalities while the rural roads are operated by the STA (Trafikverket, 2015).

1.4 Definitions

All accidents	Accidents where someone is slightly or severely injured or killed.
Severe accident	Accidents both where someone is severely injured or killed or where someone is severely injured only. This

	depends on the context but is explained further in the report.
Fatal accidents	Accidents where someone is killed.
All injured	Number of people getting slightly or severely injured or killed in the accidents.
Severely injured	Number of people severely injured or killed in the accidents or severely injured only. This depends on the context but is explained further in the report.
Killed	Number of people killed in the accidents.
Cumulative category	The category includes the accidents or people injured with higher degree of severity. E.g. fatal accidents are also included in both the categories severe accidents and all accidents. Severe accidents are however not included in the category fatal accidents.
Mutually exclusive category	The category does not include the accidents or people injured with higher degree of severity. E.g. severe accidents only includes severe accidents, not fatal accidents.

1.5 Disposition

The background and rise of the Power Model will be explained in order to gain a deep understanding of the model. The parameters and their impact will also be described. This is done by a meta-analysis to highlight other research within the area, both about the original Power Model and further studies and development of the model and its input parameters. This also to compare how the accident data has been interpreted before and to learn from previous research. The exponents of the model will be clarified to see what they are representing and how the used exponents have been established.

In order to evaluate how well the model corresponds to today's traffic situation, a case study will be performed. The case study will be based on accident data from the Swedish Traffic Accident Data Acquisition (STRADA) and by knowing how the mean speed changed from one year to another, it can be compared to the number of accidents and people injured that occurred that specific year and the Power Model's prediction precision can thereby be determined. The result will also be validated by analysing the data used in the study.

Conclusions can thereafter be drawn whether the Power Model is valid with today's conditions or if the model needs to be changed in some way to make the predictions more accurate.

A connection will also be drawn to eventual changes or improvements that have been made both within the infrastructure, but also in the area of car technology and healthcare, from when the model was first put in to use up until today and how that can have an impact on the predicted, as well as occurring, traffic accidents and people injured. Following will be a discussion about the development and how these are, or can be, included in the model.

2 Background and origin of the Power Model

In 1967, Sweden went from driving on the left hand side to the right hand side. The speed limits were very low after the change, 40km/h in urban areas and 60km/h in rural areas. This was in order to avoid accidents related to the driving side change. In the year 1971, 70, 90, 110 and 130km/h became standardised speed limits on Swedish roads (Nilsson, 2005). These speed limit changes gave rise to a palpable change in number of accidents both when increasing, as well as decreasing, the speed on the roads. The increasingly evident pattern that speed and accidents correlated in some way lead to the introduction of the Power Model. Its creator, Göran Nilsson, formulated an equation to be able to calculate the results of speed limit changes before they were implemented (Nilsson, 2000).

The Power Model is used to predict the change in number of accidents or people injured, also with respect to accident and injury severity, when the mean speed changes. An important assumption when using the Power Model is that only the mean speed changes, everything else, e.g. road design and vehicle technology, is unchanged (Nilsson, 2005).

Furthermore, the original Power Model assumes that the number of accidents where people get injured or killed is proportional to the speed change squared, which correspond to the relative change in movement energy. Another assumption is that the number of fatal accidents is proportional to the speed change to the power of four. From this follows the fact that the probability that an accident is of serious or fatal character is proportional to the power of three (Nilsson, 2000).

First the mathematical correlation between speed and the different types of accidents were more or less assumed. Later, however, Göran Nilsson verified the model by a number of case studies, during the 70's, performed in Denmark, USA, Australia, the Netherlands as well as in Sweden. The results of the studies confirmed that the model corresponded well to reality (Nilsson, 2000) and the model was later published in 1981 (Cameron & Elvik, 2010). The source and detail of the data that the studies are based on, and the methodology used in the analyses, is however unknown.

According to Göran Nilsson there are at least five major benefits that promotes the model. Göran Nilsson (Nilsson, 2000) states:

- *The model is easy to derive and is symmetrical. Both increases and reductions in speed can be taken into account.*
- *The model highlights the pure effect of the speed change on road safety.*
- *The model can be used in any environment.*
- *The model takes into account if the accident statistics are reported in the form of accidents and/or injured/killed in traffic.*
- *The model is relatively insensitive to how the speed has been recorded since the relative speed difference is used.*

2.1 The parameters of the Power Model

As mentioned before, the Power Model can predict both the number of accidents or the number of people injured. The requirement is that there are accident or injury data along with mean speed data available.

From the original equation it is easy to derive the predicted number of accidents or people injured as can be seen in Equation 2 and Equation 3 respectively.

$$Accidents\ after = \left(\frac{Mean\ speed\ after}{Mean\ speed\ before}\right)^{Exponent} * \ Accidents\ before \qquad (2)$$

$$People\ injured\ after = \left(\frac{Mean\ speed\ after}{Mean\ speed\ before}\right)^{Exponent} * \ People\ injured\ before \qquad (3)$$

Accidents and people injured can both be calculated, using specific exponents depending on what is to be calculated. Accidents and people injured are calculated in the same way, but the exponents used for calculating the number of people injured are normally higher than when calculating the number of accidents. This is due to the fact that there may be more than one person injured in each accident. As mentioned before, the exponents were mathematically assumed in the beginning and later on they were confirmed with empirical tests (Nilsson, 2000).

3 Change of external conditions since the models genesis

Since the development of the original Power Model in 1981, there has been a huge increase in traffic work. From 1981 to 2015, the total traffic work done by Swedish recorded vehicles in Sweden increased by almost 63%, from 51.2 to 80.7 billion vehicle kilometres annually (Trafikanalys, 2017). Alongside this there has also been a notable development in e.g. the safety of cars, infrastructure and in legislations.

3.1 Infrastructural development

When Sweden changed from left-hand to right-hand traffic in 1967 several other measures regarding vehicle and infrastructure technology were also implemented to increase the traffic safety, amongst them speed limits. Despite the implementations, Sweden recorded that 1,307 people had been killed in traffic in 1970, which is the highest number ever recorded in Sweden (Brüde, u.d.). Afterwards, the yearly number of fatalities related to traffic started to decrease and in 1985 it had been lowered to 808 (Rabe, 2014).

The 1990's was the decade when the presence of two important infrastructural measurements increased. One of them was that many intersections were reconstructed into roundabouts which increased the safety. Further, roads in rural areas began to be rebuilt and equipped with a wire railing to separate the directions in order to avoid head-on collisions (Brüde, u.d.).

A later element is the introduction of speed cameras (ATK's), alongside the roads which measure the vehicles' speeds. Just like previous mentioned measures, the cameras have contributed to increased traffic safety inter alia since the mean speed levels have decreased. In 2012, the number of fatalities had decreased to 286 (Brüde, u.d.) and in 2016, 263 people were killed in traffic (Transportstyrelsen, 2017). In Figure 1, the yearly number of fatalities from 1970 can be seen. For this period, there is a clear trend of decreased number of fatalities, even though the reduction has lessened in recent years.

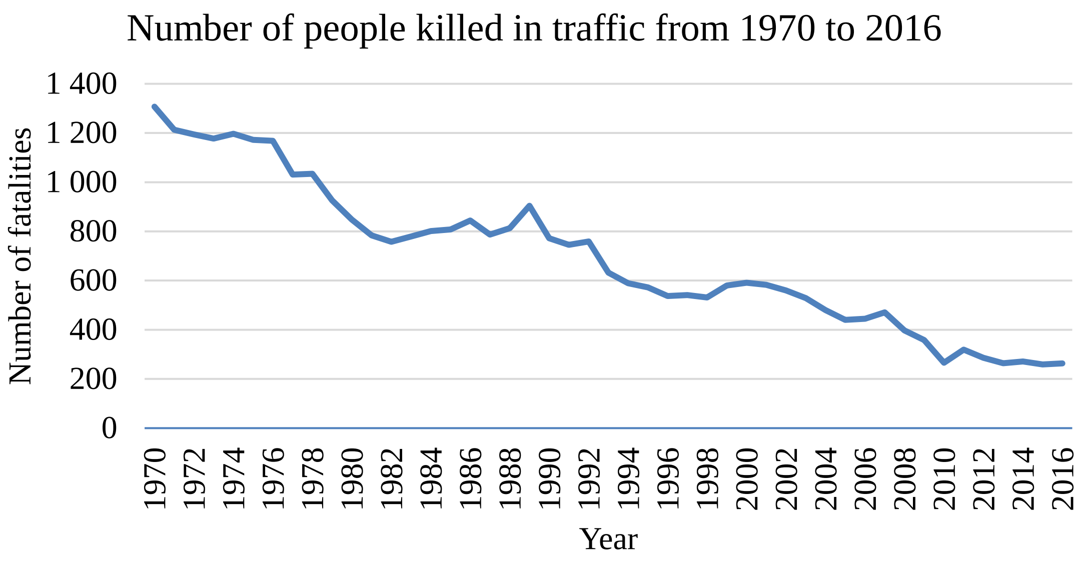

Figure 1: Number of people killed in traffic from 1970 to 2016 (Rabe, 2014) (STRADA, 2006-2015) (Transportstyrelsen, 2017)

3.2 Speed regulations

In 1971, a speed limit system was introduced which restricted the road users to drive maximum 50km/h within urban areas. In rural areas the standardised speed limit became 70km/h (Wilhelmsson & Anderzén, 2005). Other speed limits in the new system were 30, 90 and 110km/h. All previous 130km/h-roads were thus lowered to 110km/h (Nilsson, 2001). This system forms the basis for today's speed limits in Sweden, even though it has changed in some ways.

In 2009 a change was adapted in the existing speed limit regulation (Rabe, 2012). From then, 40, 60, 80, 100 and 120km/h became possible limits for the speed. The reasons were both out of safety and environmental aspects. The implementation of this was done in two steps and in total the speed limit was increased by 10km/h on 2700 kilometres of road while it was decreased by 10km/h on 17500 kilometres of road (Vadeby, et al., 2012).

3.3 Car safety development

In the 1970's there were less knowledge on the effects of a crash with a car and how it would affect the passengers in the vehicle. Safety thinking and improvements have however improved over the years (National Roads and Motorists' Association, u.d.). The first major safety improvement were the three-point belt that were developed by the Swedish engineer Nils Bohlin in 1959. The belt, however, had no great success by itself. It was not until the roller belt, developed by Hans Karlsson in the 1960's and let the passenger move freely but was tightened when required, that the combination of the two began to be properly introduced into larger parts of new cars. However, due to poor utilization of the new safety improvement it became law to use seat belt, 1975 in the front seat and 1988 in the whole car for all passengers (Allt om vetenskap, 2005). The use of the three-point belt has reduced the risk of being killed or seriously injured in traffic by approximately 50-70%, compared to not using seat belt at all (Trafikverket, 2015).

The airbag is another device that has had great influence on the car safety. Modern cars with frontal- and curtain airbags have greatly reduced the risk of being killed or seriously injured in a car crash. Driver fatality in frontal crashes has been reduced by 29% with the use of frontal airbags and fatality in driver-side crashes has been reduced with 41% with side airbags. If a combination of seatbelt and airbag is used, the risk of death is reduced by 51% (Insurance Institute for Highway Safety Highway Loss Data Institute, 2016).

In the early 1970’s the anti-lock braking system (ABS) was introduced. ABS lets the driver keep the brakes fully pressed without receiving skid on the car from the lockup of the brakes if the driver has to stop in a short distance. This feature was, however, not too successful in the beginning but is common today. Already the early models of the ABS reduced the stopping distance with around 40% (Koscs, 2013).

The understanding of what is happening during a crash has developed a lot thanks to car safety organisations and their crash testing (John Hughes, 2012). The organisations themselves are no innovators in car safety but functions as a consumer rating system. The safety research may however have impacted the safety of cars by highlighting safety issues and lifted the importance of car safety in the consumer's decision making, making the safety in cars a high priority for car manufacturers (van Ratingen, et al., 2015).

The development of cars has not only increased the safety but has maybe in some ways decreased the same. For example, the dashboard in modern cars is packed with instrumentation and controls for things like air-condition, radio, GPS and a lot of other features. This amount of information will distract drivers from the actual driving in various levels and will influence the driver's attention on what is happening on, and besides, the road (National Roads and Motorists' Association, u.d.).

3.4 Important traffic safety decisions

Beyond the previously mentioned improvements in infrastructure and vehicle technology, there are some laws and regulations that have contributed to increased traffic safety in the last decades (Brüde, u.d.). In 1965, motor vehicle inspection was introduced. This meant that every vehicle had to pass the inspection once a year (Bilprovningen, u.d.). If not, the vehicle could be banned from utilization in road traffic until the fault was repaired (Opus bilprovning, u.d.). Only in a few years, this lead to a significant reduction of the number of road traffic accidents (Bilprovningen, u.d.).

Furthermore, a regulation about a minimum tread depth of tires was introduced in 1968 and in 1975 utilization of helmets for motorcyclists became mandatory. In 1990, four important measures were implemented; a new driving license education program was established and the regulation about the minimum tread depth of tires became even stricter. To reduce speeding, ATK’s were installed along the most accident-prone road stretches and the allowed blood alcohol content (BAC) was lowered to 0.2 per mille. Later on, more workarounds were adopted to deal with drugs and alcohol. The Police extended their drug controls along the roads (Brüde, u.d.) and even the allowed BAC for grossly drunk driving was lowered from 1.5 to 1 per mille (Motorförarnas Helnykterhetsförbund, u.d.).

All of these improvements have led to a need to update the model since the traffic environment is not the same as it was when the model was first presented.

4 STRADA

STRADA is a comprehensive database with information about accidents and people injured caused in road traffic. It can be found how many people that have suffered a certain degree of injury. There is also information on what kind of accidents that have occurred and the people involved are sorted depending on gender and age. Additionally, the location where an accident has occurred and the sequence of events are registered (STRADA, 2006-2015). The database includes information from the Police and from hospitals. The Police examine the location where an accident takes place and gather information about the causes of the accidents and the degree of injury. The hospitals also report about degree of injury and additionally the hospitals are able to include statistics from accidents that never are reported to the Police, which often include pedestrians and cyclists (Transportstyrelsen; A, u.d.).

STRADA was introduced as the new official accident database in 2003 and was preceded by years of work in order to establish a new database. The former database did not include all accidents and was therefore misleading. The lack of quality of the old database led to underestimation of the traffic safety issues and as a consequence the needed safety measures were not implemented (Vägverket, 2007). When the new system was introduced it could help to prioritise between different traffic safety measures and also tell where they should be implemented in order to reduce fatalities and the number of people seriously injured as much as possible (Transportstyrelsen; B, u.d.).

In recent years, some changes have been made in STRADA. Since 2003, fatalities caused by sudden illness are not included in the statistics. The number of fatalities caused by this reason were estimated to be somewhere between 20 and 40 at this time and the majority considered elderly people. From 2010 and onwards, neither suicides are part of the statistics. One of the reasons for that is the increasing number of suicides committed in road traffic. The Police have started to investigate suicide accidents more in detail and from 2010 to 2012 the suicides had doubled to 36 (Brüde, u.d.).

5 Changing the signposted speed

When changing the signposted speed, the mean speed on the road most likely changes as well (Vadeby & Björketun, 2015). From an examination when the change of mean speed was measured it was clear that a reduction of the signposted speed limit by 10km/h generated a mean speed reduction of around 2-3.5km/h. Changing the signposted speed limit with 20km/h resulted in a mean speed reduction of approximately 3.5km/h. On the other hand, when the signposted speed increased with 10km/h, the mean speed went up by 3-4km/h. Notable is that these measurements only included passenger cars (Vadeby & Björketun, 2015).

The STA already have generalised values for how the mean speed change when the signposted speed limit change. Reducing the speed limit by 10km/h give rise to a mean speed reduction of 4km/h according to the STA, while a reduction of the speed limit by 20km/h reduces the mean speed by 8km/h. Increasing the speed limit by 10km/h leads to a mean speed increase of 4km/h. These are however slightly higher compared to the measured changes in the previous section. Also here, the values are exclusively for passenger cars (Vadeby & Björketun, 2015).

6 Updated versions of the Power Model

Since the models genesis, it has been updated a number of times. In the five following subchapters, different updates that have been done are declared. Each subchapter represent one performed study.

6.1 Traffic safety dimensions and the Power Model to describe the effect of speed on safety

In this paper, the author Göran Nilsson describes different methods by which the traffic safety situation can be described and quantified but focuses on using a multidimensional visualized method. An investigation of the Power Model was also done to validate the model and to show the changes in risk for accidents and its consequences and to also highlight important relationships between accidents and mean speed on the road (Nilsson, 2004).

Nilsson starts off by stating the importance of having relevant data. The availability of basic accident data was not an issue but it also needs to be accompanied with more specific, less available, data about the activities behind the traffic safety problems and accidents along with the exposure. The main registration of accident data was done by the Police but was also done by hospitals and insurance companies. Nilsson, however, argues that data coming from other sources than the Police may have reduced trustworthiness due to the fact that the data was collected for different purposes than traffic safety. He further states that very little data was originally presented in a way that was useful for the purpose. Therefore the data had to be sorted and matched into already set matrixes, matching the people injured or killed with the right vehicle and cause of the accident. The right data, alongside the exposure, which can be described as the number of involved vehicles, time spent in traffic, distance travelled etcetera, lie as a good base for evaluation and validation of the model.

Nilsson also made a validation of his own model. The validation was based on data recorded during the years 1967-1972 where a lot of roads received new speed limits. The actual change in accidents were compared to the, by the model, calculated change in accidents in percent. On roads where the speed limit were changed from 110km/h to 90km/h, the mean speed was reduced by 5-7km/h.

Moreover, Nilsson draws the conclusion that the change in the number of all injury accidents *"seems to correspond to the* ***second power*** *of the relative speed change"* and for fatalities *"correspond to the* ***fourth power*** *of the relative speed change".*

To further validate his model, Nilsson performed another investigation with data from 1979. The speed limit was this time also changed from 110km/h to 90km/h but now resulted in a mean speed decrease of 11km/h. Here, the categories are presented in cumulative categories and the following results can be seen in Table 1.

Table 1: Difference between predicted and actual outcome (Nilsson, 2004).

Accident consequence	**Actual accident change**	**Predicted accident change with the Power Model**
All injury accidents	-25%	-20%
Fatal and serious injury accidents	-34%	-28%
Fatal accidents	-52%	-36%

From this, Nilsson draws the conclusion that the change in the number of serious injury accidents *"corresponds well to the* ***third power*** *of the relative speed change".*

Further, Nilsson made additional validations of the Power Model by the evaluation of fatalities and severe injury accidents on more than 100 road sections of the, by the time typical, 13 meter road type. Data were gathered between 1991 and 1997 and the objective was to investigate the changes in accident situation when only the mean speed changed. At 62 road sections the speed limit was 110km/h and at 43 sections the speed limit was 90km/h. The mean speed of each road section could be matched to the roads rate of fatal, fatal and serious or all injury accidents. The rate was calculated by dividing e.g. number of fatal accidents by number of kilometres driven to get the fatal accident rate etc. For each mean speed level, each rate was compared to the average rate of fatal, fatal and serious or all injury accidents for each measured road. This could then be compared to the same calculated rates from the Power Model in relation to 100km/h. The same methodology was used when the model was validated for number of fatalities per fatal accidents, fatalities and severely injured per fatal and serious injury accident and all people injured per all injury accident.

Results showed that the Power Model had varying correspondence with the different types of accidents, fatal accidents, fatal and serious injury accidents and all injury accidents.

Furthermore, Nilsson concludes from the analysis that the Power Model has "*very good correspondence"* with the empirical data concerning the relation between all types of accidents. An exception, however, was the number of fatal accidents and fatalities per fatal accident where the model was underestimating compared to reality. The reason for the poor conformity between the Power Model and the fatal accidents was explained by Nilsson to be due to the low numbers of accidents, giving greater relative impact on the final result.

Nilsson continues to clarify that the model is to be used on a macro level to describe the number of accidents correlated to a change in speed and that it is only valid when the mean speed is changed. Any other measure on the traffic safety has to be taken into account separately. It is also to prefer to have data on both number of accidents and number of people injured in each accident. If data on number of people injured per accident is unavailable, the effects of the speed measure(s) on the traffic safety will be underestimated. Nilsson also highlights that cases where only the speed is changed on a road is rare and to handle situations where other safety measures also are implemented he states two possible solutions:

- *"Make corrections for other changes in the safety situation, which are known and influence the traffic safety situation."*
- *"Judge whether the difference from the result of the Power Model can be assigned to other (unknown) changes or whether the difference is just due to random fluctuations of accident numbers."*

Finally, Nilsson adds that there also can be difficulties, even though it is plausible, to use the model for calculating different kinds of accidents.

6.2 Speed and road accidents: an evaluation of the Power Model

In this report, Rune Elvik, Peter Christensen and Astrid Amundsen performed a meta-analysis of previous studies connecting speed and accidents to evaluate the Power Model and to update the exponents according to the studied data (Elvik, et al., 2004).

From 98 studies, done in Norway, 460 estimates where the speed had changed in some way could be included in the analysis. From this the six different variants of the Power Model was updated with new exponents. A sensitivity analysis of the models were also done.

By comparing the accidents before and after a speed change an exponent could be derived for each accident or injury severity level for each one of the 460 events that were studied. An interval for the exponent for each accident or injury severity level was established within the limit of 95% confidence. The final exponent was then chosen as a mean in the given interval shown in Table 2 below. In this study, however, Elvik, Christensen and Amundsen chose to reformulate the model so that the different categories of accident or injury severity are not cumulative but are handled as mutually exclusive categories.

Table 2: Final exponents and their corresponding 95%-confidence (Elvik, et al., 2004).

Accident or injury severity	Exponent	Interval
All injury accidents	2.0	(1.3 - 2.7)
Serious injury accidents	1.2	(1.1 - 3.7)
Fatal accidents	3.6	(2.4 - 3.7)
All injured road users	2.7	(0.9 - 4.5)
Serious injured road users	3.0	(2.2 - 3.8)
Fatalities	4.5	(4.1 - 4.9)

Conclusions from the meta-analysis in this case shows that the speed is the most influential factor on accidents or people injured and also that it has a strong statistical correlation. The analysis further shows that if the speed goes down, in 95% of the cases, the number of accidents or people injured also decreases and if the speed increases the accidents or people injured also increases in 71% of the cases. Larger change in speed will also lead to larger impact on the number of accidents or people injured. The model seems to work in all kinds of traffic situations, any country and at any given time.

Elvik, Christensen and Amundsen continues with discussing some limitations they had in the meta-analysis. Firstly, 77 out of 175 studies could not be included in the analysis since they did not include the necessary data. Secondly, the accident and/or speed data can be untrustworthy. Further, the analysis was probably influenced to some extent by other limitations but was neglected by Elvik, Christensen and Amundsen. This since it was thought to have little, or no impact on the results.

6.3 The Power Model of the relationship between speed and road safety

In 2004, Göran Nilsson carried out a validation of his own Power Model, which is described in previous chapters. This study by Rune Elvik, aims to analyse whether that version of the Power Model was still valid and also to update the model in order to include findings from later than 2004 (Elvik, 2009).

The study from 2004 was based on 98 studies while the more recent study relies on 115 studies. During the latter study, some differences from the previous one were observed through a meta-analysis. Firstly, it was found that the exponents generated from the studies, tend to depend significantly on the speed before the change. This was initially suggested in an analysis made by Ezra Hauer and James Bonneson from 2006 and then confirmed by Elvik in 2009. The test was done with a gradually speed reduction of 10km/h, from 115 to 105km/h, from 105 to 95km/h and so on all the way to 35km/h. The number of accidents was assumed to start at 100 and then the percentage decrease in number of fatal accidents associated with the change of speed is shown in Figure 2.

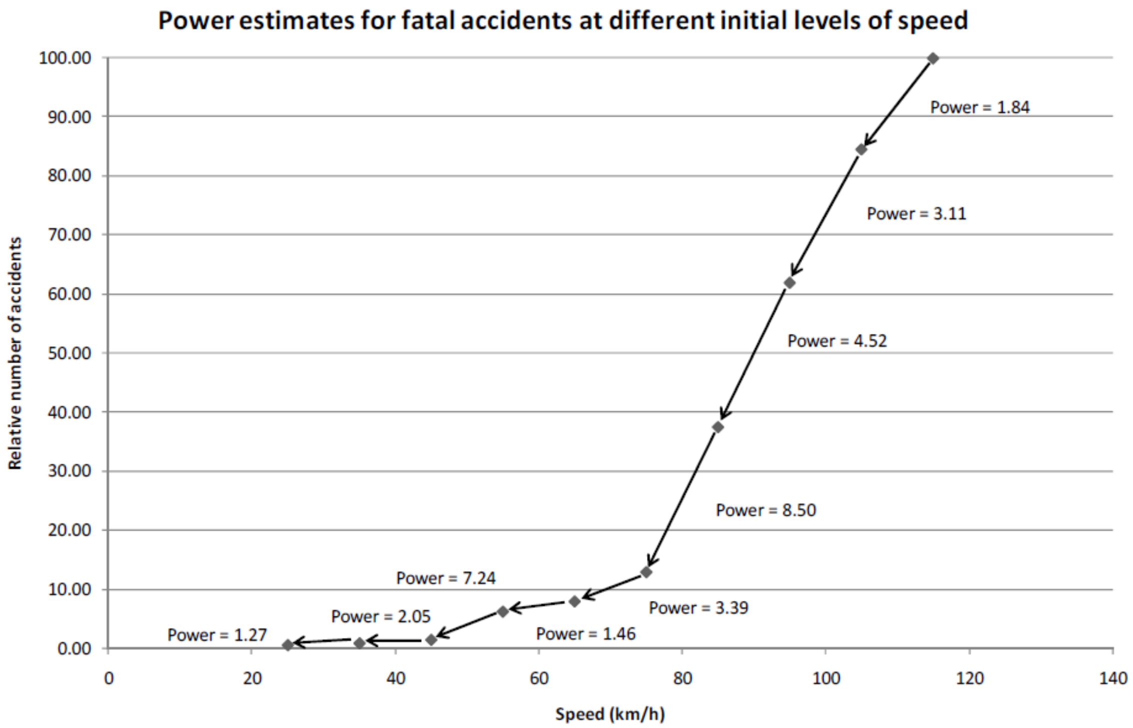

Figure 2: Power estimates for fatal accidents at different initial speed levels (Elvik, 2009).

The figure makes it clear that there are different exponents which better fit the data depending on the initial speed. The exponents are lower for low and high speed and higher in the middle. This suggests that a logistic function would be a better model than the Power Model in order to handle the impact of the initial speed. However, this relationship was only found for fatal accidents. For all injury accidents, the Power Model was valid and not depending on the initial speed.

Further, the exponents were also shown to depend on the traffic environment. This was found from a test where rural and urban roads were analysed separately and the exponents were observed. Before, there were only one version of the Power Model used for all traffic environments, which did not handle different effects from the surrounding areas. After this finding, two new versions were created depending on the traffic environment, one for urban areas where the speed was lower than 60km/h and one for rural areas where the speed was higher than 60km/h. The difference in exponents between rural and urban roads can be seen in Table 3. The categories all injury accidents and all injured road users are cumulative categories while the others are mutually exclusive categories.

Table 3: Exponents for the revised Power Model (Elvik, 2009).

Accident or injury severity	**Rural roads / freeways**		**Urban / residential roads**	
	Best estimate	**95% confidence interval**	**Best estimate**	**95% confidence interval**
All injury accidents	1.6	(0.9, 2.3)	1.5	(1.2, 1.8)
Serious injury accidents	2.6	(-2.7, 7.9)	1.5	(1.4, 2.6)
Fatal accidents	4.1	(2.9, 5.3)	2.6	(2.4, 4.6)
All injured road users	2.2	(1.8, 2.6)	1.4	(1.6, 2.4)
Seriously injured road users	3.5	(0.5, 5.5)	2.0	(2.0, 4.0)
Fatalities	4.6	(4.0, 5.2)	3.0	(3.7, 4.9)

During the study it was found that the effect of speed on injury severity was smaller than earlier knowledge has shown since other factors like vehicle technology and healthcare are developing, which is visualised in Figure 3. Therefore, the values of the exponents generally have been changed to lower values than before.

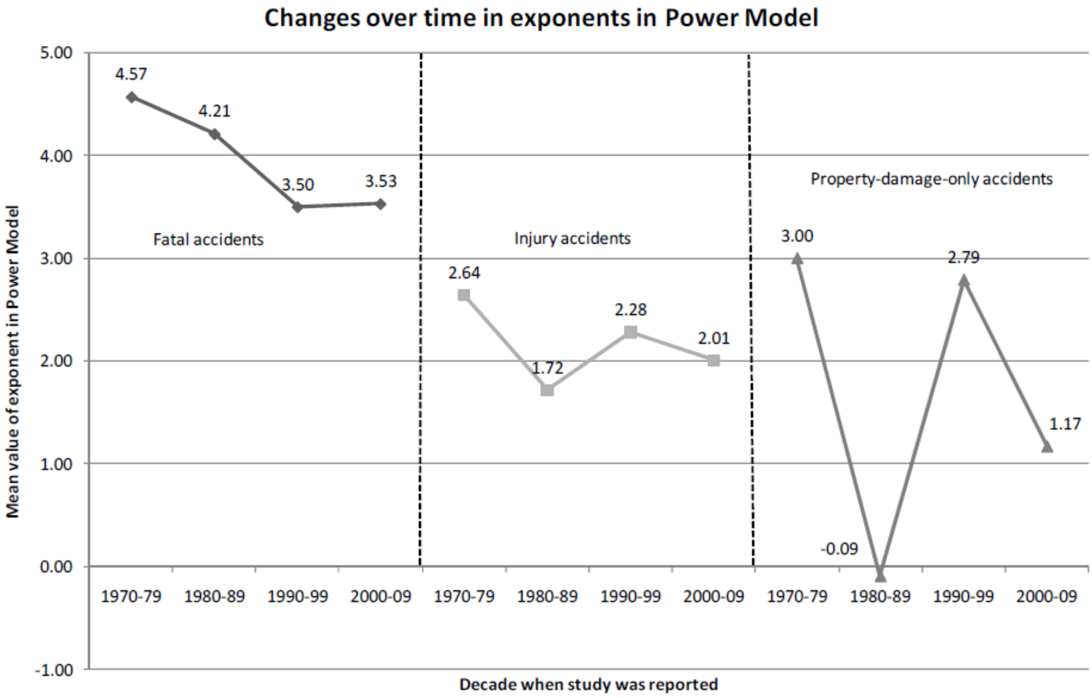

Figure 3: Changes over time in exponents in the Power Model (Elvik, 2009).

6.4 Nilsson's Power Model connecting speed and road trauma: Applicability by road type and alternative models for urban roads

In this report by Max H. Cameron and Rune Elvik, the aim was to test Nilsson's Power Model to see if it was applicable in all road environments and not only on rural roads. This was done by further evaluating Elvik, Christensen and Amundsen's meta-analysis from 2004 mentioned in Chapter 5.2. The raw data file that Elvik, Christensen and Amundsen did their analysis on was re-analysed along with each study's corresponding road environment (Cameron & Elvik, 2010).

The studied environments were divided into five different environmental categories.

- Motorway or freeway (urban or rural).
- All-purpose rural highway.
- All-purpose urban highway (urban arterial road).
- Residential access road (residential street or collector road).
- All types of environment.

According to Cameron and Elvik some of the injury categories connected to some specific environmental categories was included in very few studies, thus reducing the reliability of the results for these power estimates. These power estimates are however ignored when the power estimates are done for all areas together. It was also noted that the power estimate for an environmental category with a large number of studies influence the overall power estimate the most.

From the meta-analysis Cameron and Elvik draws the conclusions that across all levels of injuries the urban or rural highways and freeways have a considerably higher power estimate than arterial roads. On all levels of injury, the high speed freeway shows to have the highest power estimates in general. Furthermore, the power estimates' pattern fits well into all environmental categories and injury levels except for people seriously injured on the urban arterial roads. This power estimate then has a great influence on the summarised power estimate for this injury category which will be greatly reduced. This was also the problem Elvik, Christensen and Amundsen had in their original meta-analysis. It was concluded that the power estimation for fatalities on rural highways and freeways was considerably higher that on urban arterial roads.

When combining the results with a meta-regression analysis, Cameron and Elvik come to the conclusion that the power estimate for the seriously injured on urban arterial roads was connected to the general lower speed. If the already low speed was reduced, accidents connected to the speed will not be reduced to any mentionable degree. This would also be reflected the opposite way on the rural highways and freeways. Because of this result, Cameron and Elvik narrowed the environmental categories down to only two, "Rural and freeway" and Urban and residential", which will reflect the speed differences within the two road environments.

In 2009, Elvik provided 66 new power estimates, from 17 new studies, to the meta-analysis done in 2004. This, however, did not change the result, shown in Table 3, to any larger extent. In this update, Elvik adjusted the power estimates for all injury accidents to fit more correctly to the pattern both within this study and also the original Power Model. The final power estimates are shown in Table 4 along with the 95% confidence interval. These are also the exponents that the STA apply when using the Power Model according to Simon Sternlund[1].

Table 4: Adjusted exponents for the revised Power Model (Cameron & Elvik, 2010).

Accident or injury severity	**Rural roads and freeways**		**Urban and residential**	
	Best estimate	**95% confidence interval**	**Best estimate**	**95% confidence interval**
All injury accidents	1.6	(0.9, 2.3)	1.2	(0.7, 1.7)
Serious injury accidents	2.6	(-2.7, 7.9)	1.5	(0.9, 6.5)
Fatal accidents	4.1	(2.9, 5.3)	2.6	(0.3, 4.9)
All injured road users	2.2	(1.8, 2.6)	1.4	(0.4, 2.4)
Seriously injured road users	3.5	(0.5, 5.5)	2.0	(0.8, 3.2)
Fatalities	4.6	(4.0, 5.2)	3.0	(-0,5, 6,5)

[1] Simon Sternlund (Traffic Safety Analyst, Swedish Transport Administration), e-mail conversation with the authors on the 21'st of February.

6.5 Speed distribution and traffic safety

In the report *Hastighetsspridning och trafiksäkerhet* by Anna Vadeby and Åsa Forsman from 2012, the purpose was to evaluate how the speed distribution affects the traffic safety in terms of number of people injured and fatalities (Vadeby & Forsman, 2012).

The study claims that the speed affects the number of accidents in different ways. From one point of view, it was the speed level itself that was most important. Higher speeds entails higher risk for accidents since the reaction time and stopping distances become longer. Also, the severity of the accidents becomes higher with higher speed. The other point of view was that vehicles close to each other disturbs each other if they are travelling with different speeds, which might cause accidents.

Whether which one of the aspects that have the highest impact, several studies have been made. In the 1970's, the U-curve was created which meant that vehicles travelling significantly faster or slower than the mean speed suffered an increased risk of being involved in an accident than vehicles travelling close to the mean speed. More recently, this theory has been questioned and several studies made around the heirloom showed that only vehicles travelling faster than the mean speed suffer from increased risk for being involved in an accident, not the ones travelling slower. Hence, the U-curve is no longer valid according to these studies which instead suggest that the risk increases exponentially with higher speed. However, how much the risk increases with higher speed was hard to say and in the studies the authors discuss the impact of external parameters, for instance the driver's age and experience, which besides the speed tend to affect the number of accidents as well.

Other factors than mean speed and the speed distribution are also taken into account when looking at traffic safety. For instance, standard deviation, percentiles and the share of vehicles that travel too fast are of interest. How different speed reducing measures affect these factors were evaluated in the study by Vadeby and Forsman. The measures examined were reduction of the speed limit, both on a road without ATK's and on a road where ATK's already existed and implementation of new ATK's. Implementing new ATK's had the biggest impact on both the mean speed and the 85-percentile which were reduced with 8 and 11% respectively. Reducing the speed limit on a road where there were ATK's also had a good impact on traffic safety and reduced the mean speed with 7% and the 85-percentile with 8%. Reducing the speed limit on a road without ATK's had the lowest impact even though the mean speed was reduced by 3% and the 85-percentile by 3%. The vehicles that drove fastest were the ones most affected by implementation of new ATK's since they reduced the speed a lot more than those driving slower before the ATK's were implemented. This also turned out to increase the share that held the speed limit. Before, 40% of all vehicles drove too fast and after the implementation only 10% drove too fast.

7 Users of the Power Model

In Sweden, the Power Model is mostly used by the STA within socioeconomic calculations and scientific studies. It is also used for indirect communication around the speed-injury connection, which can be used e.g. to motivate lowering of speed limits close to schools according to Johan Strandroth[2]. The model is also frequently used in strategic planning and speed management documents in Europe. The extension of the model's use here is however not specified (Cameron & Elvik, 2010).

The exponents the STA uses can be seen in Table 5. The exponents for all accidents and all people injured are cumulative categories, which means that they include both slightly, severe and fatal accidents or people injured. The exponents for severe and fatal accidents, severely injured and fatalities are however mutually exclusive categories. This means that each of these categories are presented individually (Cameron & Elvik, 2010).

Table 5: Exponents that are used by the STA.

Accident or injury severity	**Rural roads and freeways**		**Urban and residential**	
	Best estimate	**95% confidence interval**	**Best estimate**	**95% confidence interval**
All injury accidents	1.6	(0.9, 2.3)	1.2	(0.7, 1.7)
Serious injury accidents	2.6	(-2.7, 7.9)	1.5	(0.9, 2.1)
Fatal accidents	4.1	(2.9, 5.3)	2.6	(0.3, 4.9)
All injured road users	2.2	(1.8, 2.6)	1.4	(0.4, 2.4)
Seriously injured road users	3.5	(0.5, 5.5)	2.0	(0.8, 3.2)
Fatalities	4.6	(4.0, 5.2)	3.0	(-0.5, 6.5)

[2] Johan Strandroth (Traffic Safety Analyst, Swedish Transport Administration), e-mail conversation with the authors on the 2'nd of February.

8 Methodology for the case study

In the case study, actual changes in mean speed from one year to another for a specific road stretch were matched to accidents and people injured. This to see the Power Model's ability to predict the actual number of accidents and people injured. To find the road stretches with the most significant changes in mean speed, only road stretches where the speed limit has changed during the period 2007-2014 were included. These road stretches were identified by looking at regulations conducted by the STA and their precursor Vägverket. The regulations were compared with the previous ones in order to observe the speed limit change and to identify the specific road stretches where the changes were made and their lengths. By searching for changes in regulations in speed limits in Transportstyrelsen's regulatory database these stretches and speed changes could be found (Transportstyrelsen, 2017). The time interval was chosen by respect to the fact that the available data from STRADA includes the period 2006-2015. Information about accidents and people injured needed to be available one year before and after the speed limit change to be able to include them in the case study. When data about accidents and people injured was collected, data from years close to the speed limit change were used to the highest possible extent. Coordinates for all road stretches were also recorded to enclose each of the road stretches to be able to search for accidents only within this area in STRADA.

Since the Power Model requires that no parameter but the mean speed changes, road stretches that were rebuilt or changed during this period were excluded from the analysis. Information about reconstructed road stretches were also obtained from the STA (Trafikverket; A, u.d.). Also, road stretches shorter than 10 kilometres were neglected and not included in the case study. Furthermore, only road stretches in rural areas operated by the STA were included in the case study since traffic information were only available for these road stretches. This since most roads in urban areas are operated by municipalities which make the search for traffic information harder and more time consuming. A visualisation of the road stretches included in the case study is shown in Appendix I. More information about the included road stretches is shown in Appendix II. Only accidents that occurred on a consistent road stretch are included in the analysis, which means that accidents that occurred in intersections, roundabouts etcetera, are excluded from the analysis. This because accidents in those areas tend to be influenced by other factors than the speed level (Rimsler, 1999).

The STA's Road Traffic Map was used to find measurements of mean speeds and traffic volumes, annual average daily traffic (AADT), on the chosen road stretches. The number of times that mean speeds and traffic volumes are measured on a road each year are varying from one to six times, with an interval of about four to five years. If no measurements were found, for both one year before and after, the road stretch was removed from the case study. If the road stretch was long and had many measuring points available, up to three measuring points were included in the mean speed and traffic compilation (Trafikverket; B, u.d.). The traffic volumes were compared to take into account a possible increase or decrease in traffic which will affect the traffic exposure on the road.

When the year for speed change, mean speed, traffic volumes and coordinates for all road stretches were gathered, STRADA was used to find all accidents for these road stretches. To find the accidents and people injured connected to a road stretch, the accident database was filtered by:

- **Coordinates** To locate accidents only on the specified road stretch.
- **County** Which county the road stretch is located in.
- **Road environment** Excluded urban road stretches.
- **Road operator** Excluded individual and municipality road stretches.
- **Road section** Excluded all accident locations that is not a consistent road stretch, for example intersection, roundabouts etcetera. This was, as stated, done to remove all accidents unrelated to speed.

The data about mean speed, traffic volume, road stretch length and traffic accidents for all road stretches with sufficient data were compiled into one document to be able to evaluate the Power Model. The accidents were divided into three categories, all accidents, severe accidents and fatal accidents. The number of people injured were also divided into similar categories, all injured, severely injured and killed. Accidents and people injured were normalised to numbers per one million vehicle kilometres. The mean speeds were also calculated with respect to the traffic volume and the road stretch length. This to enable a comparison between all road stretches.

By using the mean speed before and after a speed change, along with the number of accidents and people injured in each category before the speed change, the number of accidents and injured in each category after the speed change was calculated using the Power Model. The exponents used are the same as the ones that the STA uses which are presented in chapter 6.4. An important notation is that the category fatal accidents/killed is not fitted into the category severe accidents/severely injured, or vice versa. These categories are so called mutually exclusive. These are however included into all accidents and all people injured. The different road types, meeting-free roads and normal roads, were evaluated separately.

Two different approaches were used for the normal road stretches to check the Power Models conformity with reality. In approach 1, each accident and injury severity category were summarised into one total sum for all normal road stretches. One total mean speed for the road stretches before and one after were also calculated. With this, the Power Model was used once for each category and was compared with reality. A percentage difference between what the Power Model predicted and the real outcome was calculated along with what the exponents should have been to foresee the accidents and people injured correctly. This was done when the mean speed was increased or decreased separately to enlarge the statistical basis and thereby, in theory, get a more realistic result.

In approach 2, the road stretches were evaluated individually. By doing this each road stretch’s mean speed was included in the calculations instead of using a mean speed for all road stretches combined. A percentage difference between what the Power Model predicted and the real outcome was calculated along with what the exponents should have been to foresee the accidents and people injured correctly for each road stretch separately. Thereafter, the road stretches’ percentage differences were aggregated into one total difference, one for each category. A 95’th percentile which returns the mean of the interior 95% proportion of the data was also calculated in order to exclude extreme values. Additionally, the standard deviation of the total mean value was calculated.

The percentage difference in both approaches was calculated by using Equation 4. The same equation was used for the number of people injured.

$$Percentage\ difference = \frac{(Accidents\ predicted\ by\ the\ model - Accidents\ in\ reality\ after)}{Accidents\ in\ reality\ after} \qquad (4)$$

Furthermore, the meeting-free road stretches were also analysed with the two approaches. Since there are only three road stretches of this type, accident and injury data for nine years were used in order to enlarge the data set and obtain more reliable results.

Moreover, the exponents which would have generated the correct number of accidents and people injured were developed. This was done with an iteration methodology.

The Power Model assumes that if the mean speed is reduced the number of accidents and people injured also decrease. A validation whether this corresponds to reality was also carried out. This was done simply by checking if the number of accidents or people injured decreased when the mean speed decreased on a certain road stretch, and vice versa. A more detailed description of all calculations can be found in Appendix III.

To confirm the results, the mean speed measurements and the accident database STRADA, was validated. This was done by comparing the mean speed changes and STRADA with prevailing knowledge. STRADA was also compared with itself year by year to make sure no significant changes in accident patterns were occurring.

8.1 Limitations

Roads stretches with no accidents or people injured before or after the mean speed change were excluded from the analysis in approach 2. If there are no accidents or people injured before or after the speed change it is impossible to compare the model's prediction with reality.

Another limitation was the reporting in STRADA. There may be faults in the coordinates or the wrong road section might be reported. Certain road stretches did not have any coordinates at all which made the exact location impossible to identify. Some accidents may not have been reported at all.

Furthermore, some road stretches had very few measurement points for mean speed and traffic volume which decreases the probability that the information is valid for the whole stretch. On the other hand, some stretches had plenty of measurement points and in these cases a maximum of three points were included with respect to the expenditure of time.

Additionally, the data set used in the analysis was limited. A total of 188 road stretches with a change in the signposted speed during the analysed period were identified but 33 of them were unusable since they either had been rebuilt or there were data missing. Including more road stretches or data for more years would have generated a more accurate result. However, due to the time limitation only data for one year before and one year after the speed limit change were included.

9 RESULTS

A total of 793 accidents and 1189 injured persons on 5826 km of road stretches have been analysed. The case study showed that when the mean speed went down on a road stretch the number of accidents or people injured went down in 50.4% of the cases. Reversed, the case study also showed that if the mean speed went up on a road stretch the number of accidents or people injured went up in 50.0% of the cases.

9.1 Approach 1

In approach 1, each accident and injury severity category were summed to one total number per category. The road stretches were divided into different cases with respect to mean speed change and road type where the three first cases only includes the normal road stretches and the fourth case only includes meeting-free road stretches. The numbers in the following tables are presented in number of accidents or people injured per 1,000,000 vehicle kilometres.

9.1.1 Case 1 - Mean speed reduction

A total of 132 road stretches were included in this case. The total mean speed went down from 89.0km/h to 85.4km/h. The difference between what the Power Model predicted and the reality can be seen in Table 6.

Table 6: Comparison between the Power Model and the reality for case 1.

Accident or injury severity	Reality before	Reality after	Prediction by the Power Model	Difference (prediction vs reality after)
All injury accidents	0.100	0.122	0.093	-23.5%
Severe accidents	0.005	0.007	0.005	-36.3%
Fatal accidents	0.005	0.004	0.004	+18.5%
All injured	0.160	0.168	0.146	-13.2%
Severely injured	0.006	0.007	0.005	-27.1%
Killed	0.005	0.004	0.005	+23.8%

For all the different accident and injury severities except for fatal accidents and killed the difference in percent is negative which means that the Power Model underestimates the number of accidents and people injured after the mean speed change and the exponents should be lower to be more accurate. It can be seen that the number of accidents and people injured for the majority of the categories have increased despite a reduction of the mean speed. For fatal accidents and killed, the numbers are reduced as the mean speed is reduced.

9.1.2 Case 2 - Mean speed increase

When doing the same kind of analysis but for all the 20 road stretches where the mean speed have increased, the total mean speed went up from 85.8km/h to 87.7km/h. Table 7 shows the comparison between reality and the Power Model.

Table 7: Comparison between the Power Model and the reality for case 2.

Accident or injury severity	Reality before	Reality after	Prediction by the Power Model	Difference (prediction vs reality after)
All injury accidents	0.113	0.135	0.117	-13.6%
Severe accidents	0.006	0.008	0.006	-26.0%
Fatal accidents	0.003	0.011	0.003	-71.3%
All injured	0.191	0.204	0.200	-1.9%
Severely injured	0.006	0.008	0.006	-24.5%
Killed	0.014	0.011	0.016	+45.1%

As in case 1, the Power Model underestimates the outcome for the majority of the categories. However, if the difference in percent is negative the exponents should be higher in this case. In this case it is true that the accidents and people injured increase when the mean speed increases in 5 of the 6 categories.

9.1.3 Case 3 - All normal road stretches

In this case, all the 152 normal road stretches are included, no matter if the mean speed has increased or decreased. The total mean speed went down from 88.7km/h to 85.7km/h. The outcome is presented in Table 8.

Table 8: Comparison between the Power Model and the reality for case 3.

Accident or injury severity	Reality before	Reality after	Prediction by the Power Model	Difference (prediction vs reality after)
All injury accidents	0.101	0.123	0.096	-21.7%
Severe accidents	0.005	0.007	0.005	-35.9%
Fatal accidents	0.005	0.004	0.004	-4.6%
All injured	0.163	0.171	0.151	-11.6%
Severely injured	0.006	0.007	0.005	-26.9%
Killed	0.006	0.004	0.005	+23.0%

It can be seen that the number of accidents and people injured have increased for all categories except for fatal accidents and killed, despite the decreased total mean speed. This is the opposite of what the Power Model suggests. Here, exponents in the Power Model should have been, lower, or even negative, in order to predict the outcome of the reality.

9.1.4 Case 4 - Meeting-free road stretches

This analysis only includes three road stretches. The total mean speed went down from 96.4km/h to 94.7km/h. Table 9 shows the comparison between reality and the Power Model.

Table 9: Comparison between the Power Model and the reality for case 4.

Accident or injury severity	Reality before	Reality after	Prediction by the Power Model	Difference (prediction vs reality after)
All injury accidents	0.082	0.093	0.080	-14.0%
Severe accidents	0.001	0.003	0.001	-81.9%
Fatal accidents	0.003	0.001	0.002	+122.9%
All injured	0.152	0.133	0.146	+9.9%
Severely injured	0.001	0.004	0.001	-84.6%
Killed	0.003	0.002	0.002	+47.3%

All injury accidents and all injured are relatively correct predicted by the Power Model. However, the model underestimates the number of accidents but overestimates the number of people injured. Again, the number of accidents and people injured increases in 3 of 6 categories even though the mean speed went down.

9.2 Approach 2

In approach 2, the road stretches were first evaluated individually and then the results were aggregated. As in approach 1, the road stretches were divided into different cases with respect to mean speed change and road type. For this approach, average difference is an average value of how much the model's predictions for each individual road stretch deviate from the reality in percent. In the 95'th percentile, the 5% most extreme values are excluded and the standard deviation is based on the average difference.

9.2.1 Case 5 - Mean speed reduction

The Power Model's prediction compared to reality can be seen in Table 10.

Table 10: Comparison between the Power Model and the reality for case 5.

Accident or injury severity	**Average difference**	**95'th percentile**	**Standard deviation**
All injury accidents	+8.5%	+3.9%	92.6%
Severe accidents	+2.7%	+2.7%	42.1%
Fatal accidents	-15.0%	-15.0%	0.0%
All injured	+33.2%	+23.5%	163.9%
Severely injured	+9.3%	+9.3%	32.7%
Killed	-16.9%	-16.9%	0.0%

In this case, the results are consistent for all categories but the model overestimates the number of accidents and people injured except from the fatal accidents and the people killed. Fatal accidents and killed is however only based on data from one single road stretch which makes the result unreliable. The standard deviation is significantly high which indicates a large variation for each road stretch.

9.2.2 Case 6 - Mean speed increase

Table 11 shows the comparison between reality and the Power Model for normal road stretches where the mean speed has increased.

Table 11: Comparison between the Power Model and the reality for case 6.

Accident or injury severity	**Average difference**	**95'th percentile**	**Standard deviation**
All injury accidents	+7.0%	+7.0%	77.3%
Severe accidents	#N/A	#N/A	#N/A
Fatal accidents	+2.7%	+2.7%	0.0%
All injured	+56.2%	+56.2%	120.7%
Severely injured	#N/A	#N/A	#N/A
Killed	+416.5%	+416.5%	0.0%

The fatal accidents differ with 2.7% which corresponds well to the reality but is only based on one road stretch which makes the result unreliable. The number of fatal accidents and killed is overestimated but it is only based on one road stretch with one accident including five fatalities. The 95'th percentile is the same as the average difference since few road stretches are included. The standard deviation is high for all injury accidents and all injured which suggest that there are large variations. For fatal accidents and killed the results are based on one road stretch which is the reason why the standard deviation is zero for these categories. The #N/A in some fields is due to no data.

9.2.3 Case 7 - All normal road stretches

The outcome for all normal road stretches combined is presented in Table 12.

Table 12: Comparison between the Power Model and the reality for case 7.

Accident or injury severity	Average difference	95'th percentile	Standard deviation
All injury accidents	+8.3%	+1.9%	90.8%
Severe accidents	+2.7%	+2.7%	42.1%
Fatal accidents	-6.1%	-6.1%	8.9%
All injured	+36.0%	+21.5%	159.4%
Severely injured	+9.3%	+9.3%	32.7%
Killed	+199.8%	+199.8%	216.7%

In this case, the Power Model generates accurate predictions for all categories except for people killed. The category for killed is highly influenced by the specific accident mentioned in the previous case. This number was significantly lower after the speed limit change which is the reason for the model overestimating the outcome. Additionally, it can be seen that the outcome is overestimated for all the three injury categories.

9.2.4 Case 8 - Meeting-free road stretches

The findings for the meeting-free road stretches can be seen in Table 13.

Table 13: Comparison between the Power Model and the reality for case 8.

Accident or injury severity	Average difference	Standard deviation
All injury accidents	-3.5%	38.2%
Severe accidents	-56.4%	0.0%
Fatal accidents	+335.5%	0.0%
All injured	+20.1%	32.0%
Severely injured	-58.3%	0.0%
Killed	+122.3%	0.0%

The Power Model's correspondence for the categories all injury accidents and all injured complies well with reality. For the remaining categories the difference is only based on one road stretch and will not give a representable answer.

9.3 Correction of exponents

Table 14 and Table 15 shows a summary of what the exponents should be changed to according to the observed number of accidents and injured in the case study.

Table 14: What the exponents should be according to approach 1.

Approach 1	**Mean speed reduction**	**Mean speed increase**	**All normal roads**	**Meeting-free roads**
All injury accidents	-4.83	8.17	-5.45	-6.89
Severe accidents	-8.48	16.13	-10.22	-93.85
Fatal accidents	8.18	60.19	2.74	49.29
All injured	-1.20	3.05	-1.34	7.53
Severely injured	-4.10	16.13	-5.54	-102.11
Killed	9.73	-12.11	10.57	26.43

Table 15: What the exponents should be according to approach 2.

Approach 2	**Mean speed reduction**	**Mean speed increase**	**All normal roads**	**Meeting-free roads**
All injury accidents	3.45	-1.85	3.83	-3.25
Severe accidents	3.55	#N/A	3.56	-14.24
Fatal accidents	0.45	1.50	0.10	-31.50
All injured	9.30	-25.50	12.90	2.50
Severely injured	6.78	#N/A	6.78	-14.24
Killed	0.45	-150.90	0.45	14.72

Comparing what the exponents should be according to approach 1 and 2, the results differ a lot and no obvious patterns can be observed. In the comparison, most values contradicts which partly can be explained by the fact that some data was removed in approach 2. However, this was not the case for the all injury accidents and all injured categories.

9.4 Authentication of mean speed and STRADA

To verify that the mean speed changes that were observed in the analysis are reasonable they were compared with what the literature suggests. The mean speed changes from the case study, with respect to the signposted speed limit, are shown in Table 16.

Table 16: Mean speed changes for different changes in signposted speed.

Signposted speed difference (km/h)	Mean speed change (km/h)	Standard deviation (km/h)
-20	-4,14	5,42
-10	-2,96	2,81
+10	1,67	1,98

The mean speed changes observed in the case study corresponds well to what the literature suggests and with what previous studies have found.

Additionally, several factors in STRADA were evaluated in order to confirm that the data is valid and does not have any significant divergence from one year to another. This evaluation includes all accidents reported to STRADA from 2006 to 2015. The number of accidents and people injured for each category and year is shown in Figure 4, in which increasing trends for all accidents and all injured can be observed. No major changes in the accident dataset can be noticed. What is also to be noted is that the number of severe and fatal accidents and injured persons is only a fraction of all accidents and people injured.

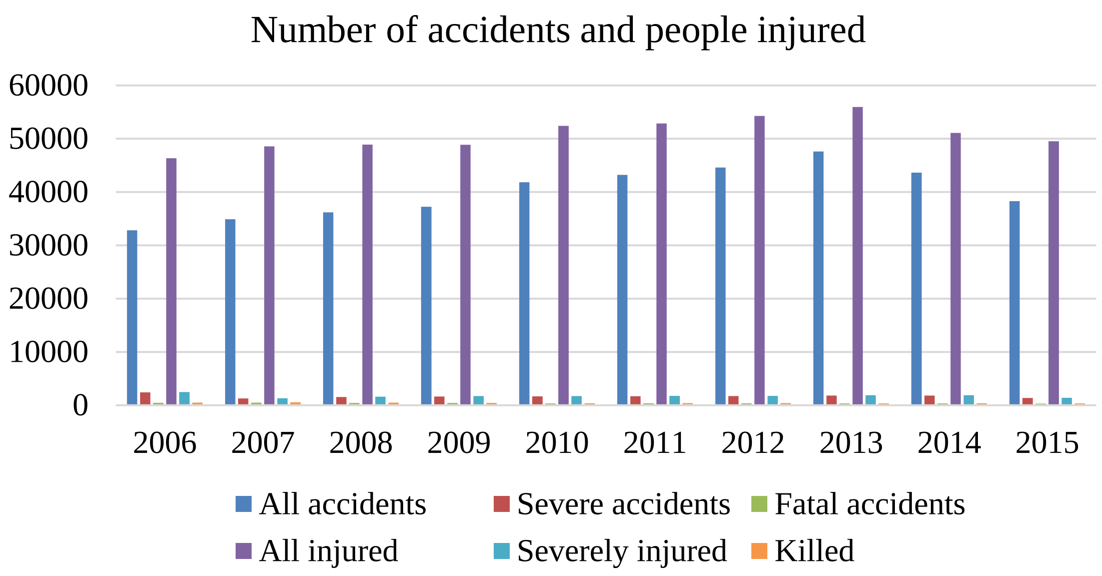

Figure 4: Number of accidents and people injured.

In Figure 5, the age distribution of all persons involved in some kind of accident are presented. An overall even age distribution can be noted with a slight increase for people of 65+ years. Yet again, the accident dataset remains overall constant.

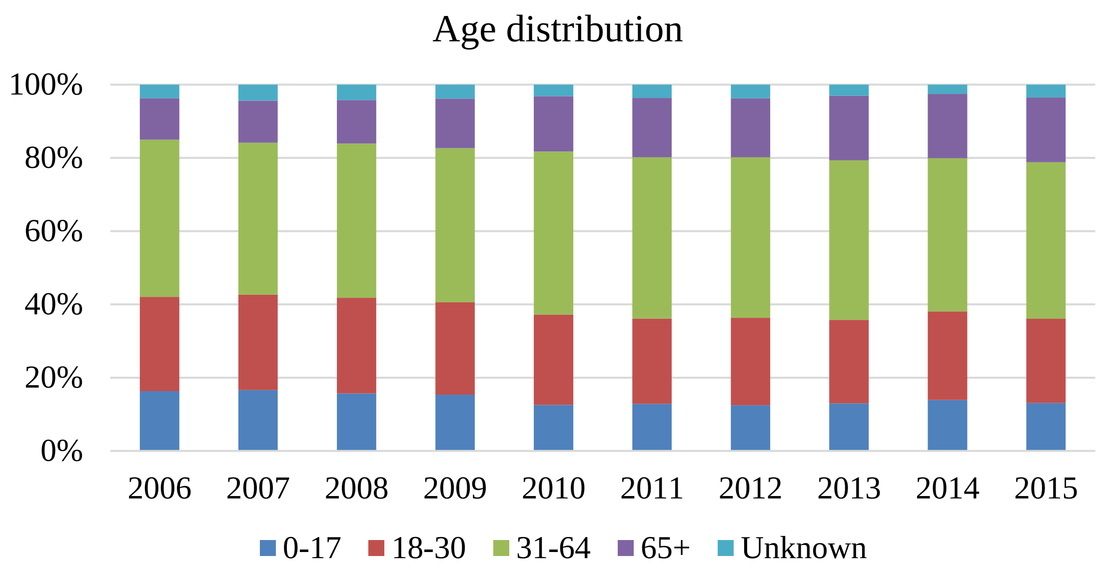

Figure 5: Share of accidents connected to age distribution.

In Figure 6, the number of people injured in traffic by means of transportation is presented. A reduction of the share of people injured in car accidents can be seen. This has resulted in that the share of accidents with pedestrians and bicyclists have increased.

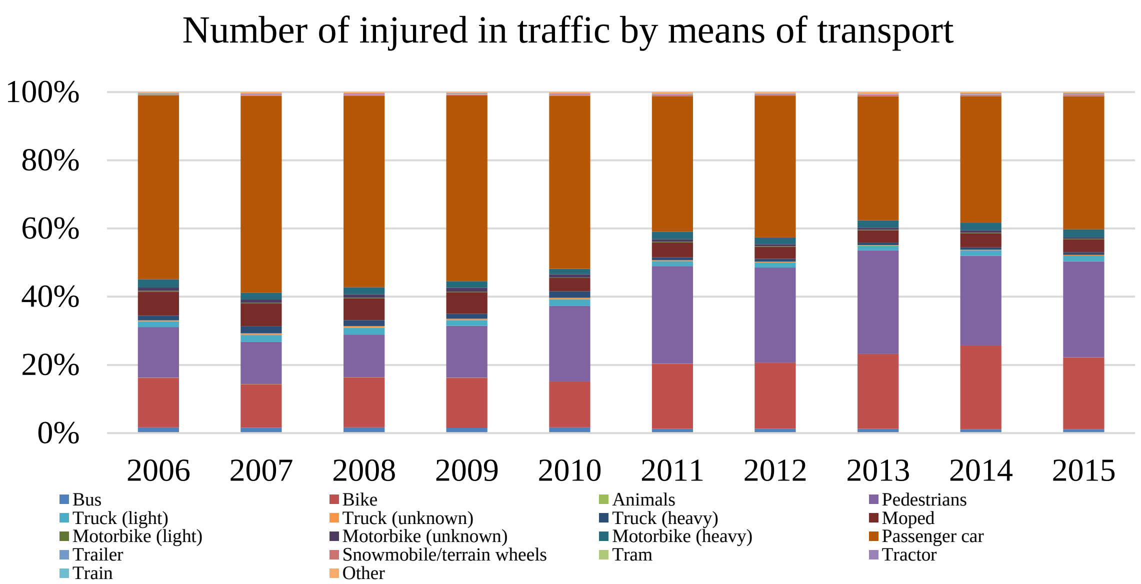

Figure 6: Number of injured in traffic by means of transport.

In Figure 7, the percent of the total number of accidents that occurred due to suspected alcohol are presented. Noticeably, the higher the severity of the accident the higher is the probability that alcohol is involved. Accidents suspected to alcohol has seen a decreasing trend but increased a lot in 2015.

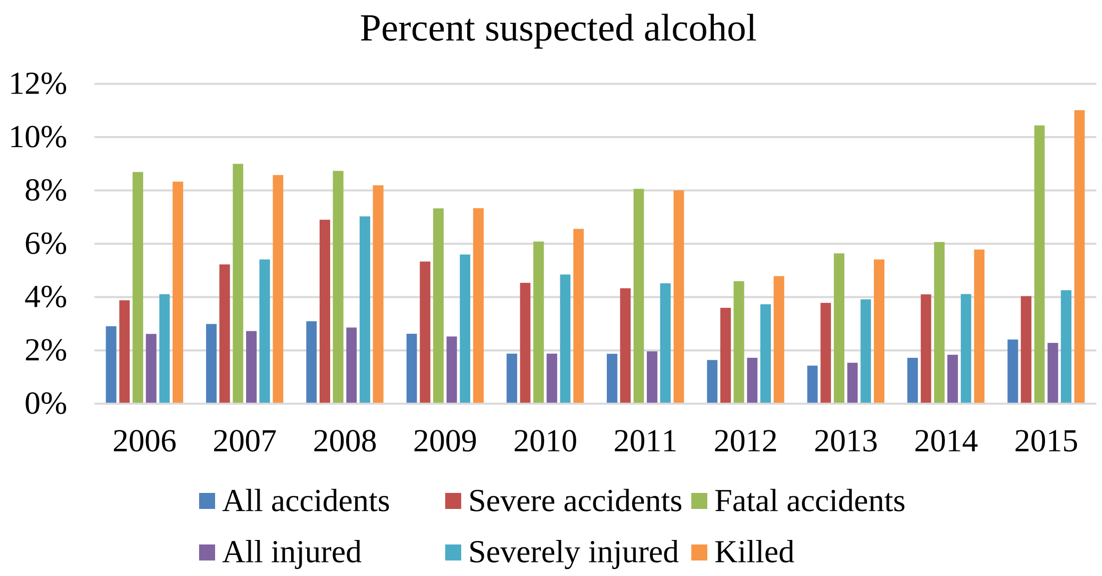

Figure 7: Share of accidents in which alcohol is suspected.

10 DISCUSSION

There has been a number of updates on the Power Model and which exponents to use to generate the most correct predictions. The majority of the updates has led to conclusions that the model's prediction is accurate, even though it is not a hundred percent correct. On the other hand, there are generally little information on exactly how the updates has proceeded with the exception of the very basic approaches. Many times no information was found on which roads were taken into these studies or which years. The methodology used in this case study however differs from the methodology Göran Nilsson used in his different validation attempts. In one of the methods in the case study an accident rate was used but was then compared with a reference road. However, with the different approaches as a base it can be determined that many of the previous studies have been done in different ways and with different results. Hence, the result is depending on which methodology that is applied.

To have the right data is of essence in this kind of study. In Nilsson's updated study from 2004 he states that it is *"preferred"* to have data about number of accidents and people injured persons before and after a speed change (Nilsson, 2004). This motivates the methodology used in the performed case study since the same road stretches are evaluated before and after a mean speed change. Nilsson's approach when comparing road stretches with a reference road then becomes questionable since the road environments are different.

There are several limitations with the Power Model itself. One of them is the assumption that everything remains unchanged except the mean speed. If a case study like this is done, that scenario is impossible to fulfil since parameters like vehicle technology and healthcare constantly are developing and making corrections for these are difficult. Generally, the exponents have shown to decrease over time for all the different categories. This is probably due to the fact that the infrastructure, car safety technology and traffic safety decisions has improved the safety in the traffic environment. This reduces the speed's impact on the traffic safety. With this development, the Power Model has to be evaluated and validated every few years to keep the exponents up to date. Another limitation is that the model does not take speed variation but only mean speed into account. Most probably, the risk for accidents is lower if most vehicles are travelling close to the mean speed than if most vehicle's speeds deviate a lot from the mean speed on the road, which promotes that the speed variation and not only the mean speed affects the number of accidents.

Despite the development in car technology, healthcare and infrastructure, other factors like drugs and alcohol, will always have an impact on traffic safety. In the study, it was found that alcohol was suspected in approximately 8% of all fatal accidents over the studied period. These accidents are hard to prevent even though the mean speed is reduced and here the Power Model comes to short since these accidents do not correlate with the mean speed.

Results of the case study

The exponents used today result in that the Power Model predicts that if the mean speed is reduced, the number of accidents and people injured are also reduced, and vice versa. According to Elvik, Christensen and Amundsen this should be true in 95% and 71% of the cases, respectively. The results show that the number of accidents or people injured is reduced in around 50% of the cases when the mean speed is lowered and number of accidents or people injured persons is increased in around 50% of the cases when the mean speed is increased. This is confirmed in several of the cases in approach 1 even though the results are not very far from reality. The findings in this study question this correlation between the change in mean speed and the number of accidents and people injured.

When case 1 to 3 were analysed, only 1 value out of 18 is higher than 50%. However, only 2 values are less than 10%. The Power Model, anyhow, predicts the outcome for the road stretches better with approach 2 than approach 1. In case 5 to 7, 3 values are higher than 50% while as many as 9 categories are less than 10%. This is thought to be due to some data being overlooked and only taking road stretches with small variations from year to year into account. This indicates that the model can be good at predicting accidents and people injured on normal road stretches, but what is a good model is highly relative. The very best predictions were obtained from case 3 and 7 in which all normal road stretches were included. This indicates that the more data included the better prediction. However, the generally large standard deviations show that the model is uncertain on single road stretches.

The Power Model's prediction of all accidents and people injured for meeting-free road stretches is relatively good. For the more severe categories the deviations are greater, which is due to the limited amount of data and these results should be interpreted carefully since only three road stretches are evaluated. This strengthens the thesis that the more road stretches that are included the more accurate the result. It also supports the statement that it is unreliable on single road stretches. Due to the small amount of data this is based on, no conclusions are drawn for meeting-free road stretches.

There are no visible pattern whether the model generally overestimates or underestimates the outcome. This since for the normal road stretches the model overestimates the outcome in 50% of the cases and underestimates the other 50%. This is also true when looking at the direction of mean speed change. This is thought to be connected to the previously mentioned problem with accidents increasing when the mean speed decreases in around 50% of the cases, and vice versa. From this it can be concluded that there is no point in analysing the road stretches separately with respect to the direction of the mean speed change. The relation is instead yet again that the more road stretches included the better the model’s prediction. There are, however, a possibility that the underestimates and the overestimates cancel each other out, and thereby providing convincing results.

Correction of the exponents

Generally, if the mean speed goes down, because of the increase in accidents and people injured in the case study, the exponents should be lower, or even negative. The small changes in mean speed do not reflect the great variations in accidents or people injured. Since the mean speed ratio is significantly small it has to be raised to large numbers, i.e. the exponents have to be large to have an impact on the result. As stated in most studies from the meta-analysis, the initial speed level is of influence on the number of accidents or people injured. Therefore, different exponents should be chosen when looking at road stretches with different speed levels and also traffic environment. The interval of the speed levels in this study is however small which allows this to be overlooked.

Authentication of mean speed and STRADA

The measured average mean speed changes correlate to what the literature suggests. Even if it has a large standard deviation this can be reconnected to the speed distribution. This suggests that this part of the case study is predominantly correct.

There are no significant changes in any of the evaluated factors in STRADA except for an increase in the share of accidents involving pedestrians and bicyclists along with an increase in suspected alcohol in year 2015, which drastically increases from the year before. This will not influence the overall result of this study to any significant extent. The reliability of the case study is also strengthened due to the even amount of accidents per year. In order to fully validate it would have been necessary to compare the data from STRADA with another database where traffic accidents are recorded, which could not be done due to the time limitation.

Limitations

Some accidents may not have been reported and some reported accidents are not able to use since there are missing data. Generally, the accidents have increased from year to year over the studied period, which can be explained by an increased reporting to STRADA from the Police and healthcare. Another explanation can be the constantly increasing traffic volume.

The number of mean speed and traffic volume measurements included for each road stretch will affect the result. Which day, and for how long, the measurements were done will also have an impact. The more data included will of course improve the accuracy of the result but will be more time consuming.

Only road stretches which had received changed signposted speed was included in the case study. This because of the idea that the change in mean speed should be most significant on these stretches. Of course any road stretch could be included in the analysis, no matter how big, or small, the change in mean speed is.

Reflections

The case study has shown greatly varying results and conclusions have been drawn from this. However, the limit for when the model can count as good is diffuse. What margin of error can be said is acceptable for a model like this? If there generally is a high uncertainty, of course a higher deviation is expected but who decides the limit of the uncertainty?

Questions can also be asked why the number of accidents and people injured increase when the mean speed decreases. The reason for this can be the increased flow of information to the driver in the car. Instruments like GPS, telephones, radio etcetera, has become a distraction for the driver and can increase the number of accidents. Another thought is that the developing car safety might make the people driving their new cars sense a feel of that they are untouchable and will therefore unintentionally drive faster, and thereby be included in, or cause, more accidents. Moreover, the development in healthcare, alongside the development in car safety, might be an explanation to the fact that the number of accidents have increased while the fatalities have decreased.

The small changes in mean speed that occur when the mean speed is reduced from e.g. 95 to 92km/h, which only corresponds to a lowering with approximately 3%, will probably give small impact on the prediction. If the mean speed was changed more, patterns in the results would probably become more clear and distinct.

Finally, questions can be raised when the Power Model is of good use. That the model is used in socioeconomic calculations to motivate lowering of speed limits outside of, for examples, school areas might not be legitimate. Because of the models poor ability to predict changes on single road stretches these calculations might become misleading. Using the Power Model in socioeconomic calculations on the macro level to, for example, propose a lowering of the signposted speed on all national roads might however be relevant.

11 CONCLUSION

Updates of the Power Model have been conducted every few years. The basic approaches used in the different updates have varied a lot and have most likely influenced the given results in some way. Generally, however, more specific information of how these updates were done are very limited.

The performed case study shows that the model can be consistent for the categories which can be based on large amounts of data like all accidents and all people injured. It is not reliable for any of the more severe accident or injury categories and has high uncertainty on single road stretches. Generally, the conclusion is that the more data included the more accurate prediction by the Power Model. Due to the large deviations it should not be used to promote speed changing measures on single road stretches. It can however be used on a macro level.

The Power Model is only valid when the road and traffic circumstances remain completely the same. This has shown to be very rare and hard to achieve. If the model is used to predict only for a couple of years into the future the results can be accurate. However, if the model is used to predict accidents and people injured for a long period of time, the circumstances will change and the model will become invalid. The exponents have shown to decrease over time for all the different categories. This can partially be explained by the development of car safety technology, infrastructure and legislations over time. This then requires the model to be continually updated every few years as it has been done previously. Also, the exponents can be lower gradually if a prediction is done for a longer period of time.

Another factor that makes the model more uncertain is the model's assumption that if the mean speed decreases the number of accidents or people injured will also decrease and vice versa. According to the case study, this turned out to be true in only around 50% of the cases.

The two approaches in the case study, as well as the previously done studies, show that the methodology used to obtain appropriate exponents for the model can have an impact on the results. This causes confusion about the previously done updates, but saying which methodology is the most correct is hard to say.

12 PROPOSALS FOR FURTHER STUDIES

To obtain a result which is more reliable for all the analysed categories, a similar study including more data could be performed, including road stretches which not necessarily have received a change in the signposted speed. This will however require a lot of time since the STA, which is the main holder of traffic data in Sweden, is lacking tools to quickly withdraw and combine the data necessary. To increase the accuracy of such a study, a validation of the accident database STRADA against another accident database would be of interest. This in order to evaluate the quality of the data in STRADA and make sure that the case study is based on valid and accurate data.

The model's assumption that only the mean speed changes and everything else remains unchanged is hard to apply on a case study based on the reality. If the model's exponents were to be updated, it would be of interest to evaluate how other parameters like vehicle technology, healthcare, alcohol and speed distribution affect the number of accidents and people injured and how to include them in the Power Model.

In the case study, it turned out that the number of accidents many times increased even though the mean speed decreased. In this report, some reflections are made to why this happens. However, a more in depth study can be made about why this is the case and what it is that makes this happen. If possible, it could be of great use if findings in this area could be implemented to, and taken into account for, in the Power Model.

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APPENDIX

I. Map overview of the road stretches included in the case study

Figure 8: Map overview of the road stretches included in the case study. Blue roads are not included because of data missing or if the road was reconstructed.

II. List of information over road stretches included in the case study

Table 17: List of information over road stretches in the case study.

Road	County	Year for speed change	Location (from)	Location (to)	Signposted speed before	Signposted speed after
e20	Västra Götaland	2012	väg e6	jonseredsmotet	90	80
e20	Örebro	2008	västra götalands länsgrän	1200m öster om väg 5	90	100
e20	Södermanland	2008	västmanlands länsgräns	2000m väster om traf	110	100
e10	Norrbotten	2008	törböle	morjärv	110	100
86	Västernorrland	2009	3000m nordväst om väg 3	500m sydost om väg 6	110	100
395	Norrbotten	2009	anttis	väg 99 pajala	110	100
e45	Västerbotten	2008	väg 363 sorsele	norrbottens länsgrän	110	100
365	Västerbotten	2009	800m norr om väg 561 väs	väg 353 lycksele	110	100
95	Norrbotten	2009	västerbottens länsgräns	väg 373 abborträsk	110	100
95	Norrbotten	2009	väg e45 hjulträsk	baktåive	110	100
365	Västerbotten	2009	1100m norr om väg 702 ly	väg 363 rusksele	110	100
90	Västernorrland	2009	väg 975 näsåker	1500m söder om väg	110	100
e10	Norrbotten	2008	7100m nordväst om väg 7	väg 875 kauppinen	110	100
99	Norrbotten	2009	väg 98 övertorneå	väg 392 pajala	110	100
394	Norrbotten	2009	väg e10	väg 395 anttis	110	100
342	Jämtland	2009	väg 826 strand	8000m öster om väg 8	110	100
84	Jämtland	2009	väg 351 hedeviken	2200m norr om väg e4	110	100
342	Jämtland	2009	1900m väster om väg 801	1900m söder om väg	110	100
392	Norrbotten	2009	väg 835 ansvar	3000m söder om satt	110	100
95	Norrbotten	2009	arjeplog	jäkkvik	110	100
95	Norrbotten	2009	fälloheden	kålmis	110	100
374	Norrbotten	2009	3700m norr om väg 94	väg 662 bredsäl	110	100
95	Västerbotten	2009	väg 370 boliden	norrbottens länsgrän	110	100
e45	Västerbotten	2008	väg 92 storberget	väg 360 vilhelmina	110	100
e45	Västerbotten	2008	väg 1067 lövliden	enskild väg till verksa	110	100
370	Västerbotten	2009	2200m väster om väg 846	väg 1011 lillholmträsk	110	100
e45	Västerbotten	2008	väg e12 storuman	väg 1006 lomselenäs	110	100
99	Norrbotten	2009	väg 900 myllyoki	väg e45 karesuando	110	90
95	Norrbotten	2009	väg 373 abborträsk	väg 94 yttertjärn	110	90
370	Västerbotten	2009	väg 95 boliden	2200m väster om väg	110	90
365	Västerbotten	2009	väg 370 bäverhult	norrbottens länsgrän	110	90
392	Norrbotten	2009	väg 98 nybyn	väg 835 ansvar	110	90
374	Norrbotten	2009	väg 62 bredsäl	väg e45	110	90
339	Jämtland	2009	väg 745 aspås	väg 344 föllinge	110	90
98	Norrbotten	2009	väg 392 nybyn	väg 841 haapakylä	110	90
395	Norrbotten	2009	masugnsbyn	anttis	110	90
95	Norrbotten	2009	jäkkvik	riksgränsen	110	90
87	Jämtland	2013	bringåsen	1000m öster om åbac	90	100
44	Västra Götaland	2009	väg 47 baggården	väg 2585 håle	90	80
31	Kalmar	2009	stallvägen nybro	800m norr om väg 56	90	80
13	Skåne	2009	väg 1323 höör	väg 113 hasslebro	90	80
44	Västra Götaland	2009	ågårdsrondellen lidköpin	väg 2704 eolsborg	90	80
76	Uppsala	2009	stockholms länsgräns	väg 292 harg	90	80
136	Kalmar	2009	väg 961 algutsrum	450m norr om väg 96	90	80
233	Västmanland	2009	dalarnas länsgräns	väg 68 kärrbo	90	80
202	Västra Götaland	2009	väg 3061 undenäs	väg 49 svanvik	90	80
31/47	Jönköping	2014	vetlanda centrum	500m nordväst om vä	90	80
83	Gävleborg	2009	väg 50 bollnäs	västernorrlands läns	90	80
344	Jämtland	2009	väg 370 lillsjöholm	väg 87 selsviken	90	80
84	Jämtland	2009	riksgränsen	väg 315 hedeviken	90	80
42	Västra Götaland	2009	väg 40 borås	väg 2020 brunnehed	90	80

340	Jämtland	2009	väg 339 krokom	väg 689 häggsjövik	90	80
26	Dalarna	2009	värmlands länsgräns	e45 johannisholm	90	80
156	Västra Götaland	2009	väg 40 ryamotet	väg 27 tranemo	90	80
164	Västra Götaland	2009	väg 2180 loviseholm	e45 åmål	90	80
356	Norrbotten	2009	väg 670 degernäs	väg 691 avafors	90	80
62	Värmland	2009	väg 717 kärnhede	väg 239 ekshärad	90	80
348	Västernorrland	2009	väg 917 bredbyn	västerbottens länsgrä	90	80
46	Västra Götaland	2009	väg 40 ulricehamn	väg 26 borgunda	90	80
142	Gotland	2009	väg 140 fidenäs	väg 148 visby	90	80
62	Värmland	2009	5700m norr om väg 930 h	3100m söder om väg	90	80
122	Blekinge	2009	väg 28 uddabyggd	kronobergs länsgräns	90	80
296	Dalarna	2009	väg e45	gävleborgs länsgräns	90	80
301	Dalarna	2009	3300m norr om väg 70	6900m söder om väg	90	80
140	Gotland	2009	väg 142 fidenäs	väg 601 tofta	90	80
147	Gotland	2009	väg 148 visby	väg 148 stora banne	90	80
143	Gotland	2009	väg 144 hallute	väg 608 roma	90	80
149	Gotland	2009	visby	väg 670 stenkyrka	90	80
144	Gotland	2009	väg 142 sindarve	väg 143	90	80
141	Gotland	2009	väg 142 hemse	väg 142 klintehamn	90	80
310	Gävleborg	2009	4900m sydväst om väg 71	väg 84 korskrogen	90	80
84	Gävleborg	2009	jämtlands länsgräns	väg 678 färila	90	80
50	Gävleborg	2009	dalarnas länsgräns	väg 619 alfta	90	80
305	Gävleborg	2009	väg 84 delsbo	1800m söder om väg	90	80
307	Gävleborg	2009	väg e4 lindsta	väg 305 hassela	90	80
301	Gävleborg	2009	väg 209 voxna	väg 50 alfta	90	80
303	Gävleborg	2009	väg 272 säbyggeby	väg e4 hagsta	90	80
154	Halland	2009	väg 767 falkenberg	västra götalands läns	90	80
153	Halland	2009	väg 810 krusagården	väg 728 fegen	90	80
24	Halland	2009	väg 527 tormarp	skånes länsgräns	90	80
339	Jämtland	2009	väg 344 föllinge	väg e45 harrbäcken	90	80
346	Jämtland	2009	väg e45 hoting	västernorrlands läns	90	80
320	Jämtland	2009	västernorrlands länsgrän	väg 717 ansjö	90	80
321	Jämtland	2009	väg 542 svenstavik	väg 587 månsåsen	90	80
345	Jämtland	2009	väg 795 ulriksfors	västernorrlands läns	90	80
84	Jämtland	2009	väg e45 älvros	gävleborgs länsgräns	90	80
323	Jämtland	2009	väg e14 bräcke	väg 726 nyhem	90	80
132	Jönköping	2009	väg 985 hakarp	väg 32 bredestads ky	90	80
133	Jönköping	2009	480m öster om väg 993 gr	väg 32 säby	90	80
152	Jönköping	2009	väg 27 bredaryd	väg 846 skillingaryd	90	80
125	Jönköping	2009	väg 47	väg 777/780 näshult	90	80
127	Jönköping	2009	väg 128 sävsjö	väg 47 vetlanda	90	80
134	Jönköping	2009	väg 32 eksjö	östergötlands länsgrä	90	80
136	Kalmar	2009	väg 924/925 ottenby	väg 137 algutsrum	90	80
125	Kalmar	2009	trafikplats lindsdal	350m söder om kråks	90	80
120	Kalmar	2009	kronobergs länsgräns	väg 25 örsjö	90	80
122	Kronoberg	2009	blekinge länsgräns	väg 27 rävåsen	90	80
124	Kronoberg	2009	väg 25	väg 600	90	80
99	Norrbotten	2009	väg e4 haparanda	väg 795 luppio	90	80
383	Norrbotten	2009	väg e4 börjeslandet	väg 356 brändkläppe	90	80
13	Skåne	2009	väg 984 bötteberg	väg e22 hörby	90	80
117	Skåne	2009	väg 1902 hässleholm	kronobergs länsgräns	90	80
24	Skåne	2009	väg 1848 bälinge	väg 21 finnja	90	80

114	Skåne	2009	väg 24 örkelljunga	väg 13 munka-ljungby	90	80
101	Skåne	2009	väg 566 arrie	470m väster om ande	90	80
118	Skåne	2009	väg 19 dundershuset	väg 1631 åhus	90	80
276	Stockholm	2009	väg 1017 roslags-kulla	väg 1179 frötuna	90	80
263	Stockholm	2009	uppsala länsgräns	vallstavägen märsta	90	80
273	Stockholm	2009	väg 894 lindskrog	uppsala länsgräns	90	80
219	Södermanland	2009	väg e4.09 nyköping	väg 800 mölna	90	80
273	Uppsala	2009	stockholms länsgräns	väg 661 bärby	90	80
282	Uppsala	2009	väg 273 almunge	stockholms länsgräns	90	80
254	Uppsala	2009	väg 813 simtuna	väg 72 heby	90	80
172	Värmland	2009	väg e18 årjäng	2000m öster om väg 1	90	80
62	Värmland	2009	väg 968 klaråsen	riksgränsen långflon	90	80
364	Västerbotten	2009	väg 651 botsmark	väg 811 västra hjoggb	90	80
360	Västerbotten	2009	1500m väster om väg 961	väg 365 lycksele	90	80
364	Västerbotten	2009	väg e4 sandbacka	200m norr om väg 63	90	80
320	Västernorrland	2009	väg 86 kovland	jämtlands länsgräns	90	80
331	Västernorrland	2009	1000m norr om väg 736 vi	väg 87 märrviken	90	80
334	Västernorrland	2009	väg 332 kläpp	väg 335 grillom	90	80
345	Västernorrland	2009	jämtlands länsgräns	väg 331 krångsången	90	80
331	Västernorrland	2009	väg 345 ramsele	jämtlands länsgräns	90	80
346	Västernorrland	2009	väg 90 junsele	jämtlands länsgräns	90	80
250	Västmanland	2009	500m norr om väg 590 ko	väg 66/68 oti	90	80
154	Västra Götaland	2009	hallands länsgräns	väg 27 kila	90	80
e45	Västra Götaland	2012	väg 2064 liden	väg 2221 solberg	90	80
166	Västra Götaland	2009	väg e45 mellerud	väg 164 kårslätt	90	80
193	Västra Götaland	2009	väg 47 rännefalla	väg 195 linderyd	90	80
172	Västra Götaland	2009	väg 2120 grösäter	väg 164 steneby	90	80
182	Västra Götaland	2009	2000m öster om väg 1765	väg 46 timmele	90	80
e20	Västra Götaland	2012	väg 1898	vara	90	80
e20	Västra Götaland	2012	väg 2755 jättadansen	väg 26 hasslerör	90	80
187	Västra Götaland	2009	väg 47 lång	väg 44 ågården	90	80
49	Västra Götaland	2009	väg 2918 karlsborg	örebro länsgräns	90	80
194	Västra Götaland	2009	väg 49 huseby	väg 195 källebo	90	80
172	Västra Götaland	2009	väg 694 nordmanneröd	väg 173 färgelanda	90	80
163	Västra Götaland	2009	väg 1012 grebbestad	väg 165 naverstad	90	80
165	Västra Götaland	2009	väg 911 hällevadsholm	väg 163 naverstad	90	80
190	Västra Götaland	2009	200m öster om väg 557 b	2000m norr om norra	90	80
186	Västra Götaland	2009	väg 190 nossebro	väg 47 grästorp	90	80
185	Västra Götaland	2009	väg 40 bottnaryd	väg 26/47 mullsjö	90	80
47	Västra Götaland	2009	jönköpings länsgräns	väg 46 norra falköpin	90	80
169	Västra Götaland	2009	väg 160 almön	väg 721 aröd	90	80
183	Västra Götaland	2009	väg 42 fristad	väg 1848 besene	90	80
202	Västra Götaland	2009	e20 krontorp	väg 200 töreboda	90	80
204	Örebro	2009	väg 205 svartå herrgård	250m söder om 691 la	90	80
52	Örebro	2012	väg 207 odensbacken	södermanlands länsg	90	80
134	Östergötland	2009	jönköpings länsgräns	950m väster om väg 2	90	80
209	Östergötland	2009	1000m väster om väg 846	2600m nordväst om v	90	80
211	Östergötland	2009	1400m söder om väg 109	väg 51 örnmon	90	80
131	Östergötland	2009	väg 134 österbymo	jönköpings länsgräns	90	80
135	Östergötland	2009	väg 23/34 bränntorp	800m öster om väg 6	90	80
35	Östergötland	2009	väg 686/724 broddebo	väg 732 åtvidaberg	90	80
50	Dalarna	2011	väg 874 rostberg	gävleborgs länsgräns	80	90

III. Step-by-step calculations

Each of the 8 cases were calculated separately using the steps described in this section.

Approach 1

The mean speed was available for each road stretch before and after the speed change. The average mean speed for all road stretches was calculated by summarising each roads contribution to the mean speed with respect to the vehicle kilometres driven on each road stretch. For each road stretch the number of vehicle kilometres was calculated and divided by the total number of vehicle kilometres driven on all road stretches combined. The mean speed for each road stretch was then multiplied with the road stretches' share of vehicle kilometres and summarised for all road stretches to receive an average mean speed for all road stretches.

The number of vehicle kilometres on each road stretch were obtained by using the following equation.

$$Vehicle\ kilometres = Road\ stretch\ length * Traffic\ volume \tag{5}$$

The number of accidents per 1,000,000 vehicle kilometres were obtained by using the following equation. This was also done for the number of people injured.

$$Accidents\ per\ 1{,}000{,}000\ vehicle\ kilometres = \frac{\sum Number\ of\ accidents}{\sum Vehicle\ kilometres} * 1000000 \tag{6}$$

The Power Model's prediction was obtained by using the following equation. This was also done for the number of people injured.

$$Accidents\ after = \left(\frac{Mean\ speed\ after}{Mean\ speed\ before}\right)^{Exponent} * \ Accidents\ before \tag{7}$$

The percentage difference between the model's prediction and the reality was obtained by using the following equation.

$$Percentage\ difference = \frac{Power\ Model's\ prediction - Reality\ after}{Reality\ after} \tag{8}$$

When calculating what the exponents should have been to predict the outcome correctly the following equation was used. This was also done for the number of people injured

$$New\ exponent = \frac{log\left(\frac{\sum Accidents\ per\ 1{,}000{,}000\ vehicle\ kilometres\ after}{\sum Accidents\ per\ 1{,}000{,}000\ vehicle\ kilometres\ before}\right)}{log\left(\frac{Average\ mean\ speed\ after}{Average\ mean\ speed\ before}\right)} \tag{9}$$

Approach 2
The mean speed was available for each road stretch individually.

The number of vehicle kilometres on each road stretch were obtained by using the following equation.

$$Vehicle\ kilometres = Road\ stretch\ length * Traffic\ volume \tag{10}$$

The number of accidents per 1,000,000 vehicle kilometres for each road stretch were obtained by using the following equation. This was also done for the number of people injured.

$$Accidents\ per\ 1{,}000{,}000\ vehicle\ kilometres = \frac{Number\ of\ accidents}{Vehicle\ kilometres} * 1{,}000{,}000 \tag{11}$$

The Power Model's prediction was obtained by using the following equation. This was also done for the number of people injured.

$$Accidents\ after = \left(\frac{Mean\ speed\ after}{Mean\ speed\ before}\right)^{Exponent} * \ Accidents\ before \tag{12}$$

The percentage difference between the model's prediction and the reality for each road stretch was obtained by using the following equation.

$$Percentage\ difference = \frac{Power\ Model's\ prediction - Reality\ after}{Reality\ after} \tag{13}$$

An average percentage difference, 95'th percentile and standard deviation were then calculated from the percentage differences for each individual road stretch.

Correlation between mean speed and change in number of accidents and people injured

For all the road stretches, a check was performed to see if the number of accidents of people injured went down if the mean speed went down.

If the mean speed decreased, all the road stretches on which the number of accidents or people injured also decreased, were counted and divided by the total number of road stretches which had received a decreased mean speed. The exact same methodology was used for the road stretches where the mean speed increased.