Centerline Rumble Strips – Safety Evaluation

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Road casualties attract more and more attention as they are one of the main death causes in our world today. Having in mind that "prevention is better than cure", the Danish Ministry of Transportation, Road Directorate and municipalities have been doing a lot of efforts on reducing the road casualties. These authorities are engaged in suggesting and implementing a number of simple and practical preventative measures such as speed enforcement, red light cameras, daytime running lights on vehicles, black spot, centerline rumble strips etc.

Studies on the effect of most of these measures were carried out and showed that they have improved the road safety. However, the centerline rumble strips measure was not one the evaluated measures.

In this final project, it is chosen to evaluate whether the centerline rumble strips treatment improves the road safety. And how much does it contribute to the road safety improvement. By applying the traditional before and after method of road safety measure evaluation and meta-analysis, the result of the analysis have shown that the centerline rumble are very effective and can prevent accidents of up to 20% of the total accidents. This is however lower than the 40% accident reduction desired by the May 2007 action plan.

Preface

This project report is worked in connection with the 10th semester of the transportation engineering education at Aalborg University's faculty of engineering and science.

This is the first of its kind project of centerline rumble strips in Denmark and aims to evaluate whether installation of centerline rumble strips has achieved any effect. The evaluation is performed on the bases of accident data retrieved from Road Directorate websites.

The project report is divided into seven chapters. In the first chapter, the introduction, it will be first of all mentioned why attention on road accidents is essential. So as to enlighten the importance of road casualties, the deaths caused by road accidents will be compared with the deaths caused by the other main factors which also cause deaths, such as the cancer and heart diseases, suicide etc. The chapter will also include and compare the road accidents in the past years. It will end with mentioning the aim of this project and how it will be implemented.

Chapter two, which is mainly explaining about the treatment itself, begins with the factors which can cause road accidents, such as distraction, drowsiness and fatigue. Then the countermeasures of these factors, the treatment, will be mentioned. The chapter then glances little bit about the history and the kinds of the different kinds of rumble strips. In the end of the chapter, some of the advantages and the disadvantages of the treatment will be briefly named. And one final thing in this chapter is project scope.

Chapter 3, the current state of knowledge, introduces previous international studies on the evaluation of the effect of centerline rumble strips. Five different studies were included.

In order to implement the evaluation of the centerline rumble strips treatment, methodology and project data is necessary. The first part of chapter four deals with the methodology. The methods applied in deciding the individual site specific effect and the general mean of the whole sites is presented. The second part of the chapter presents how and where the project data was found.

Finally the result of the analyses, the discussion where the findings are explained and the conclusion are respectively explored in chapters 5, 6 and 7.

There is a CD accompanied with the project report. The CD includes Excel files containing the calculations and the data of the analyses.

Abstract

Each year many people are killed on the roads in Denmark. Although the number of people killed by vehicles on the roads is slowly declining, it is still too many. In the past two years alone there were about 558 deaths in Denmark. This does not only concern to the authorities but for the nation as a whole. There are professionals who are always developing and implementing measures against the road traffic problems. Centerline rumble strips is one of the many infrastructure related measures applied to prevent the occurrence of car accidents, especially cross over, run off the road and head-on accidents.

International studies have claimed that centerline rumble strips can reduce accident numbers by more than 15%. Centerline rumble strips are being installed on many of the Danish rural roads in the last decade with the goal of reducing the road casualties. As previous studies on how effective this measure is are not conducted in Denmark and many roads have centerline rumble strips installed, it is necessary to implement an appropriate study.

This study will investigate whether centerline rumble strips really work. By using previously recorded accidents data and traffic volumes from the Road Directorate, this paper will evaluate the effectiveness of safety improvement on each site as well as the overall safety program. For the evaluation of the each safety improvement, before and after observation approach is applied and for the evaluation of the overall safety improvement, meta-analysis method is applied. 35 sites from locations all over the country were included in the analyses.

The evaluation result complied with the international studies. The total number of accidents was reduced by 20% following the installations of the centerline rumble strips. As there were limitations on the number of roads included in the analyses, and as it is believed that many more roads with centerline rumble strips will be available, it is suggested to implement similar studies in the future.

Keywords: Meta-analysis, Centerline rumble strips, Road safety

Abstrakt (abstract in Danish)

Flere og flere mennesker bliver dræbt på vejene i Danmark hvert år. Selv om antallet af mennesker døde på grund af trafikulykke har faldet svagt, er det stadig uacceptabel. I de sidste to år alene var der næsten 558 trafik dødsfald i Danmark. Det er mange – ”hvert ulykke er en for meget” Dette trafiksikkerheds problem bekymrer ikke kun for pågældende myndighederne, men for nationen som helhed. Der er mange fagfolk såsom trafikplanlæggere og ingeniører der udvikler og gennemfører foranstaltninger mod de mange eksisterende trafiksikkerheds problemer. Rumlestriber langs midtlinjer er en af de mange foranstaltninger der anvendes for at reducere antallet af trafikofre.

Internationale undersøgelser om sikkerhedsmæssigeffekt af rumlestriber langs midtlinjer viste en reduktion på mere end 15 % i alle uheld. I dag er der mange veje i Danmark hvor rumlestriber blev installeret med formål at reducere tilskadekomne. På grund af manglende undersøgelse om hvor effektiv denne rumlestriber foranstaltning er, er det nødvendigt at gennemføre en passende undersøgelse.

Denne undersøgelse vil evaluere hvor meget rumlestriber langs midtlinjer forbedre trafiksikkerheden. Evalueringen er baseret på trafik og uhelds data fra vejdirektoratets hjemmeside. De anvendte metoder er det traditionel før-og-efter undersøgelse og meta-analysis. I alt er der 35 lokaliteter over hele Danmark som er inkluderet i analysen.

Som forventet rumlestriber langs midtlinjer forbedrer trafiksikkerheden. Installationen af rumlestriber langs midtlinjer har medført et fald i antal af alle uheld på 20 procent. På grund af begrænsninger på antallet af vejene der indgår i analysen, foreslås der gennemførelsen af lignende undersøgelser i fremtiden.

Nøgleord: Trafiksikkerhedsmæssigeeffekt, meta-analysis, rumlestriber langs midtlinjer

Contents

Chapter 1 – Introduction

Depending on where you are on the world, deaths are caused by different factors. In the third world, for example, such as the countries in Sub-Saharan Africa and South Asia, the major causes of deaths are poverty, droughts or homicide and operations of wars. In the developed nations, where security, production of goods, treatment and technology are advanced, the road accidents are now the most important of accidental deaths. Although these differences exist, the general situations of road accidents in our world are very alarming as the lives of more than a million people around the world are lost in road accidents each year, and it is predicted that the road crashes will be the fifth leading cause of death worldwide by 2030 [United Nations, 2010]. This is because the number of vehicles using the roads continues to grow. In the world today, the issue of road traffic safety remains to be one of the most discussed areas. The adoption of a draft resolution on road safety action by the United Nations General Assembly in 2010 shows how serious the world is on this matter.

In Denmark, looking at the last two years almost 558 people have been killed on the roads [Vejdirektoratet, 2011a]: To put these figures into a realistic perspective, it is useful to make comparison with casualties resulting from other forms of death causes. Table 1.1 shows the major causes of loss of potential life years in Denmark. The table, which presents only the first six major causes of life years lost, shows, unfortunately, that road traffic accident is the fourth principal cause of lost life years.

Table 1.1: The major causes of years of potential life lost in Denmark by men and women [Madsen, a]

Cause of the death	Men	Women	Total
Ischemic heart disease	24500 yrs	8300 yrs	32800 yrs
Lung cancer	14200 yrs	11200 yrs	25400 yrs
Suicide	15100 yrs	5300 yrs	20400 yrs
Road traffic accidents	13200 yrs	3900 yrs	17100 yrs
Home – and leisure accidents	11400 yrs	3400 yrs	14800 yrs
Breast cancer	-	13100 yrs	13100 yrs

From a national standpoint, road traffic accidents are especially important because many of the victims are young people, predominantly males, who are at or just approaching the prime of life, see figure 1.1. What makes the road traffic accidents even more important is that it costs a lot to the community. When a serious road accident happens, many people suffer serious injuries that change their lives forever. This is very costly as there are many who are involved in the work; the police and ambulance crews, the doctors and nurses, the equipment for treatment, psychologists. The list does not end; there are also material costs, environment and a loss of person's ability to work. Economists can evaluate these costs in terms of crowns and cents but no one can equate money to the human suffering involved.

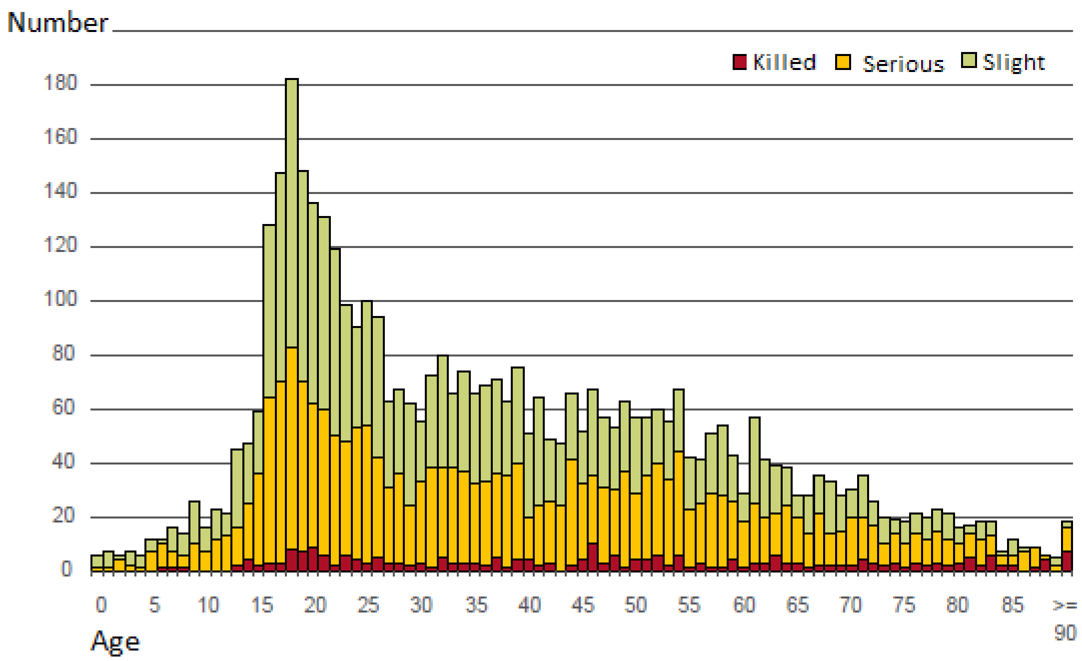


Figure 1.1: Number of traffic road accident casualties by severity and age by the year 2010 [Vejdirektoratet, 2010a]

According to the Road Directorate's traffic accident overview of 2010, the toll of road accidents is in its lowest level since 1930 (excluding the World War II). The figures from the road directorate show that 3498 people were injured on Danish roads in 2010, where the injuries of the previous year were 4174. This positive result shows that the engineers, planners, municipalities, road directorate and all the authorities concerned the transportation are endeavouring their best to create a suitable environment for the safety of the society in terms of road traffic. Although the number of killed and injured on the entire road network of Denmark, in general, has been declining substantially over the past years, the numbers of accidents are still high and some more effective safety measures are necessary. The transportation authorities know this and they are daily working on the safety of their communities.

Road traffic safety, which is a collective term for the safety of roads and their users, should be of interest to everyone; not only the interest, as some people think, of transportation planners and engineers. The problems on our roads caused by the traffic accidents, such as the deaths and the long lasting injuries affect everyone. The ministry of transportation has issued a road safety action plan called "Hver ulykke er én for meget, trafiksikkerhed begynder med dig" (each accident is one too many, traffic safety starts with you). The objective of the plan is to reduce deaths and injuries caused by road accidents and by looking at the title of the action plan, it is obvious that it is conveying a message to everyone, telling them that the road accidents should not be accepted among the society and that the traffic safety is the responsibility of everyone.

The different works on road safety done by the transportation authorities, which is mainly reducing the number of road accidents, includes inventing and setting up safety equipment, improving drivers' behaviour etc. Road traffic accidents are theoretically described, as not only the failure of the driver but rather the whole traffic system failure – that is the interaction among three elements: human (driver), vehicle and equipment and road and environment (road infrastructure) [Madsen, a]. Effective safety measures which are likely to reduce the number of accidents are aimed to the three above mentioned factors of road accidents. The vehicles can be designed in a way they can reduce the frequency of accidents and the severity of accidents. This can be done by installing signalling devices on vehicles, periodic vehicle tests or inspection etc. The human, which is the most important factor of road accident causation, can be trained and tested so as to use roads and vehicles safely. Children can be taught how to use roads at an early age. The drivers are trained and tested before they use vehicles on the roads. At last the other road accident causation factor, which is important to do something about, is the road infrastructure and its environment. All kinds of roads can be designed and improved so as to minimise the common types of accidents. The measures include installing automatic speed controllers at certain points where the speed limit may be exceeded, building speed calming bumps at residential areas, speed differentiation on certain road stretches, identifying and treating accident black spots, installing rumble strips at the edge of the travel lane or at the middle of the two opposite travel lanes (centerline rumble strips).

Studies on the effect of the most aforementioned measures have been conducted, see Elvic, 2009. But there are not enough studies (in Denmark) on the effect of the last mentioned measure concerning the rumble strips. This is because the uses of rumble strips are new in Denmark. They were first used in Denmark in 2004 in order to awaken the sleepy drivers before running off or running into the wrong lane. [Vejdirektoratet, 2010b].

It is believed that the most effective way to reducing road casualties is to examine the common types of accidents and the common contributory factors before suggesting a solution. A study on accident situation and severity depending on accident types suggests that one of the most severe accidents is that occurs between the traffic flow on the opposing directions [Madsen, b]. The installation of the rumble strips is a solution to these types of accidents. They warn drivers who unintentionally cross the roadway centerline. Due to the lack of a study showing the effectiveness of this measure, it is necessary to make a new study so as to evaluate how effective these rumble strips are.

The main objective of this project work is to make study on the effectiveness of centerline rumble strips. So as to improve the road traffic safety, the Danish Road Safety Commission, which operates under the ministry of justice and responsible for identifying traffic safety problems and combating the growing number of traffic accidents, issues constant national action plans for traffic safety. The latest action plan of May 2007 has set a new overall national goal for 2012. The new target is 40 percent reduction on the number of people killed, seriously and slightly injured by the end of 2012 compared with the 2005 levels. It will be evaluated if this goal is reached after the means of centerline rumble strips are used on some road stretches.

The method used in the evaluation is before and after evaluation study applying statistical analysis in order to identify the likely effects and in order to test, if the safety effects are significant and, if so, if the effect of the treatment varies between different types of sites.

Chapter 2 – Rumble strips, the treatment

As mentioned in the introduction part, roadway departure crashes (SVROR (single run-off- road and head-on crashes) remain to be a major problem in relation to the road safety. Before the measures against these types of crashes are described, the causes of the road departure are mentioned. The driver can leave his travelling lane intentionally or unintentionally.

The driver's intentional road departure can be caused by a foreign object on the road or an animal that wades out the road, where the driver attempts to avoid hitting it and hence runs off the edge of the pavement or crosses into the lane of the opposite direction. It could also be caused by an environmental condition such as a thick fog, smoke or snow on the road which can make the driver slide off his travelling lane. These types of road departure crashes can be reduced with reactive measures, such as removing the objects on the road or placing road signs showing that an animal can walk on the street or as we often hear on the radio announcements warning that something are on the road. Moreover these types of road departures crashes are rare compared with the unintentional road departure crashes.

The most and deadliest road departure crashes are related with inattentiveness, carelessness or a plain distraction. There are many things which take the driver's attention away from the driver's task of controlling the car and thereby increase the risk of car crashing. These can be the distracting things that are found inside or outside the car, which can distract the driver visually, manually or/and cognitively. The following are the main distracting activities [Herrstedt, 2004]:

- Using mobile phones
- Talking to passengers
- Using navigation devices, such as GPS or reading maps
- Entertainment, such as watching videos, changing the radio station or CDs
- Eating and drinking
- Grooming (mainly women)
- Roadside advertisements (they take your eyes from the road) etc.

Another factor which takes the driver's attention away is the drowsiness or fatigue. This is a serious hazard facing all kinds of drivers, but it is particularly dangerous for the young drivers. Many young drivers say they drive drowsy on a regular basis [Drowsy Driving, 2011]. This is because they are very tired while they get behind the wheel as they have to rush to early classes, after-school jobs or late night socializing and thereby do not get enough sleep. Fatigue affects driving by reducing the ability of the driver to instantaneously react to unexpected situation. This can then lead a very serious car crash.

It is obvious that the things related with the driver inattention, whether it is distraction, drowsiness or simply something else in the driver's mind, are major causative factors of car crashes. The question is what has been done to deal with these driver inattention problems?

Although adequate sleep (in the case off drowsiness and fatigue), and that law enforcement (in the case of using mobile, eating etc) and educating the drivers are very effective tools, there are other countermeasures to help get the driver's attention back to the controlling of the vehicle. One of them is a proactive roadway countermeasure such as rumble strips. See the following paragraph on a mother of a car crash victim who is probably right when she points the rumble strips as a life safer.

An American mother, Cindy Sease, whose daughter was killed as a backseat passenger in a car crash on a highway in South Carolina said, "Perhaps if there had been a rumble strip on the road where my daughter was killed she would be alive today". It is thought that the driver of the car was distracted at the time of the crash because she was taking pictures of the back seat passengers. The teen driver of the car lost control, overcorrected, ran off the road, and eventually struck a tree. [Roadway Safety Foundation, 2011].

What are rumble strips?

Rumble strips, which are countermeasures against run-off-the-road accidents and head-on collisions, are rows of grooves placed along the verge of the road (shoulder rumble strips) or at the middle of the road (centerline rumble strips) to warn the inattentive drivers who are departing the lane they are travelling on. These raised or grooved patterns suddenly produce an uncomfortable vibration and noise as the motor vehicle tires pass over the rumble strips, so as to stimulate the driver's attention [Herrstedt, 2005].

Historically, the person who invented the rumble strips is unknown but it was Garden State Parkway in New Jersey, an American state which became the pioneer of rumble strips as it first implemented them in 1952 [Wikipedia, 2011]. The rumble strips were first used only on highways, but later they were also widely used on the other road types including rural two-lane roads, multiline undivided highways and urban roads, such as on and off ramps. The majority of the rumble strips are found on rural roads rather than the urban ones. Initially, they were rolled-in rumble strips. Later, they were modified into milled rumble strips. Many states began to use rumble strips in 1960's. In 1990's the rumble strips spread rapidly and today there are 46 of the 50 states within the United States which use the rumble strips as a safety measure tool.

In Denmark, the shoulder rumble strips have been used for a long time, but the centerline rumble strips have first reached Denmark in 2004 [Vejdirektoratet, 2010b].

The types of rumble strips

In terms of their purpose of use, the rumble strips are divided into four common categories [NCHRP, 2009]:

- Shoulder Rumble Strips
- Centerline Rumble Strips
- Mid lane Rumble Strips
- Transverse Rumble Strips

Shoulder Rumble Strips

Shoulder rumble strips are the first type of rumble strips in the world and they have been used for a long time. As shown on figure 2.1, the shoulder rumble strips are placed outside of the travel lane or in some cases a long side of the edge of the travel lane. These types of rumble strips are primarily designed to reduce the solo accidents known as single-vehicle run off- road (SVROR) – these are types of crashes that are related with one vehicle whose driver is departing off the road [Herrstedt, 2005].

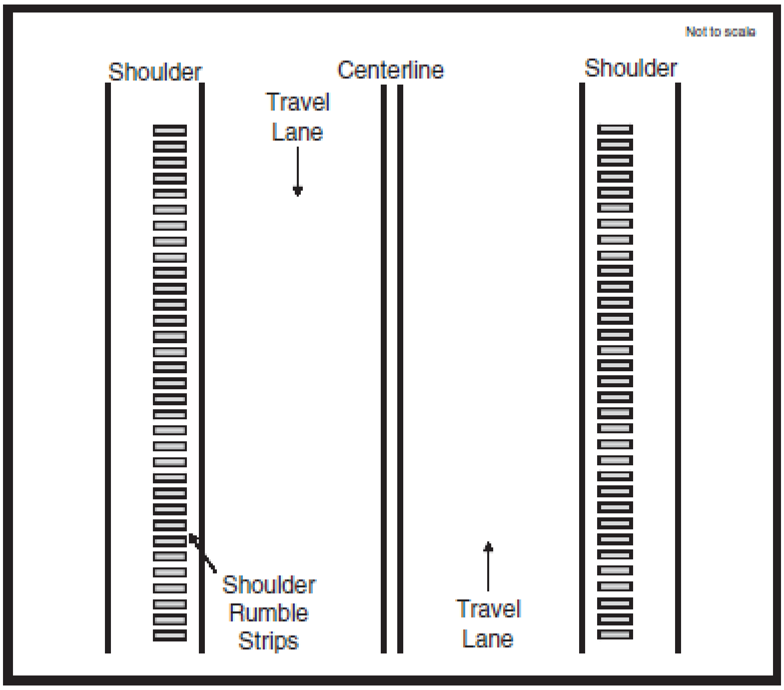


Figure 2.1

Typical shoulder rumble strips installation [NCHRP, 2009].

Centerline Rumble Strips

Centerline rumble strips are placed at the centerline of a roadway – that is the line between the two lanes of a roadway. These types of rumble strips mainly intended to protect cross-over crashes or head on collisions on two-lane roadways. Figure 2.2 illustrates a typical centerline rumble strip installation.

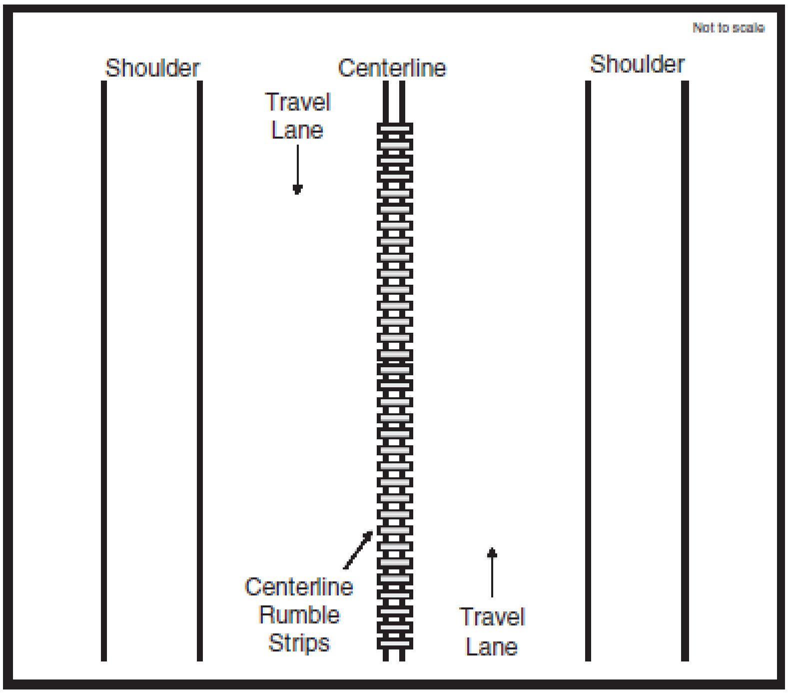


Figure 2.2

Typical centerline rumble strips installation [NCHRP, 2009].

Midlane Rumble Strips

Midlane Rumble Strips are ideal rumble strips meaning that they were designed and discussed for sometime in USA, but they are not installed anywhere in the world. They are placed in the center of a travel lane and are designed to potentially protect both cross-over crashes and SVROR crashes. See figure 2.3 for a typical midlane rumble strip concept.

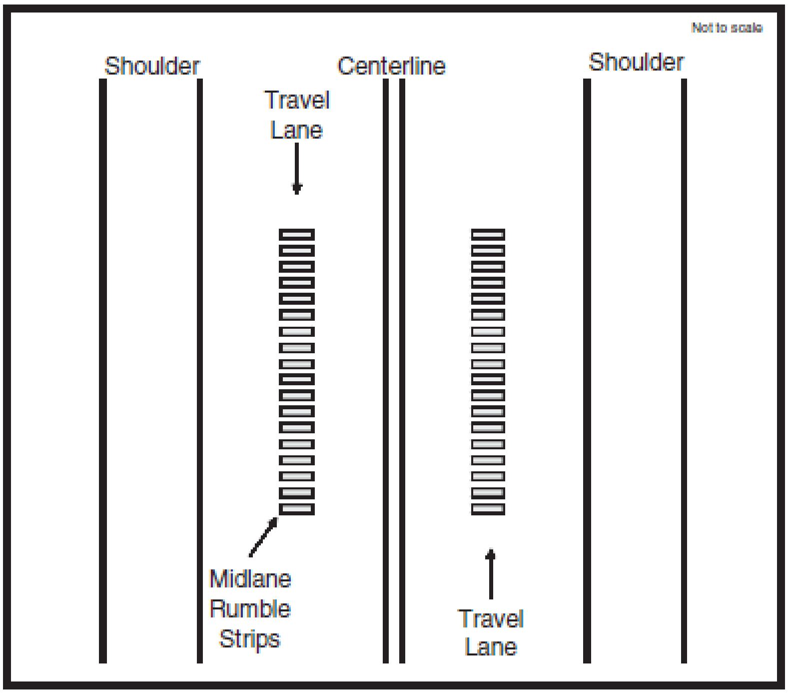


Figure 2.3

Typical midlane rumble strips concept [NCHRP, 2009].

Transverse Rumble Strips

Transverse rumble strips are placed more or less across the full width of the travel lanes. They are primarily used on locations where the motorists are needed to take an action of reducing the speed they are travelling on. These locations can be at the entrance of an urban area after coming from a rural area. The drivers are alerted on approaching intersections, toll plazas, horizontal curves, work zones, or any other unexpected situations. See figure 2.4 for a typical transverse rumble strips installation.

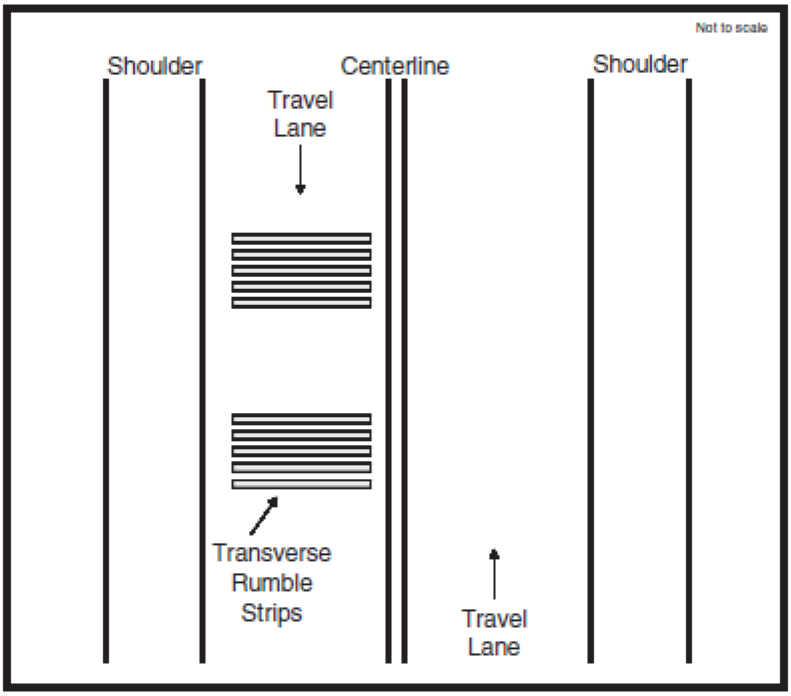


Figure 2.4

Typical transverse rumble strips installation [NCHRP, 2009].

In relation to their installation method, form and size, the rumble strips are divided into four parts:

- Milled
- Rolled
- Formed
- Raised

Apart from their different way of installation, the four rumble strips also produce different amount of noise and vibration. Although, there are four types of rumble strips, only two of them are widely used around the world, namely, milled and rolled rumble strips. The four types are discussed below.

Milled Rumble Strips

Milled rumble strips are made by milling machines which cut grooves in the existing pavements. Unlike the rolled rumble strips, the milled rumble strips can be used both for new and existing roads, and their easiness of implementation makes them to be the preferred types by many states and the most transportation agencies which install the rumble strips. They can easily and effectively be integrated with existing asphalt and Portland cement concrete pavements structures. Dimensions of the milled rumble strips vary between 5 to 7 inches (13 to 18 cm) wide and the spacing between them is about 12 inches (30 cm) and the depth is approximately 0.5 inches (1.3 cm). The amounts of sound and vibrations they produce depend on their dimensions. A general rule of thumb is the wider and deeper the rumble strips are, the more sound and vibrations they produce [FHWA, 2011]. Figure 2.5 shows a picture of milled rumble strips.

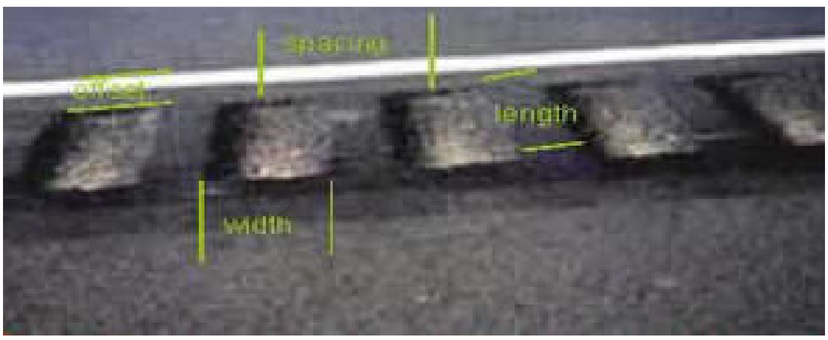


Figure 2.5: *Typical milled rumble strip picture [FHWA, 2011].*

Rolled rumble strips

Rolled rumble strips are only used on a new road shoulder where the concrete is not cured yet. They are rounded and V-shaped grooves which are pressed or rolled into the asphalt. They are installed by using a rolling compactor with especially designed roller. Rolled rumble strips are less effective than milled rumble strips this is because the noise and the vibration they produce is less noticeable than milled rumble strips. They rolled rumble strips can vary any number of dimensions. Their common dimensions are approximately, however, 32 mm deep, 400 mm wide and 600 mm to 1000 mm length [FHWA, 2011]. See figure 2.6 for a picture of rolled rumble strips.

Figure 2.6

Typical rolled rumble strip picture [FHWA, 2011].

Formed rumble strips

Formed rumble strips are also V-shaped grooves and are pressed into the concrete or asphalt surface during the finishing process. They are normally 32 mm deep and 40 mm wide. They are not used many places in the world, because of their difficult installation compared with the milled rumble strips [FHWA, 2011].

Raised rumble strips

Like the milled rumble strips, the raised rumble strips can be used for both new and existing roads. They are rounded or rectangular shaped markers or asphalt bars which adhere to the asphalt or to the concrete. They are about 50 to 305 mm wide and their height can range from 6 mm to 13 mm. Because of their height, it is difficult to maintain especially in the winter season, where removal of snow is necessary. Their use is, therefore, restricted to the warmer climates [FHWA, 2011]. See figure 2.7 for a picture of raised rumble strips.

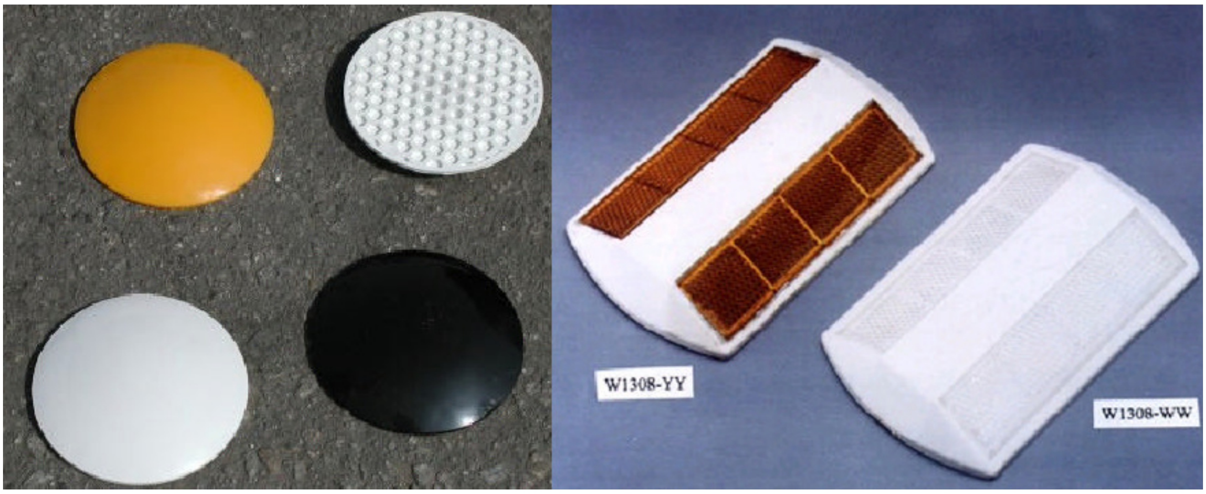


Figure 2.7

Typical raised rumble strip picture [FHWA, 2011].

The negative and positive compilation of rumble strips

Although studies on the centerline rumble strips, which is the type of the rumble strip that this project concentrates on, will be discussed in the next chapter, in this section the general advantages and disadvantages of rumble strips will be briefly mentioned. Many independent studies on the effectiveness of rumble strips are performed across the United States. One of them is a study named after the state and the date it was performed "2006 Study Minnesota". This study showed that a reduction of 13% in total single vehicle run off road crashes has occurred [FHWA, 2011]. Apart from their ability of saving lives, the rumble strips have many other advantages. They are the most cost effective safety treatment as they have a very high benefit-cost ratio [Gedeon, 2011].

The negative effects or the drawbacks of rumble strips are not as many as their positive effects. The one drawback that is known is possible noise issue particularly with an urban environment. The noise from the rumble strips can be disturbing the residential neighbourhoods which are close to the roads. But it is common that, with or without rumble strips, the neighbourhoods those are located at the surroundings of roads suffer from the traffic noise. This means that the noise problem will always be there regardless of the rumble strips installations. The noise from the rumble strips can, however, be more or less treated. Placing the rumble strips several feet from the pavement can be medicate or reduce the noise produced by the rumble strips.

Project scope

Now as the definition of rumble strips, their types and their negative and positive effects are discussed, let the scope of this project looked at deeply. As mentioned in the introduction part, the scope of this project is limited to centerline rumble strips. The objective of this project is to perform an evaluation on the effectiveness of the safety of centerline rumble strips. Many studies on the different types of rumble strips are performed in the United States and Canada, but although centerline rumble strips are also used here in Denmark, studies on their safety effectiveness are not conducted [Vejdirektoratet, 2010b]. Articles on safety effectiveness of rumble strips always refer to researches conducted on roads in the United States. This makes necessary the need of such a project.

Chapter 3 – Current state of knowledge

So as to get an overview and a fundamental background on a proposed topic, most of the research papers include their work a chapter explaining a review of the current state of knowledge. This section gathers information or glances at what other studies have written about the effectiveness of centerline rumble strips. Some sources which evaluated the effectiveness of centerline rumble strips will be presented and the methods used in the investigation and the results revealed in their investigation in this field will also be presented. Apart from the knowledge gathering on the centerline rumble strips road safety effectiveness, the main purpose of this literature review is also to provide inspiration for the subsequent analysis task, and thus to form the basis for the decisions and choices taken in connection with this. The literature review is also an important part of a study because it updates the reader to the state-of-art of the study in question.

Although there are variations on the results of the studies, where they vary from limited effect to an excellent one, they all point out that the centerline rumble strips have some kind of positive effects. Some of the studies suggest that the treatment on certain sites may not have reduced the total number of accidents occurred but they suggested that the overall crashes have been reduced. Moreover the studies show that the treatment has reduced the fatality of the accident. Due to the diversity of the rumble strips dimensions, driver's behavior or culture, weather conditions and the placement of the rumble strips, it is reasonable to believe the variety of the individual results from the conclusion of the studies.

Since studies on the effectiveness of centerline rumble strips are not, so far, available in Denmark, the studies reviewed here are performed outside Denmark, mainly the United States (the main user of centerline and shoulder rumble strips). The following are some of the current studies on the effectiveness on centerline rumble strips:

- 2003 US Study tilted Effectiveness of rumble strips on Texas Highways
- 2004 US Study – Safety Evaluation of Centerline Rumble Strips
- 2005 Japanese – Development and practical use of rumble strips as a new measure for highway safety
- 2008 US Study – Evaluation of the Effectiveness of Pavement Rumble Strips
- 2011 US Study – Centerline rumble Strip Effectiveness

These five previously published studies will be summarized in the following sub-sections.

2003 US Study tilted Effectiveness of rumble strips on Texas Highways

This study, which is the oldest of the five studies presented here and whose authors are Paul J. Carlson, an associate research engineer from Texas Transportation Institute and Jeff D. Miles a graduate student from Texas A & M University, was performed in September 2003 in Austin Texas.

The study was sponsored by the Research and Technology Implementation Office of Texas Department of Transportation.

The purpose of the research was to determine the relative effectiveness of three types of rumble strips: transverse rumble strips, edge line rumble strips and centerline rumble strips. The edgeline and transverse rumble strips had already been installed on the roads of some cities in Texas State. It was then necessary to prove how effective they were in terms of road safety. But the centerline rumble strips had not been installed on Texas highways by the time of the research (2003), nevertheless, some districts, such as Brownwood and Bryan, had been planning to install centerline rumble strips by the end of 2003. It was, therefore, necessary for Texas Transportation Department to evaluate how effective centerline rumble strips are, so they can use and develop guidelines on how to implement future centerline rumble strips on Texas Highways. The study has taken the numbers it has used in the evaluation on the centerline rumble strips from sites on Pennsylvania, because centerlines had not been installed on Texas cities by the time of the research (previously mentioned) [Carlos and Miles, 2003]. As this final project is bout centerline rumble strips, only the findings on the centerline rumble strips are presented here.

This study has used a benefit-to-cost ratio approach to evaluate the effectiveness of centerline rumble strips. Although benefit – cost ratio is prominently used for financial analysis, such as evaluating if the benefits of a potentially invested project exceed its cost, it can also be used to examine the road safety treatments. Table 3.1 and 3.2 summarize the result from the study.

	Costs per Crash ($)
Fatal	3,883,811 *
A Injury	1,043,826
B Injury	69,990
C Injury	5,543
PDO	2,217
Fatalities/Fatal Crash	1.35
Cost of Rumble Strips/Foot	1.50
Reduction from Rumble Strips	0.2

* Cost of Fatal Crashes ($2,882,516) x 1.35 Fatalities/Fatal crash

Table 1: ADT=< 1500

	Head-on and opposing flow side swipe crashes **	WASH	NC	IL	PA	TX
a.	Fatal	3	6	0	8	36
b.	A Injury	6	24	1	23	50
c.	B Injury	7	38	1	43	76
d.	C Injury	3	16	3	79	60
e.	PDO	24	21	3	66	50
f.	Annual Crash Cost	18,474,156	51,149,555	1,137,096	58,672,275	197,771,167
g.	Miles	1,971	13,776	1,325	9,862	41,923
h.	Estimated Rumble Strip Cost/Mile	7,920	7,920	7,920	7,920	7,920
i. (g x h)	Estimated Rumble Strip Total Cost	15,612,696	109,103,544	10,490,832	78,107,040	332,029,764
j.	Estimated Pvmnt Life (yrs)	8	8	8	8	8
k. (f x j)	Total Crash cost over Pvmnt Life	147,793,249	409,196,442	9,096,768	469,378,202	1,582,169,337
l.	Annual Cost Reduction Due to Rumble Strips***	3,694,831	10,229,911	227,419	11,734,455	39,554,233
m. (j x l)	Total Cost reduction over Pvmnt Life	29,558,650	81,839,288	1,819,354	93,875,640	316,433,867
n. (m / i)	**Estimated B/C**	**1.89**	**0.75**	**0.17**	**1.20**	**0.95**
o. (a x 1.35 x 0.2)	Expected Annual Lives Saved	0.81	1.62	0.00	2.16	9.70
p. (j x o)	Expected Lives Saved over life of Pvmnt	6.47	12.93	0.00	17.25	77.61

** Crash data from HSIS except for Pennsylvania and Texas

*** Assumes 20% reduction in head-on and opposing flow side swipe crashes and related costs

Table 2: ADT 1500-2999

	Head-on and opposing flow side swipe crashes **	WASH	NC	IL	PA	TX
a.	Fatal	5	12	7	17	47
b.	A Injury	16	18	18	32	58
c.	B Injury	24	36	15	49	74
d.	C Injury	9	12	0	79	60
e.	PDO	32	14	28	68	74
f.	Annual Crash Cost	37,920,862	68,011,794	47,087,471	103,445,383	248,756,924
g.	Miles	1,197	5,080	2,163	3,182	9,067
h.	Estimated Rumble Strip Cost/Mile	7,920	7,920	7,920	7,920	7,921
i. (g x h)	Estimated Rumble Strip Total Cost	9,478,498	40,232,808	17,128,584	25,201,440	71,815,984
j.	Estimated Pvmnt Life (yrs)	8	8	8	8	9
k. (f x j)	Total Crash cost over Pvmnt Life	303,366,897	544,094,355	376,699,770	827,563,060	2,238,812,320
l.	Annual Cost Reduction Due to Rumble Strips***	7,584,172	13,602,359	9,417,494	20,689,077	49,751,385
m. (j x l)	Total Cost reduction over Pvmnt Life	60,673,379	108,818,871	75,339,954	165,512,612	447,762,464
n. (m / i)	**Estimated B/C**	**6.40**	**2.70**	**4.40**	**6.57**	**6.23**
o. (a x 1.35 x 0.2)	Expected Annual Lives Saved	1.35	3.23	1.89	4.58	12.67
p. (j x o)	Expected Lives Saved over life of Pvmnt	10.78	25.87	15.09	36.65	113.99

** Crash data from HSIS except for Pennsylvania and Texas

*** Assumes 20% reduction in head-on and opposing flow side swipe crashes and related costs

Figure 3.1

Safety analysis of centerline rumble strips [Carlos and Miles, 2003] (1 of 2).

	Costs per Crash ($)
Fatal	0 *
A Injury	1,043,826
B Injury	69,990
C Injury	5,543
PDO	2,217
Fatalities/Fatal Crash	0.00
Cost of Rumble Strips/Foot	1.50
Reduction from Rumble Strips	0.2

* Cost of Fatal Crashes ($2,882,516) x 1.35 Fatalities/Fatal crash

Table 3: ADT 3000-4499

	Head-on and opposing flow side swipe crashes **	WASH	NC	IL	PA	TX
a.	Fatal	9	12	10	17	62
b.	A Injury	17	10	53	27	56
c.	B Injury	20	20	33	53	57
d.	C Injury	15	14	3	61	61
e.	PDO	41	11	28	56	65
f.	Annual Crash Cost	54,273,183	58,545,781	96,549,263	98,379,835	303,722,198
g.	Miles	585	2,370	1,144	1,831	4,575
h.	Estimated Rumble Strip Cost/Mile	7,920	7,920	7,920	7,920	7,921
i. (g x h)	Estimated Rumble Strip Total Cost	4,634,784	18,769,608	9,060,480	14,501,520	36,236,436
j.	Estimated Pvmnt Life (yrs)	8	8	8	8	9
k. (f x j)	Total Crash cost over Pvmnt Life	434,185,466	468,366,251	772,394,107	787,038,676	2,733,499,782
l.	Annual Cost Reduction Due to Rumble Strips***	10,854,637	11,709,156	19,309,853	19,675,967	60,744,440
m. (j x l)	Total Cost reduction over Pvmnt Life	86,837,093	93,673,250	154,478,821	157,407,735	546,699,956
n. (m / i)	**Estimated B/C**	**18.74**	**4.99**	**17.05**	**10.85**	**15.09**
o. (a x 1.35 x 0.2)	Expected Annual Lives Saved	2.43	3.23	2.69	4.58	16.71
p. (j x o)	Expected Lives Saved over life of Pvmnt	19.40	25.87	21.56	36.65	150.37

** Crash data from HSIS except for Pennsylvania and Texas

*** Assumes 20% reduction in head-on and opposing flow side swipe crashes and related costs

Table 4: ADT >4500

	Head-on and opposing flow side swipe crashes **	WASH	NC	IL	PA	TX
a.	Fatal	33	36	17	65	190
b.	A Injury	54	57	35	94	260
c.	B Injury	66	34	26	133	324
d.	C Injury	58	37	9	193	291
e.	PDO	107	17	50	171	333
f.	Annual Crash Cost	189,710,421	201,937,719	104,539,175	361,324,937	1,034,346,890
g.	Miles	979	3,539	994	2,801	8,897
h.	Estimated Rumble Strip Cost/Mile	7,920	7,920	7,920	7,920	7,921
i. (g x h)	Estimated Rumble Strip Total Cost	7,750,433	28,028,088	7,870,104	22,183,920	70,473,929
j.	Estimated Pvmnt Life (yrs)	8	8	8	8	9
k. (f x j)	Total Crash cost over Pvmnt Life	1,517,683,368	1,615,501,753	836,313,396	2,890,599,496	9,309,122,010
l.	Annual Cost Reduction Due to Rumble Strips***	37,942,084	40,387,544	20,907,835	72,264,987	206,869,378
m. (j x l)	Total Cost reduction over Pvmnt Life	303,536,674	323,100,351	167,262,679	578,119,899	1,861,824,402
n. (m / i)	**Estimated B/C**	**39.16**	**11.53**	**21.25**	**26.06**	**26.42**
o. (a x 1.35 x 0.2)	Expected Annual Lives Saved	8.89	9.70	4.58	17.52	51.20
p. (j x o)	Expected Lives Saved over life of Pvmnt	71.14	77.61	36.65	140.13	460.80

** Crash data from HSIS except for Pennsylvania and Texas

*** Assumes 20% reduction in head-on and opposing flow side swipe crashes and related costs

Figure 3.2

Safety analysis of centerline rumble strips [Carlos and Miles, 2003] (2 of 2).

By dividing the roadway into four types in terms of their traffic volume, this study shows the benefit to cost ratio of each traffic volume roadway. The result of the analysis shows that the more the traffic volume (AADT), the more benefit – cost ratio. According to the figures 3.1 and 3.2, the traffic volume of up to 1500 AADT result a B/C ratio of 0.95 (Texas State). This is almost 1 and it means that the treatment will not, more or less, change anything. However, the benefit – cost ratio increases to 6.23 as the traffic volume reaches between 1500 and 2999. The benefit – cost ratio increases even further to 15.09 as the traffic volume reaches between 3000 and 4449. Eventually the traffic volume of more than 4500 AADT can result a benefit – cost ratio of more than 26.42.

2004 US Study – Safety Evaluation of Centerline Rumble Strips

This section presents the second American Study which was conducted in January 2004 (one year after the previous Texas Highways Study). This study was performed in Massachusetts State and it was of course sponsored by the Massachusetts Highway Department [Noyce and Elango, 2004].

Massachusetts Highway Department (MassHighway) has implemented several road safety measures, where one of them was the installations of centerline rumble strips on several places of its roads. The department has then decided to undertake research programs, where it evaluates the effectiveness of the different preinstalled road safety measures. This study is a part of the MassHighway's research program.

This study had three phases. The first phase was a survey of transportation agencies so as to know more about their applications of the centerline rumble strips treatment. The second phase had dealt with the collection and the evaluation of the effectiveness of the centerline rumble strips treatment. The third phase of the study, which was evaluating the drivers' behaviour in connection with their reactions towards the centerline rumble strips, is omitted in this literature review as this project work is delimited to only the effectiveness of the centerline rumble strips. The road segments that were included in the analysis of the research were routes 2, 20 and 88 in Massachusetts State. These routes combine all the two-lane rural roads in the state. The data used in the analysis is the crashes related with the head-on-collisions that had occurred two years before the installation of the treatment and two years after [Noyce and Elango, 2004].

In spite of the fact that statistics, according to Mark Twain (an American author), is one of the three lies along with the lies and damned lies, it still remains to be a powerful mathematical feature which is prominently used in the field of transportation engineering. This study has used statistical approach called before and after (BAA) to evaluate the effectiveness of the centerline rumble strips. This method compares the number of accidents before the treatment to the number of accidents after the treatment. It will be, in detail, presented in the next chapter, but so far it is left to be mentioned that it is a before and after statistical procedure used in this study.

The following important conclusion was drawn from the results of this research:

According to the first phase of the study (a survey of transportation agencies throughout USA), 20 of the all surveyed 50 American States said that they had installed centerline rumble strips. The survey revealed that the main general reason for using centerline rumble strips was to improve road safety and they were installed on the road segments at the locations where there were frequent crashes. The states have reported that there were noise problems, pavement deterioration and danger on the motor cycle and bicycle users.

In the second phase of the research, the effectiveness of the treatment was presented. Two of the three routes included in the analysis – route 2 and 88 – were installed in 1998, where the other route (route 20) was installed in 1996. As shown on Table 3.1, which summarizes the result of the targeted crash frequency (crashes involved in head-on-collisions), there is not a significant change on routes 20 and 88 while there is a slight change on route 2.

Table 3.1: Targeted crash frequency data for study sites [Noyce and Elango, 2004].

Route\Year	1995	1996	1997	1998	1999	2000
Route 2	7	8	7	4 (before); 1 (after)	6	5
Route 20	6	7 (before); 2 (after)	5	6	5	6
Route 88	0	0	1	0 (before); 0 (after)	1	1

The study, however, presents an improvement of road safety in terms of fatality of the crashes. Table 3.2 shows that the centerline rumble strips are effective in preventing or minimizing the fatal crashes. No fatal crashes happened on routes 2 and 88 after the installation of centerline rumble strips (in 1998). On route 20, there was 1 fatal crash in 1996 (before the treatment), 2 fatal crashes in 1997, 1 fatal crash in 1998, but then in 1999 and 2000 no fatal crashes were reported.

Table 3.2: Fatal crashes at study sites [Noyce and Elango, 2004].

Route\Year	1995	1996	1997	1998	1999	2000
Route 2	0	0	3	3 (before); 0 (after)	0	0
Route 88	0	0	1	0 (before); 0 (after)	0	0
Route 20	0	1 (before); 0 (after)	2	1	0	0

2005 Japanese – Development and practical use of rumble strips as a new measure for highway safety

This study was presented and published on a journal of the Eastern Asia Society for Transportation Studies. Eastern Asia Society Transportation (EASTS), which was founded in 1994, is a panel which combines the transportation experts from 13 Asian countries. The principal purpose of the organization is to exchange knowledge and experiences related with transportation so as to improve transportation system. In order to share knowledge and experience the organization organizes conferences once in two years. It has also established a journal where transportation researches are published [EASTS, 2011]. Transportation experts from Japan have presented this study on centerline rumble strips in 2005.

Like the other high volume traffic rural roads around the world, roads that connect Japan's big cities together have experienced head-on-collisions with high fatality. These crashes occur on two lane rural roads. The way to prevent these types of crashes is the installation of the traditional median barriers between the opposite lanes. This preventive measure is, however, very expensive. After recognizing how American transportation agencies have become successful in preventing these crashes with the use of a very simple and cheaper method, Japan followed American footsteps and began to use centerline rumble strips as a measure against head-on-collisions.

The first rumble strip in Japan was installed on the National Route 5 at Yakumo Town. In March 2005 there were 61 locations – 111.9 km – of centerline rumble strips on this route alone. It became necessary to investigate how effective they are, which is why this study was performed in 2005 [Hirasawa et al, 2005].

The study evaluates 24 locations on route 5. The installations of the centerline rumble strips included in the analysis were completed between 2002 and 2003. The number of head-on-collisions that occurred two years before the treatment was available and taken from the transportation agencies of Japan. The numbers of the head-on-collisions after the installation of the rumble strips were not all 2 years old. They have; therefore, extrapolated two years more before the accident rate of before and after was compared.

Table 3.3 compares the number of accidents before and after the use of the centerline rumble strips treatment. None of the 24 examined locations have experiences an increase of head-on-crashes. And as expected nearly all of them have had a reduction of these types of crashes. At the bottom of table 3.3, it is given a reduction rate of 55.2%, after comparing the total of the 42 head-on-collisions (before the installation of the treatment) to the extrapolated total of the 18.8 head-on-collisions.

Table 3.3: Reduction of the head-on-accidents

	Route	Length installed (m)	Date of construction	Number of head-on collisions		
				Before installation (2 years)	From installation to Dec. 1, 2004	Extrapolated after installation (2 years)
1	5	727	2002/7/22	1		0.0
2	274	2,708	2002/11/6	3	3	3.0
3	5	457	2002/12/10	1		0.0
4	37	6,197	2003/5/13	1	1	1.2
5	5	1,500	2003/5/26	3		0.0
6	40	1,178	2003/6/2	2		0.0
7	274	2,860	2003/6/9	3		0.0
8	274	5,050	2003/6/16	7	6	7.8
9	274	3,815	2003/6/23	3	3	3.9
10	5	1,507	2003/7/1	3	1	1.3
11	275	730	2003/7/8	1		0.0
12	39	1,100	2003/7/22	1		0.0
13	44	400	2003/7/25	0		0.0
14	230	2,943	2003/7/30	1		0.0
15	5	300	2003/8/5	1		0.0
16	230	1,057	2003/8/26	2		0.0
17	5	522	2003/9/22	1	1	1.6
18	276	3,448	2003/9/4	2		0.0
19	5	600	2003/9/3	1		0.0
20	393	440	2003/9/16	0		0.0
21	5	442	2003/10/2	0		0.0
22	40	382	2003/10/22	1		0.0
23	236	200	2003/10/27	1		0.0
24	38	721	2003/11/1	3		0.0
Total		39,284		42	15	18.8

Reduction rate for head-on collisions: (42-18.8)/42*100=55.2%

Apart from their effectiveness to improve road safety, according to the study, the centerline rumble strips have many other advantages. The study has listed several points mentioning the advantages of rumble strips. Here are some of them:

- *"A high degree of warning is given to drivers who deviate to the edge of the road.*
- *Two-wheel vehicles can travel more safely on sections with rumble strips than on those with center poles or chatter bars.*
- *Rumble strips do not hinder snow removal.*
- *The costs are low (half of that for center poles, and one-third of that for chatter bars).*
- *Because the rumble strips are not installed where the wheels of vehicles pass, they cause very little tire abrasion and they do not affect the traveling speed.*
- *The snow accumulated in the groove was removed by using anti-freezing agent. No disadvantages in winter road maintenance are expected" [Hirasawa et al, 2005].*

2008 US Study – Evaluation of the Effectiveness of Pavement Rumble Strips

Here is presented another American study on the evaluation of the effectiveness of the centerline rumble strips treatment. The study was aimed to evaluate the effectiveness of the two most used rumble strips – shoulder rumble strips and centerline rumble strips. The study mainly focuses on rural two lane roads in Kentucky State.

Shoulder and centerline rumble strips are installed on many roads in Kentucky State, but it is not known how much benefit they contribute in terms of safety, as a national research on their effectiveness had not been conducted yet. This made important the need of such a research and it prompted that Kentucky Transportation Center, College of Engineering and University of Kentucky employ a Transportation Research Engineer called Adam Kirk to perform this study in January 2008.

In order to conduct the analysis, the study had collected all the necessary data on the application of the rumble strips of Kentucky State. A three year old crash history from 162 road segments was compared. Some of these road segments have preinstalled rumble strips and others have not [Kirk, 2008].

The preliminary general findings of the compared crashes had been summarized in table 3.3. According to the table, the road segments with the rumble strips have 2.67 crashes per million vehicle miles (MVM), where the road segments without rumble strips have 3.91 MVM. The crash rate of the roads with rumble strips is very low than that of the roads without the treatment.

Table 3.3: Crash rate summary (crashes per MVM) [Kirk, 2008].

Crash Type	Rumble Strips	NO Rumble Strips
All Crashes	2.67	3.91
Run Off Road	0.97	1.84
Driver Inattention	1.04	1.69

2011 US Study – Centerline rumble Strip Effectiveness

One more American study, which is the last and the most recent of all the studies in this chapter, is also presented here. The study was conducted in March 2011 in Washington State (sometimes also referred to as US State). Most and the main findings of the text in this section is referred to "Olson et al, 2011".

In order to do something about the increasing head-on-collisions on its two lane rural roads, Washington State Department of Transportation (WSDOT) installed approximately 100 miles long centerline rumble strips in 2004. And within the next six years – that is from 2004 to June 2010 – WSDOT installed additional centerline rumble strips with a length of 1400 miles. Although centerline rumble strips are widely used on the Washington State roads, a proper study that examines their effectiveness was not conducted. This compelled WSDOT to establish a research team of four experts (those mentioned in the reference) to undertake such study. The study team does not only examine how effective the centerline rumble strips are but they also examine the variables that contribute the crashes, such as fatigue, speed, distracted etc.

The research team chose to analyze 69 road segments (this corresponds to 493.03 miles long centerline rumble strips) from Washington State highways where the centerline rumble strip treatment was at least 16 months old. The data included in the study was from 2002 through 2009.

The method used in the analysis is again the comparison of the rate of before and after of crashes. The difference of the two values from before and after period is expressed as a change rate. As shown on table 3.4, the rate values of the injury severity, except fatal and serious injury collisions, is expressed as per million vehicle miles traveled (MVMT). Due to the small count of collisions, a rate per 100 million VMT is used with fatal and serious injury collisions. The result on Table 3.4 shows that the centerline rumble strip treatment is very effective in reducing the crossover crashes. A reduction of 44.6% and 48.6% in all injury severities and fatal & serious injury crashes was respectively observed.

Table 3.4: Crossover Crashes rate summary (crashes per MVMT) [Olson et al, 2011].

Injury Severity	Before Rate	After Rate	Difference	% Change
All Injury Severities	0.152	0.084	0.068	-44.6%
Fatal & Serious Injury	2.512*	1.292*	1.220	-48.6%
Evident Injury	0.045	0.020	0.025	-55.5%
Possible Injury	0.020	0.018	0.002	-10.0%
No Injury	0.053	0.033	0.020	-38.9%
Unknown	0.009	0.001	0.007	-86.6%

Most severe injury of crash (one per crash) *per 100 mvmt

As mentioned before, the study also compares the contributing or causing factors the crossover crashes. Table 3.5 and the followed diagram, figure 3.1 present before and after crash rates and the percentage change with their different contributing categories. The table includes both all injury severities and fatal & serious injury crashes where the later is shown in parenthesis. According to Table 3.5, 75.3% of all crashes caused by asleep/fatigue were reduced after the treatment and the fatal and serious injury crashes were reduced up to 72.6%.

Table 3.5: Crossover crashes rates by contributing category [Olson et al, 2011].

Contributing Category	Before Rate	After Rate	Difference	% Change
Asleep/Fatigued (A/F)	0.037 (0.419)	0.009 (0.115)	0.028 (0.304)	-75.3% (-72.6%)
Inattentive/Distracted (I/D)	0.019 (0.198)	0.011 (0.057)	0.008 (0.141)	-40.9% (-71.0%)
Under Influence (UI)	0.028 (0.639)	0.024 (0.460)	0.003 (0.180)	-11.4% (-28.1%)
Speed	0.041 (0.485)	0.033 (0.574)	0.008 (-0.090)	-20.6% (18.5%)
Over Centerline (OCL)	0.050 (1.675)	0.024 (0.747)	0.027 (0.928)	-53.1% (-55.4%)
Other	0.013 (0.088)	0.008 (0.000)	0.005 (0.088)	-37.0% (-100%)
None	0.004 (0.000)	0.002 (0.000)	0.002 (0.000)	-51.1% (0.0%)

Fatal & Serious Injury results in () with rate per 100 mvmt

Figure 3.1 repeats the values in the table but another type of illustration. It is easy for the reader to see the difference in crashes (before and after treatment) with their contributing factors. They all show significant reduction of the crossover crashes.

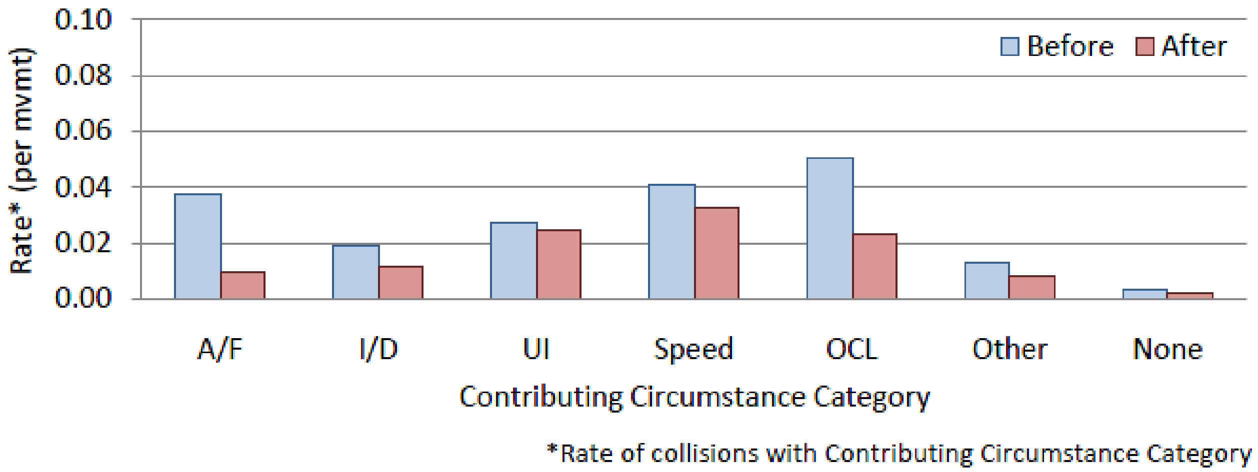


Figure 3.1

Crossover rates by contributing category: all injury severities [Olson et al, 2011].

Literature summary

The following table summarizes and acts as a conclusion of the different studies reviewed. The writer, title, date, method and the result are briefly mentioned in the table.

Table 3.6: Summary of the studies reviewed

Writer/s	Title	Date	Method	Result
Paul J. Carlson and Jeff D. Miles, Texas Transportation Institute	Effectiveness of rumble strips on Texas Highways.	2003	benefit-to-cost ratio approach.	The treatment can have benefits of the traffic volume of more than 1500 AADT
David A. Noyce and Vetri Venthan Elango	Safety Evaluation of Centerline Rumble Strips.	2004	Statistical approach - before and after (BAA) the treatment.	No significant change is reported after the treatment was put in place. Fatal crashes were reduced.
Masayuki Hirasawa, Kazuo Saito, Motoki Asano, Journal of the Eastern Asia Society for Transportation Studies	Development and practical use of rumble strips as a new measure for highway safety.	2005	Comparison of accident data before and after treatment.	A reduction of 55.2% on the head-on-collisions was reported
Adam Kirk, Kentucky Transportation Center	Evaluation of the Effectiveness of Pavement Rumble Strips.	2008	Comparison of accident data from roads with/without the treatment.	Roads without the treatment have 46% accidents more than the roads with the treatment.
Dave Olson, Brad Manchas, Richard W. Glad and Mark Sujka	Centerline rumble Strip Effectiveness.	2011	Comparison of before / after crash data	A reduction of 44.6% in all injury severities is reported.

Chapter 4 – Evaluation methodology and project data

This chapter describes the method used for the evaluation of the safety effects of the centerline rumble strips treatment.

The fundamental part of any project is to choose the best and the most appropriate methodology you will use to perform the objectives highlighted in the introduction. There are several methods to use in the evaluation of road safety effectiveness. The following three principal methods are generally adopted by most of the road safety researchers (HSM, 2011):

- Observational before after studies
- Observational cross-sectional studies
- Experimental before after studies

Observational before after studies

Observational before after studies consider both the past and the future collisions and use the crash data for time periods before and after improvement of the treated sites. This means that the data of both before and after the treatment has to be available. The most common way of conducting the observational before after study is to use a method called Empirical Bayes (EB Method). This method estimates the expected average of crashes that would have occurred at the treated sites in the after period without any conversion (without treatment). It compares this with the average number of observed crashes in the after period (with treatment). SPF (Safety Performance Function) is used to estimate the after crashes that would have been occurred on the treated sites if the treatment had not been implemented. The EB Method is superior to the other two methods, because it has the advantage of considering the statistical phenomenon called regression to the mean effect. Figure 4.1 illustrates how EB Method moves the counted number of crashes to the mean while accounting for regression to the mean effect.

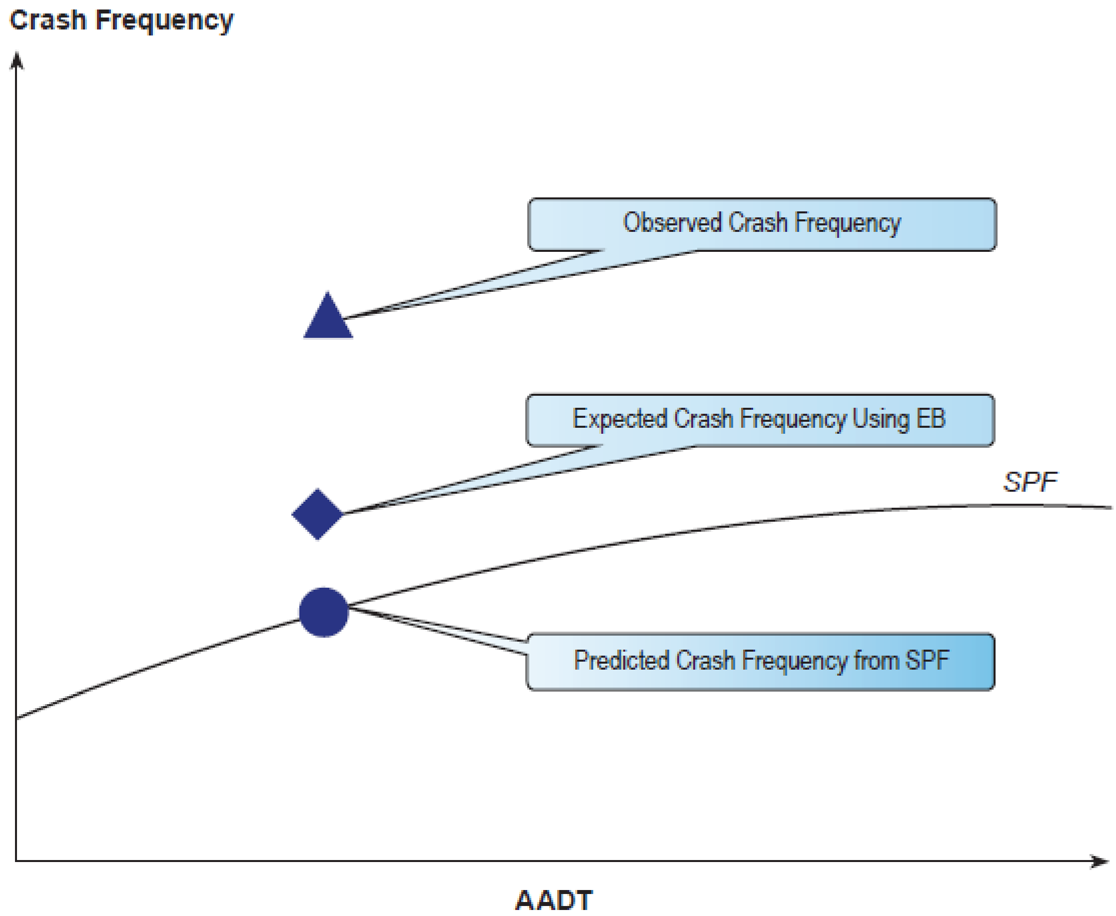


Figure 4.1

Empirical Bayes Method: "The observed crash frequency the observed crash frequency and the predicted crash frequency are combined to calculate a corrected value, which is the expected crash frequency using EB Method. The expected crash frequency will lie somewhere between the observed crash frequency and the predicted crash frequency from the SPF" [FHWA, 2010:].

Regression to the mean effect is an expression used for in the case that a road segment or an intersection with a great number of accidents in a specific period of time is possibly to encounter a reduction in the number of accidents in the subsequent period, even if no action is taken; this is just due to the random fluctuations in accident numbers. If the high-risk sites are intervened by imposing safety measures, it may be an overestimation of crash reduction, on the hand, if nothing has been done on the high-risk sites it may become an under estimation of the safety problem. Apart from taking regression to the mean effect into account, EB Method provides a more reliable and accurate estimates of road safety and lets for estimates over time of anticipated accidents [HSM, 2011].

Observational cross-sectional studies

Observational cross-sectional studies is used in the case where the before data of the treated sites are not available. This method uses the crash data from other comparable untreated sites. Unlike the EB method the observational cross-sectional approach does not obviously consider for the potential effect of regression to the mean. Moreover, it is not easy to determine the cause of the crash and the effect of the treatment which requires more statistics. This makes this method less usable and less reliable, because it may not be clear whether the observed changes in safety improvement is due to the imposed treatment or other unforeseen and unexplained factors [HSM, 2011].

Experimental before after studies

As its name states the experimental before after study is implemented in the laboratory. It is a method which measures the magnitude of the effectiveness of the potential treatment for the road safety improvement. The major difference between the two observational methods and the experimental one is that, the observational studies evaluate the improvement of the road safety, where the experimental study evaluates the effectiveness of the treatment itself and not the safety improvement. Sites to be tested for the treatment are randomly selected. This random selection can be a solution to the regression to the mean bias. Because of its liability, random selection and economic issues, this method is rarely applied in the traffic safety [HSM, 2011]. The method is widely used for the other scientific researches; an example can be while evaluating the effectiveness of new medicine.

The method chosen for this project

The method used in the investigation of the effectiveness of this treatment is EB Method.

To use the EB Method, it is necessary to have the following data in hand:

- Minimum sites of 10 to 20 where the treatment has been implemented
- Before data – 3 to 5 year old crash and traffic volume
- After data – 3 to 5 year old crash and traffic volume
- SPF for treatment site types [HSM, 2011]

Because of the availability of the mentioned data, considering the regression to the mean effect, its stability and its common use, the EB method becomes qualified for the use of this project. However, as SPF is not used in Denmark, the EB Method is modified to comply with the evaluation of the Danish roads.

To evaluate how the preinstalled centerline rumble strips improved the safety of the roads, there are two stages of calculations to be conducted:

- Local – determining the safety treatment effectiveness of each site (separate effect)
- Global – determining the safety treatment effectiveness of all sites (general effect)

Local safety effect

The local safety effect which is also called the site specific effect is calculated with the following traditional Danish formula [Madsen, c]:

$$\varepsilon_i = \frac{X_{iA}}{X_{iB} \cdot C_{TREND} \cdot C_{TRAFFIC} \cdot C_{RTMi}} \tag{4.1}$$

Where:

ε_i : Site specific effect

X_{iA} : The number of accidents at a location i, in the after period

X_{iB} : The number of accidents at a location i, in the before period

C_{TREND} : Correction factor for general accident development

$C_{TRAFFIC}$: Correction factor for traffic volume

C_{RTMi} : Correction factor for possible regression to the mean

After numbers are inserted into the formula and the calculation is performed, the result suggests the following conclusion for each treated site:

$\varepsilon_i < 1$: positive effect

$\varepsilon_i > 1$: negative effect

$\varepsilon_i = 1$: no effect

The formula is the ratio of the observed number of crashes in the after period with the treatment implemented to the corrected number of crashes in the after period without the treatment. The after period crashes without the treatment are modified with the three C-factors (C_{TREND}, $C_{TRAFFIC}$ and C_{RTM}). This is important, because omitting the correction C-factors is like assuming that the number of crashes would be the same as in the before period. Figure 4.2 illustrates this assumption.

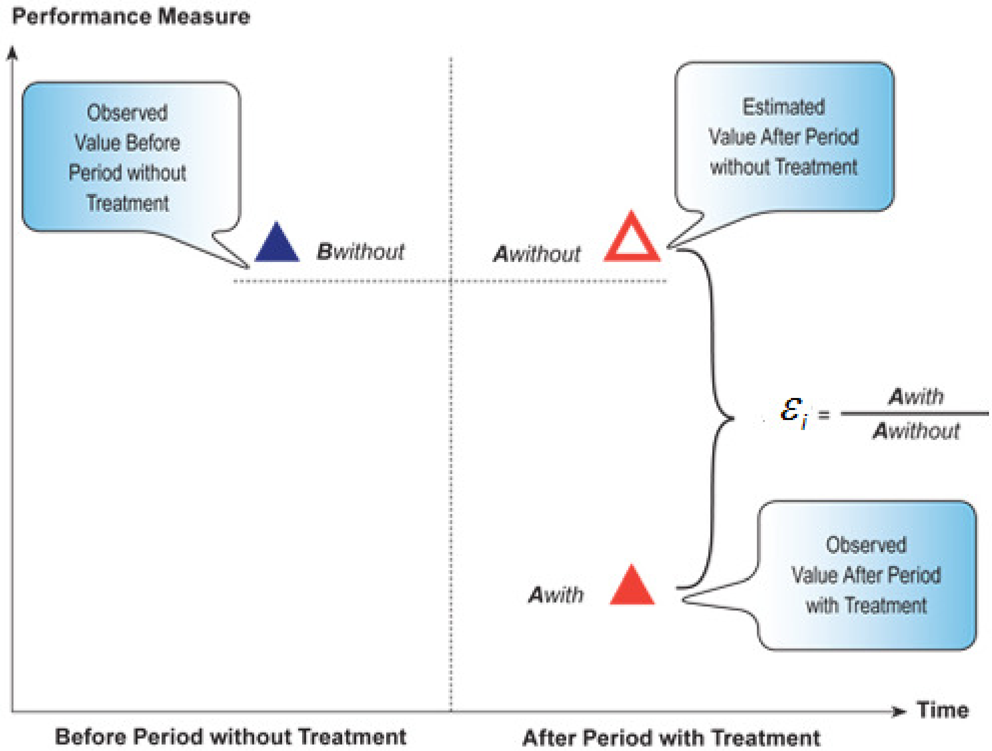


Figure 4.2

Naïve Method – simple before/after evaluation approach: A very simple way of carrying out the comparison of the number of accidents before and after implementation of road safety treatment (Awith vs Awithout). The Observed value before period without treatment (Bwithout) is assumed to be the same as the estimated value after period without the treatment (Awithout) [FHWA, 2010:].

This kind of assumption is not likely to be valid because of the fact that, as the economy grows the traffic volume, accident and the physical design of the roads change with time. The lack of consideration of the potential traffic volume, accident and road environment change and as well as the regression to the mean, this method is not recommended and it is sometimes referred to as a naïve method. It is important to recognize that the observed road safety improvement cannot be solely due to the treatment. There are number of factors other than the treatment which affect the road safety. These factors include trends in crash, traffic volume, random fluctuation in crash counts and other local changes on the road. The three C-factors in the formula (4.1) take these factors into account and they are explored next.

Trend in crash - C_{TREND}

Generally, the total number of road traffic accidents in Denmark is decreasing. This is not only due to the design conversion carried out on the roads and their surroundings, but there is also an underlying trend which depends on several factors, such as improving vehicles through technology, vehicle choice, changes in driving behavior through law enforcement, fuel prices or education, road safety campaigns etc.

It is difficult to distinguish the factors influencing the overall trends in crash. Therefore the trend in crash is often corrected with the help of a control group or a comparison group. The comparison group considers the number of accidents that have occurred on the non-treatment sites. In other words, the comparison group is used to determine what would have occurred if no treatment had been installed. While the crash data of the comparison group is available, the following formula is applied:

4.2 $$C_{TREND} = \frac{\sum_{r=1}^{R} X_{rA}}{\sum_{r=1}^{R} X_{rB}}$$

Where:

X_{rA} : Sum of the number of accidents of the comparison group, R in the after period

X_{rB} : Sum of the number of accidents of the comparison group, R in the before period

C_{TREND} : General accident development correction factor

However, this way of performing the correction of the trend in crash requires that the group selected to be the comparison group has to be valid group. The selected group can be valid when there is a consistency in the rate of crash changes between the treatment group and the comparison group. To fulfill the requirement of the validity, the numbers in the comparison group that describes the general trend in accidents must be relatively many – at least hundred accidents. It also requires that the nontreated comparison sites have the same road characteristics (traffic volume, geometrics etc.) as the treatment sites.

Moreover, the crash and the traffic data for both the treated and the nontreated comparing groups has to be collected for the same time period.

It is very essential that the control group can satisfy all the mentioned factors which had influenced the development. If the control group is not many enough, or it has different geometrics, for example, this will cause additional uncertainty in the determination of the safety effectiveness of the treatment.

In this project, it is not possible to obtain a valid comparable group. This is because it is very difficult to collect a sufficient large control group which exactly has the same characteristics as the treated group. Instead a general simpler comparison way is used. The general trends are decided from a comparison group consisting of all the state roads.

Traffic volume - $C_{TRAFFIC}$

As our economy grows, the number of motor vehicles on our roads will also grow. Consequently, the already high road casualties will increase. However, although the traffic has increased, fortunately, during recent years the total road casualties have not increased. This is because the transportation authorities are engaged in improving the traffic safety. And there are always efforts of enhancing the safety with the appliance of different measures. The point here is that there is a relationship between the traffic increase and road accidents. And when evaluating the effectiveness of any measure this has to be taken into consideration. Moreover, when a road condition is improved, it attracts more vehicles and as a result accident migration will occur. This means that the accident will move with the vehicles. It is therefore, necessary to correct the accident counts with a factor which considers the accident increase caused by the traffic increase.

$C_{TRAFFIC}$ is calculated with the following formula:

4.3 $$C_{TRAFFIC} = \left(\frac{AADT_{iA}}{AADT_{iB}} \right)^{p_i}$$

Where:

$C_{TRAFFIC}$: Correction factor for traffic volume change

$AADT_{iA}$: Annual average daily traffic after period

$AADT_{iB}$: Annual average daily traffic before period

p_i : a parameter determined by the type of the road and which describing the relationship between the traffic volume and the accident occurance

The formula establishes connection among the road design (road type), traffic volume and number of accidents. This formula makes possible to adjust the accident counts contributed on the roads in a given location caused by the change in traffic volume.

Regression to the mean C_{RTMi}

The value C_{RTMi} is a factor which considers the possible regression-to-mean bias. This value is usually applied in the case where an abnormally high accident counts are observed. The regression to the mean bias occurs when a site is treated due to an observed short term high crash count. This will lead an overestimation of the effect as the crash on the treated site will probably decrease even if the treatment was not implemented.

The Road Directorate suggests that the abnormal accident counts in the before period to be reduced by 20 to 30%, so as to correct the uncertainty caused by the regression to the mean effect [Vejdirektoratet, 2001]. There is not a proper method that considers the regression effect in Denmark.

The choice of the common factor (20% to 30% reduction) is problematic assumption, because the regression to the mean effect, which is normally considered to be unique on a particular site, is generalized. Using a general factor makes all the sites identical [Madsen d]. This may cause further uncertainty to the accident counts and hence invalidate the evaluation of the treatment effectiveness.

As previously mentioned, the regression to the mean effect is often corrected with the use of EB method which is the only known method that can practically compensate to the regression to the mean effect. This approach uses the accident models – that is the average curve which gives the normal accidents in relation with the traffic. The use of the EB Method requires the establishment of many accident models. Moreover there is uncertainty in the accident models as it is chosen from the number of accidents of an intersection and a road segment [Vejdirektoratet, 2010b].

As there is not a practical method that calculates the regression to the mean effect factor in Denmark and as the use of the EB Method is not easy to implement, it is decided to set this factor into 1.

Global safety effect

Once the treatment effect of each site is calculated, it is normal to see a result which varies a lot: some roads show a positive result, some others show negative result and others show no result at all. It is necessary to perform a statistical test so as to generalize the effectiveness of the treatment for all the road segments and to come up with one result. There are two ways of carrying out this statistical test:

- Chi-square (χ^2) method
- Meta-analysis method

The two methods are different in terms of their applications, advantages and disadvantages. This project uses meta-analysis approach because it provides better bases for assessing the safety effectiveness of the treatment. Chi-square method, for example, requires that the data used in the analysis has to have same time length in the before and after period (for example 3 years before and after), the reference or the control group has to be in same location as the analyzed group and the treatment has to be implemented In short period of less than 5 years [Jørgensen, 1981]. Moreover the correction factors used in the chi-square method are almost same. These conditions cannot be fulfilled in this project as some of the installations of the centerline rumble strips treatments are 10 years old and hence the chi-square method is not qualified for the evaluation of the safety effectiveness of this treatment.

Meta-analysis

Meta-analysis which is also called "log odds method of combining results" is a powerful method that summarizes the different results of empirical studies in social, health and other sciences. The formal definition of meta-analysis was first announced in 1976 and is as follows:

> *"The statistical analysis of a large collection of analysis results for the purpose of integrating the findings"* (Glass, 1976).

However, the use of the method first appeared in a published research on a statistical analysis of 375 previously published studies on psychotherapy by Gene V. Glass and Mary Lee Smith (Glass & Smith, 1977). Later, the method was well described and widely used in different researches by Elvik Rune. One of the Elvik papers where he used the meta-analysis is the study on the safety effect evaluation of the calming schemes of the area-wide urban traffic [Elvik, 2001]. Elvik paper combines 33 previously published studies and presents how meta-analysis is performed. This project uses the procedures presented in this study.

After the mean effect of the different studies is estimated, the meta-analysis is then used to test whether the safety effect is significant. In other words, that is, if we are more than 95% confident that a safety impact has occurred after the implantation of a safety measure. If the effect is not significant, then the result is interpreted that there is a random change in the number of accidents and injuries. Meta-analysis is also used to indicate a confidence interval for the effect, i.e. an interval that describes where the effect is within the 95% probability. Finally the homogeneity of the effects is tested i.e. the accidents are tested whether they are same effect [Elvik, 2005].

The core of the meta-analysis is that, it performs a statistical weight assigned to each site included in the analysis. The weight which is inversely proportional to its variance is carried out so that the statistical uncertainty in the average result of safety effect is minimized into its least possible way. The weight depends on the accident numbers for the site and the control group (if a comparison group is used). Depending on the homogeneity of the effect, there are two effect models used in the calculation of the weights:

- Fixed effects model
- Random effects model

Fixed effect model is used when the effect is homogeneous. This is based on the assumption that there is only random variation in findings between studies. For homogenous effect the weight and variance are calculated by the following formula [Elvik, 2005]:

4.4 $$\mathrm{w_i} = \frac{1}{v_i} \qquad v_i = \frac{1}{A} + \frac{1}{B} + \frac{1}{C} + \frac{1}{D}$$

Where:

v_i : Variance of each estimate effect

w_i : Weight of each estimate effect

A, B, C, D: the number of accidents in before and after period and the control group

The ‘B’ denominator in the variance formula must be multiplied with the C-traffic factor so as to correspond with the formula for the site specific effect (Madsen e).

As zero value cannot be used in the meta-analysis (zero cannot be a denominator for the fractional formula of calculating the variance), it is practical to use 0.5 in the case where the accident and injury numbers in the before or after period is equal to zero. If both before and after period accident counts become zero then the zero-sites will be totally left out in the analysis [Madsen, c].

Random model effect is adopted when the safety effect is heterogeneous – that is when there is a systematic variation of the effects.

The following formula is used for the weight calculation:

$$w_i{*} = \frac{1}{v_i{*}}$$

$$v_i{*} = v_i + \sigma_\theta{}^2$$

4.5 $$\sigma_\theta{}^2 = \frac{[Q-(g-1)]}{c}$$

$$c = \sum_{i=1}^{g} w_i - \left[\frac{\sum_{i=1}^{g} w_i{}^2}{\sum_{i=1}^{g} w_i}\right]$$

Where:

v_i : Variance of each estimate effect

$\sigma_\theta{}^2$: Variance component

g : Number of of the effects combined

$\sigma_\theta{}^2$: Variance component

Q : Test statistic value

c : estimator factor

As shown in the above formula, the variance is differently calculated compared with the formula for fixed effect model. This formula is added to a component called variance component which reflects the systematic variation of the effects [Elvik, 2001].

Based on the weighting of the accident numbers and the effect on each site, it is possible to calculate the mean effect. The following formula is used to estimate the mean effect:

4.6 $$\bar{y} = \exp\left(\frac{\sum_{i=1}^{g} w_i y_i}{\sum_{i=1}^{g} w_i}\right)$$

Where:

$\bar{y}$: weighted mean effect of the evaluated sites

y_i : natural logarithm of the site specific effect of each site

To test the homogeneousness of the effect, a test statistic is performed. This test statistic determines which of the two models (fixed or random) will be used in the calculation of the weight and the confidence interval. The following formula is used for this:

4.7 $$Q = \sum_{i=1}^{g} w_i y_i^2 - \frac{\sum_{i=1}^{g} w_i y_i}{\sum_{i=1}^{g} w_i}$$

After numbers are inserted in this formula, a conclusion which sounds the following is reached: If the test is insignificant, the effect is heterogeneous and vice versa. The following notation shortens the conclusion:

$Q > Q_\alpha(g-1)$: heterogeneity $\Leftrightarrow$ random model

$Q < Q_\alpha(g-1)$: homogeneity $\Leftrightarrow$ fixed model

Finally, 95% of the confidence interval for the weighted mean is calculated. The confidence interval, which is a standard statistical technique used to show the accuracy and reliability of a particular survey findings, describes where the mean effect lies within the 95% probability. Other confidence intervals 99%, 90% etc. can also be applied depending on the probability in which the effect is real. If another confidence interval is chosen the mean value and the standard error in formula 4.8 will not change but the critical value, the z-score, (1.96) will be changed into the appropriate z value, the following table (4.1) gives the confidence interval and the corresponding critical value:

Table 4.1: Confidence interval and its corresponding critical value.

Confidence interval level	Critical value (z-score)	Certainty level probability of the effect reality
99%	2,58	very high
95%	1,96	high
90%	1,64	normal

The following formula is used to calculate the upper and the lower bounds of the confidence interval:

4.8
$$95\%\mathrm{CI} = \exp\left[\left(\frac{\sum_{i=1}^{g} w_i y_i}{\sum_{i=1}^{g} w_i}\right) \pm 1.96 \left(\frac{1}{\sum_{i=1}^{g} w_i}\right)\right]$$

A confidence interval for a decrease between, for example, 10 and 45 percent is indicated by -45%, -10%. This kind of confidence interval points out that the weighted mean effect is significant, since the entire confidence interval is negative. A non significant mean effect could, for example, have a confidence interval of -10%, +20%.

Project data

Under this section of the project data, the locations of the sites in which the treatment of the centerline rumble strips are installed, the traffic volume data of the same sites and the accident counts data are briefly described. How and where they are retrieved from will be mentioned.

Evaluation sites – Centerline rumble strip locations

To implement the before – after evaluation of a safety treatment, it is essential to carefully determine locations which will include in the analysis. The requirement of any safety treatment evaluation is that, the sites have to have a reasonable long time period for which data is available – minimum 3 years before and after the treatment. A short time period of one to two years may give unusual accidents counts (much higher or lower than the normal year). The long time period is necessary for making the statistical analysis accurate and valid. On the other hand, if the time period of the data is very long, it may affect the evaluation result, as it is possible that the traffic volume and the road configurations (geometry) and are likely to change [HSM, 2011]. Three years before and after is a good choice for the time period of the data. This gives a reasonable accident development. The choice of the equal length of time for the before and after periods has been common in Denmark for many years [Jørgensen, 1981]. Its advantage is that the accidents are directly comparable. Its disadvantage, however, is that a cluster of number of accidents, which may have occurred immediately after or before the time chosen the data to be collected, may be left out.

Another factor which is important for the analysis is the number of the sites included in the analysis. Again the more sites selected, the more accurate the statistical result can be. And that is true not only for a road safety statistics, but for all studies in statistics. In this study, it is preferable that the sites are as many as 25.

Due to the spread of the sites with centerline rumble strips, it was not easy to trace the valid sites for the evaluation. There was also a big concern on whether there will be enough sites for the evaluations- sites which are at least 25 and the treatment is at least 3 years old. Fortunately, after contacts have been made with the Road Directorate, it was possible to get enough raw data of the sites with centerline rumble strips.

Although the data sent by the Road Directorate were more than enough, they did not all qualified for the analysis. The sites, which were 62, included sites with motorways and installations which were younger than 3 years. It was, therefore, necessary to sort the data. All the motorways and sites with installation of November 2009 and after were excluded in the analyses. The sites then reduced to 35 sites, see table 4.2a and 4.2b. The sites have different lengths. Some are as short as one third of a kilometer (road number 102). Others are as long as 23 km (like road number 411).

Table 4.2a: Sorted data from the Road Directorate.

	Vejnr.	Rute nr.	Betegnelse	Fra km	Til km	Længde	Vejtype	Udførelses år	Udførelses måned
1	102	14	Osted - Ringsted	46,55	46,85	0,30	Hovedlandevej 3 spor	2007	
2	136	6	Roskilde - Slangerup	14,12	16,00	1,20	Hovedlandevej 2 spor med cykelbaner	Omkring 2005	
3	136	6	Roskilde - Slangerup	16,26	22,39	5,75	Hovedlandevej	Omkring 2005	
4	142	53	Frederikssund-Elverdam	4,59	7,05	2,74	Hovedlandevej 3 spor	2007	
5	142	53	Frederikssund-Elverdam	14	14,75	0,75	Hovedlandevej	2007	
6	522		Frederikssundsvej vest for Ølstykke	32,2	32,8	0,6	Hovedlandevej		
7	102	14	Osted - Ringsted	47	50	1,72	Strækning er 10,1m bred + 2x0,2m brede kantbaner plus cyklstier i begge vejsider	2007	okt./nov.
8	119	23	Holdbækmotorveje - Bjergsted	0	28,86	23	4-sporet motortrafikvej (2-sporet hovedlandevej med cykelsti, km 10,2-12,2)	2009	oktober
9	119	23	Bjergsted - Tømmerup	28,9	32	3,1	Strækning er 7 m bred + 2x0,8 smalle kantbaner.	2007	okt./nov.
10	501	E55	Nykøbing F - Ønslev	3,3	9,27	2,33	Strækning er 9,5 m bred + 2x0,5 m kantbaner plus cykelstier i begge vejsider.	2007	okt./nov.
11	319		Åbenrå	23,16	24,3	0,945	Landevej	2007	Oktober
12	322		Toftlund - Løgumkloster	11,6	19,74	4,962	Landevej	2007	Oktober
13	338	18/30	Tørring - Give	12	25	13	Motortrafikvej	2007	spørg OO
14	600338	30	Tørring - Uldum	85,7	90,5	4,8	Motortrafikvej	2008	december
15	600338	30	Uldum - Horsens	90,8	100,1	9,3	Motortrafikvej	2007	spørg OO
16	340	30	Karlskov - Give	10,1	18	7,9	Hovedlandevej	2008	december
17	348	13	Tørring	24,2	26,5		Hovedlandevej	2006	ultimo
18	348	13	Tørring - Hjøllund	21,5	49,2	16,5	Hovedlandevej	2009	oktober

Table 4.2b: Continuation of Table 4.2a – sorted data from the Road Directorate.

	Vejnr.	Rute nr.	Betegnelse	Fra km	Til km	Længde	Vejtype	Udførelses år	Udførelses måned
19	363	28	Vejle - Bredsten	1,9	10,5	7	Hovedlandevej	2009	september
20	363	28	Vandel - Billund	21,6	26,7	5,1	Hovedlandevej	2008	december
21	401	15	Løgten - Tåstrup	18	34	12,6	Motortrafikvej	2002/2004/2005	
22	344		Brande	35,351	42,55	7,2	Motortrafikvej	2008	nov
23	348		Vejle - Viborg	49	64	9	2-sporet landevej	2006	okt
24	348		Vejle - Viborg	64	85,3	21,3	2-sporet landevej	2006	sep
25	407		SØ for Viborg, Rødkærsbro	47,595	57	9,405	Motortrafikvej	2008	nov
26	411		Viborg - Sønderrup	2,85	25,8	22,95	2-sporet landevej	2006	sep
27	422		Holstebro - Herning	2,7	16,4	10,8	8,5 meter br	2008	nov
28	442		Nord for Skive	2,4	13,2	10,9	0	2003 og 2007	nov
29	417		Holstebro - Herning	4,85	25,85	15,05		2006	
30	441			2,85	33,6	18,75		2006	
32	411			36,8	49,45	9,04		2007	
33	411			25,76	49,5	11,04		2007/2009	
34	427			4,6	14,3	9,7		2006	
35	445		Morsø	1,77	14,15	10,9	Motortrafikvej på del af strækningen	2007	

Accident data

After finding 35 sites with centerline rumble strips installed, the next step is to retrieve the crashes occurred on these locations. Sites have different periods in which the treatment had been installed. The oldest treatment was implemented in 2000 and the newest treatment is exactly three years old now. The crashes of three years before and after are retrieved. The centerline rumble strips of road number 322 have, for example, been completed in 2007. The accident data from the year of the implementation, 2007, is excluded. Three years before are 2004 – 2006 and three years after are 2008 – 2010 see table 4.3.

Table 4.3: Example of how the time period of the crash data is determined. The crash data from the year of the installation, 0-year, is omitted. The crashes of three years before and after are retrieved.

Before period (3 yrs)			Installation year	After period (3 yrs)		
1st year	2nd year	3rd year	0 - year	1st year	2nd year	3rd year
2004	2005	2006	2007	2008	2009	2010
6 total accidents			--	5 total accidents		

There are two nationwide database sources of accident data in Denmark. VIS (Road sector Information System) and Vejman. In collaboration with the counties, the Road Directorate has made the database available for those who want to carry out studies [Vejdirektoratet, 2011c].

VIS and Vejman offer all the key information about the roads and their traffic conditions. The information, which is registered in a same way regardless of who collects and updates them, is from both the stat and the county's roads. The sorted accident data retrieved from the database of the Road Directorate and its descriptive statistics are shown on tables 4.4 and 4.5.

Table 4.4: The sorted accident data retrieved from the road Directorate database sources. Only the accident data thought to be relevant for the analyses are presented here – total accidents, injury accidents and head-on-collision accidents.

			Before						After						
No.	Road no.	Total	Injury	Material	Head on collision				Total	Injury	Material	Head on collision			
					total	frontal(241-2)	overtaking (211)	u-turn (250)				Total	frontal(241-2)	overtaking (211)	u-turn (250)
1	102a	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	102b	1	0	1	0	0	0	0	0	0	0	0	0	0	0
3	136a	8	4	4	0	0	0	0	1	0	1	1	0	1	0
4	136b	11	8	3	0	0	0	0	4	2	2	0	0	0	0
5	142a	5	5	0	2	2	0	0	2	2	0	0	0	0	0
6	142b	2	2	0	0	0	0	0	1	1	0	0	0	0	0
7	119	3	2	1	1	1	0	0	3	2	1	0	0	0	0
8	501	4	2	2	2	2	0	0	6	2	4	2	1	1	0
9	319	5	3	2	1	1	0	0	1	0	1	0	0	0	0
10	322	6	3	3	0	0	0	0	5	2	3	0	0	0	0
11	338	0,5	0	0	0	0	0	0	4,5	2	2	3	2	1	0
12	600338a	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	600338b	0,5	0	0	0	0	0	0	3,5	2	1	0	0	0	0
14	340	0,5	0	0	0	0	0	0	1,5	0	1	1	0	1	0
15	348a	1	1	0	1	1	0	0	2	1	1	1	0	0	0
16	348b	7	2	5	2	1	1	0	9	4	5	2	2	0	0
17	348c	7	2	5	0	0	0	0	11	6	5	0	0	0	0
18	363a	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	401	5	2	3	2	1	1	0	5	3	2	1	1	0	0
20	344	6	5	1	4	4	0	0	5	4	1	4	2	1	1
21	407	5	2	3	1	1	0	0	2	1	1	2	2	0	0
22	411a	19	10	9	1	1	0	0	12	4	8	1	1	0	0
23	411b	5	2	3	1	1	0	0	7	4	3	1	0	1	0
24	417	8	7	1	0	0	0	0	11	5	6	1	1	0	0
25	422	22	11	11	4	2	1	1	16	9	7	1	1	0	0
26	427	8	5	3	2	1	1	0	7	5	2	1	1	0	0
27	441a	5	3	2	2	2	0	0	8	3	5	2	2	0	0
28	441b	16	11	5	0	0	0	0	6	2	4	0	0	0	0
29	441c	2	0	2	0	0	0	0	1	0	1	0	0	0	0
30	442a	10	6	4	5	5	0	0	7	3	4	1	0	0	1
31	442b	7	2	5	2	1	0	1	3	3	0	1	1	0	0
32	445	12	6	6	2	2	0	0	8	1	7	0	0	0	0
33	401b	1	1	0	1	1	0	0	5	3	2	1	1	0	0
34	363b	14	7	7	3	2	1	0	4	0	4	1	1	0	0
35	348d	26	14	12	7	6	1	0	5	1	4	2	2	0	0
	Total	232,5	128	103	46	38	6	2	166,5	77	88	30	21	6	2

(yellow)	Both before and after accidents is zero
(blue)	Either before or after accidents is zero

Descriptive statistics

When data is collected, it is important to describe the data so as to give a preliminary understanding of how the data behaves and what characteristics it has. To perform this, statistical mathematics called descriptive statistics is applied. In descriptive statistics, the mean, median, mode, standard deviation, variance and other measures of the data are calculated and presented on a table. This is different from the inferential statistics which is applied when performing data analysis so as to draw conclusions from the sample data information. The descriptive statistics of the collected crash data is presented in table 4.5.

Table 4.5: The descriptive statistics of the total accidents, before and after period.

Before		***After***	
Mean	6,642857143	Mean	4,757142857
Standard Error	1,081271316	Standard Error	0,650588431
Median	5	Median	4,5
Mode	5	Mode	5
Standard Deviation	6,396887373	Standard Deviation	3,848933062
Sample Variance	40,92016807	Sample Variance	14,81428571
Kurtosis	1,863403279	Kurtosis	0,801024145
Skewness	1,412574555	Skewness	0,938849616
Range	26	Range	16
Minimum	0	Minimum	0
Maximum	26	Maximum	16
Sum	232,5	Sum	166,5
Count	**35**	**Count**	**35**

As shown on table 4.5, the mean from before period data (6.64) is more than the mean from after period data (4.75). The mean, which is often the most important measure of the central tendency of any data, is representing the typical or average accident in the two periods. On first glance, this means that the accidents of the before period were reduced by 30% compared with the accidents of the after period. The other two descriptors of the two sets of data, the *median* and the *mode*, do not indicate big differences between the two sets of data,. The median of the before data is 5 while the median of after data is 4,5. The modes of before period and after are both 5. The two mean values of two sets of data are bigger than their mode values. This means that the data is little bit skewed to the right side.

Traffic data

As previously mentioned there is a relationship between the accidents and the number of vehicles which is why it is essential to retrieve the traffic data. The traffic volume undergoes in the formula for calculating the site specific effect of individual sites. First the traffic data of each year is retrieved from the Road Directorate's database *Mastra Nøgletalsdatabase* , before the average traffic volume is used in the formulas. The Mastra database contains detailed information on the traffic volumes. For the general comparison group, the traffic volume is also available in the Road Directorate's website. The following table (4.6) is traffic data used in the comparison group.

Table 4.6: States road network accidents by year

	Accidents			Casualties			
Year	Injury	Material damage	Total	Killed	Seriously	Slight	Total
1998	7556	9084	16640	499	4071	5104	9674
1999	7605	9301	16906	514	4217	5176	9907
2000	7346	9745	17091	498	4260	4832	9590
2001	6861	9534	16395	431	3946	4519	8896
2002	7126	9383	16509	463	4088	4703	9254
2003	6749	9386	16135	432	3868	4544	8844
2004	6209	9450	15659	369	3561	3985	7915
2005	5412	8811	14223	331	3072	3516	6919
2006	5403	9177	14580	306	2911	3604	6821
2007	5549	9484	15033	406	3138	3519	7063
2008	5020	8757	13777	406	2831	3092	6329
2009	4174	8111	12285	303	2498	2449	5250
2010	3498	7534	11032	255	2063	2090	4408

Chapter 5 – Result

After the methodology and the project data used in the evaluation of the centerline rumble strips treatment are described, the next step is to implement and present the analysis itself. By using short texts, graphs and tables, this chapter summarizes and presents the findings of the analysis. The detailed analysis is found in the CD appendix (Excel format) accompanied with the project report. Three main analyses are carried out:

- Total accidents
- Injury accidents
- Head-on-collisions accidents (category 2)

Two types of analyses are performed on each project site, local and global analysis. As most of the sites are different in terms of their locations, traffic volume, length and geometry, each project site has been evaluated independently (local analysis). To make a general conclusion of the road safety measure, it is necessary to implement a global analysis.

The three analyses have different number of observations. As mentioned in the previous chapter of the methodology and the project data, 35 sites are included in the analysis. The sites which gave no accident counts for both before and after observations are left out of the analysis. This has reduced the number of sites included in the total accident to 32 (there were 3 zero-sites). For injury accident analysis, there are 29 observations as 6 sites had no accidents with personal injuries recorded and for the head-on- collisions, after the zero sites are omitted, 24 sites are included in the evaluation. The findings of each analysis are presented below.

Total accident analysis

After evaluating each site separately (local site evaluation), the site specific effect of the most sites shows positive result. In specific 20 of the sites have shown a positive result, where the other 12 sites have shown a negative result. This means that 3 out of 8 of the treated sites have not reduced the number of accidents. See table 5.1a/b for percentage increase or reduction of the effect.

Table 5.1a: Site specific effect of the 32 sites in the total accident analysis.

No.	Road no.	Effect result in % change
1	102b	-44%
2	136a	-88%
3	136b	-65%
4	142a	-52%
5	142b	-40%
6	119	13%
7	501	73%
8	319	-79%
9	322	-6%
10	338	302%
11	600338b	393%
12	340	197%
13	348a	79%
14	348b	42%
15	348c	75%
16	401	-17%
17	344	-23%

Table 5.1b: Site specific effect of the 32 sites in the total accident analysis.

No.	Road no.	Effect result in % change
18	407	-53%
19	411a	-36%
20	411b	53%
21	417	31%
22	422	-24%
23	427	-17%
24	441a	56%
25	441b	-64%
26	441c	-52%
27	442a	-21%
28	442b	-53%
29	445	-22%
30	401b	573%
31	363b	-83%
32	348d	-83%

By applying meta-analysis method given in the previous chapter, it is possible to estimate the mean effect of the treatment as well as to test if the effect is significant and if the site specific effects are homogenous.

The analysis is begun by performing a test statistic to determine the homogeneousness of the effect. The calculation reflects that the site specific effects are heterogeneous, as $Q > Q_\alpha$ (56.75 > 42.40). **Hence it is possible to conclude that the effect of centerline rumble strips varies among the sites. It is probable that it is the deviations in the road design that causes the effects to vary**.

This prompted the use of random effects model. The mean effect of the total accident then becomes 0.77. This corresponds to an accident reduction of 23%. However, there is not statistical evidence which shows that the effect is significant. The 95% confidence interval is very wide, as its upper and lower bound range from +4% and -43% respectively. This wide interval suggests that the accident reduction is not systematic. However, the 90% confidence interval is little narrower than that of 95%. The 90% intervals range from -1% and -40% for upper and lower bounds. Table 5.4 shows that the effect is statistically significant and that the safety treatment is systematic. Consequently it can be concluded that the centerline rumble strips has a positive effect on the number of accidents – reducing the number of accidents on the average by 23% - and that the effect is significant at the 10%-level of significance.

Injury accidents

In order to evaluate if the centerline rumble strips are efficient in terms of reducing the occurrence of more severe accidents, an evaluation of 29 sites with only personal injuries was also performed. The site specific effects of these sites which are presented in table 5.2a/b show that almost half of the sites have unfortunately negative results. 15 of the 29 treated sites have a positive effect where the remaining 14 sites have negative effect.

Table 5.2a: Site specific effect of the 29 sites in the injury accident analysis.

No.	Road no.	Effect result in % change
1	136a	-87%
2	136b	-71%
3	142a	-46%
4	142b	-33%
5	119	28%
6	501	31%
7	319	-83%
8	322	-14%
9	338	230%
10	600338b	514%
11	348a	23%
12	348b	149%
13	348c	343%
14	401	53%
15	344	-7%

Table 5.2b: Site specific effect of the 29 sites in the injury accident analysis.

No.	Road no.	Effect result in % change
16	407	-31%
17	411a	-53%
18	411b	151%
19	417	-21%
20	422	5%
21	427	11%
22	441a	10%
23	441b	-79%
24	442a	-36%
25	442b	88%
26	445	-78%
27	401b	332%
28	363b	-94%
29	348d	-90%

The test statistic in the meta-analysis suggests that the effect is homogenous and therefore, fixed effects model is used for the calculations of the mean effect and the confidence interval. The weighted mean effect of the injury accidents is 0.85. This equals to 15% reduction in the injury accidents. Like the total accidents analysis, the 95% confidence interval is wide and between 15% and -37%. Applying the 90% confidence interval, which is between 10% and -34%, also shows that the effect is not significant.

Head-on-collisions

According to the literature reviews, the centerline rumble strips are installed on the roads as a countermeasure to head-on-collisions. They are very effective in reducing the head-on-collisions. It is therefore, necessary to see if and how many of these types of accidents are reduced after the sites are treated with the centerline rumble strips. 24 of the 35 sites evaluated reported head-on-collisions accidents. The individual results of the 24 sites are presented in table 5.3a/b. 13 of the sites have shown positive results while the other 11 sites have shown negative results.

Table 5.3a: Site specific effects of the 24 sites in the head-on-accidents analysis.

No.	Road no.	Effect result in % change
1	136a	193%
2	142a	-76%
3	119	-62%
4	501	16%
5	319	-65%
6	338	213%
7	340	197%
8	348a	-4%
9	348b	27%
10	401	-58%
11	344	-20%
12	407	103%

Table 5.3b: Site specific effects of the 24 sites in the head-on-accidents analysis.

No.	Road no.	Effect result in % change
13	411a	17%
14	411b	2%
15	417	229%
16	422	-74%
17	427	-52%
18	441a	4%
19	442a	-79%
20	442b	-37%
21	445	-76%
22	401b	18%
23	363b	-80%
24	348d	-75%

For the global analysis, the Q-statistic indicates that the site specific effects are homogenous; hence the fixed effects model is applied in the calculation of the mean effect and the confidence interval. According to the calculations of the general safety effect of the head-on-collisions, the mean effect becomes 0.71. This is a safety improvement of up to 29%. The 95% confidence interval whose upper and lower bound are between 12% and -37% suggests that effect is insignificant. The 90% confidence interval (3% and -52%) also shows that the safety effect is insignificant. The latter does, however, indicate that if more sites were included in the study; a significant positive effect on the number of head-on-collisions is likely.

Summary of the evaluation result

Table 5.4 summarizes the meta-analysis result. The analyses of the three types of the accidents are combined in the table. According to the table, all the three accident categories have shown a common positive effect. The mean effects of the total, injury and head-on accidents are 0.77, 0.85 and 0.71 respectively. This means that the total accidents are reduced up to 23%, injury accidents 15% and head-on accidents 29%. This complies with the American researches which informed that the application of centerline rumble strips can at least reduce the total accidents 15%. The effect of the total accident is not homogeneous and therefore random effects model is used for the calculations of the mean effect and the confidence interval. By contrast, the other two types of accidents – injury and head-on have homogenous effect. The 95% confidence interval of all the three analysis shows that the effects are not significant. When the 90% confidence interval is tried, only the effect of total accident proves to be significant. The other two analyses continue to show their insignificant effects.

Table 5.4: Summary of the meta-analysis result - total, injurt and head-on accidents.

Accident type	Number of sites (the sample)	Effect Homogeneity	Effect	Accident reduction in %	95% CI		90% CI	
					Upper bound	Lower bound	Upper bound	Lower bound
Total	32	No	0,77	23%	4%	43%	-1%	-40%
Injury	29	Yes	0,85	15%	15%	-37%	10%	-34%
Head-on	24	Yes	0,71	29%	12%	-37%	3%	-52%

Comparison of before and after accident patterns

In addition to the three main parts of the aforementioned analyses, some of the accident patterns are compared. How the accident patterns of before and after periods changed is investigated.

When an accident occurs and reported to the police, it is recorded with all the important characteristics of the accident. These characteristics include the types of accidents in terms of its severity, the time of the day the accident occurred, the accident category in terms of its situation etc. This record of accidents makes possible for latter investigation of accident patterns. By using the existing accident records, in this part of the result, the following three areas are addressed:

- Has the severity of the accident has changed from before to after?
- Has the distribution of accidents among the accident main situations changed?
- Has the time of the accident changed?

Accident severity

According to the police, personal injury accident is defined as an injury which requires a proper medical treatment. Minor injuries are not included in the injuries. Depending on their level of severity, personal injury accidents are divided into three main types: Killed, fatal / serious and slight. Personal injury accidents that result instantaneous death or death within 30 days of the accident occurrence are registered as killed. Death that comes 30 days after the accident time is considered as a fatal and serious accident. Injuries those cause concussion, fractures etc. are also noted as fatal and serious injuries. Minor injuries such as sprains, bruises, cuts and shocks that only need roadside assistance are classified as slight injuries [Vejdirektoratet, 2011b]

Table 5.5 and its graph on figure 5.1 show that all the three accident types of the personal injury indicate that the number of accidents has substantially fallen. The number of persons killed was previously 18 and now 12. This corresponds to an accident reduction of 33%. The number of fatal and serious injuries and the slight injuries in the before period were 84 and 108 respectively. In the after period they were reduced to 46 (45%) and 65(40%) respectively. In total the number of personal injury accidents in period before treatment was 210 and in the period after treatment it was 123. This is a total of injury accident reduction of 41%.

Table 5.5: Comparing number of injuries of before and after period

Personal injury type	Before	After	% change
Killed	18	12	-33%
Fatal and serious	84	46	-45%
Slight	108	65	-40%
All personal injuries	210	123	-41%

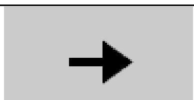
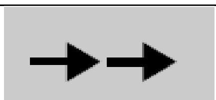
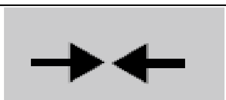
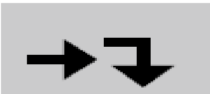
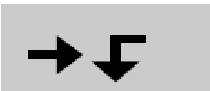
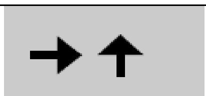
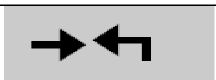
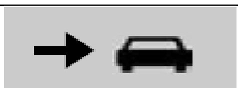
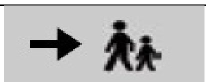
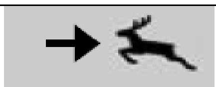
Figure 5.1

The figure illustrates the accident reduction percentage – personal injury accidents.

Accident category distribution

In Denmark, there are ten major accident categories which the police use to divide the traffic accidents in terms of how they are similar to each other and the different elements (animal, pedestrian etc.) involved in the accident. Accident categories, which are also called accident situations, are coded with numbers 0 to 9. The accidents are spread across these ten main situations with varying frequency. Table 5.6 shows an overview of the main accident situations.

Table 5.6: Overview of the accident situations

Main situation	Illustration	Description
0		Solo accident such as run-off-road collisions
1		Accidents between vehicles driving same direction without turning, such as rear-end-collisions
2		Accidents between vehicles driving same road but opposite direction without turning, such as head-on-collisions, overtaking, U-turning etc
3		Accidents between vehicles driving same road and same direction with turning.
4		Accidents between vehicles driving same road but opposite direction with turning.
5		Accident between crossing vehicles
6		Accidents between vehicles driving different roads with turning
7		Parking lot
8		Pedestrian
9		Obstruction such as animal or an object on the road

The accident numbers from the different main situations of the period before treatment and that for the period after treatment are compared. The result can be seen in table 5.6 and figure 5.3.

All the situations have had a change in the number of accidents. 8 out of the 10 main situations show a reduction of accident numbers of up to 50%, while the other 2 are increased up to 100%. The number of accidents involving solo accident (main situation 1) and pedestrian (main situation 8) are increased by 100% and 14% respectively. The increase of the solo accidents in the after period is probably due to the increase of the materials causing driver distraction/inattention. The use of the distracting things such the navigators, mobile phones and other technology are rapidly increasing. This causes the drivers to slide or run off the road while they are busy on using these materials. They forgot that they are sitting behind the wheel and hit the posts, roadside fencing guards and channels, signs and the other things on the side of the road. The increase of the accidents involving pedestrian is probably due to the increase of the accidents involving solo accidents. Most of the run-off-road accidents are solo accidents and when this occurs, pedestrians may be hit as they are one of the elements walking on the side of the road.

The number of accidents involving animals and objects obstructing the road (main situation 9), opposite driving with turning left / right (main situation 6), crossing driving without turning left / right (main situation 5), parking (main situation 7) and driving with same direction with left / right turn (main situation 3) are among those significantly reduced by 50%, 49%, 41%, 33% and 33% respectively. The accident reduction of the accidents involving head-on-collisions cannot either be ignored, as one fourth of the accidents are reduced.

Table 5.7: Accident change of before and after period distributed into main situations

Accident situation	Before	After	% change
0	102	81	-21%
1	43	49	14%
2	46	35	-24%
3	21	14	-33%
4	8	6	-25%
5	17	10	-41%
6	39	20	-49%
7	3	2	-33%
8	4	8	100%
9	10	5	-50%

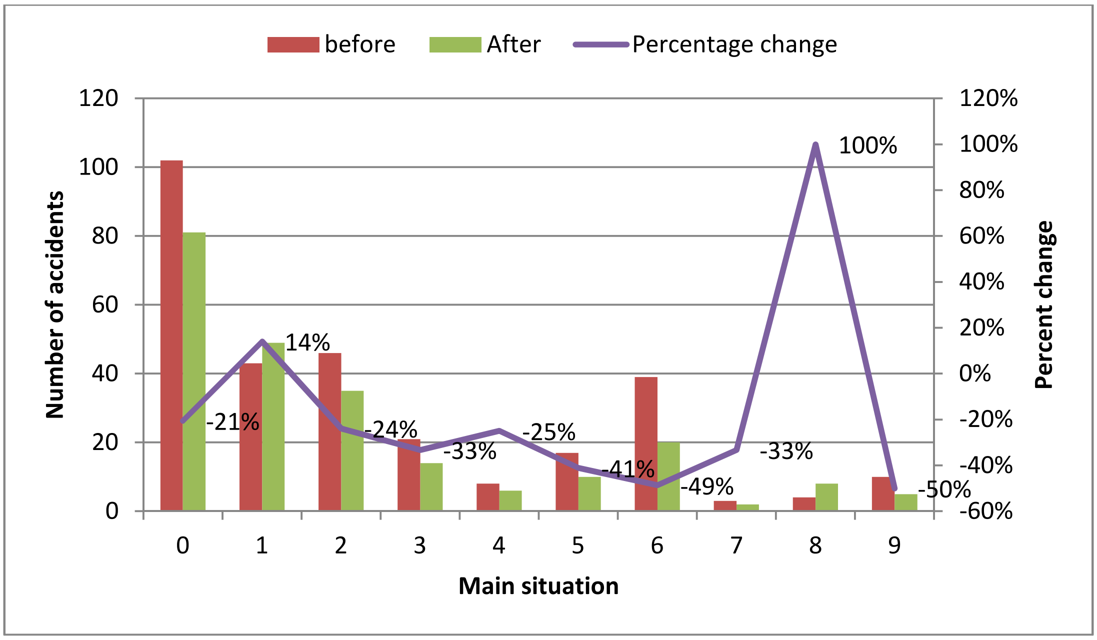


Figure 5.2: *The figure illustrates the accident change on main situations.*

The time of the accident

The number of the vehicles on the roads during the 24 hours of the day varies. Sometimes the vehicles exceed the capacity of the roads. This time of the day, which is known as the peak hour, is when people are going or coming back from their working places or schools. Other times, such as the middle of the night when most people are sleeping, the roads are empty. The different times of the day has a great impact on the accident occurrence. It is, therefore, necessary to compare the accident numbers of before and after period in terms of the time it occurred.

The Road Directorate's accident database gives the exact time in which the accident had occurred. The times are grouped in three hours, for example, from 06 – 09 (06 is included but 09 is not included, 06=>09), 09- 12 (09 is included but 12 is not included, 09=>12) and so forth. The two morning peak hours are included in the three hours of 06 to 09, and the afternoon peak hours are included in 15 to 18.

According to the following table (5.7) and the graph on figure 5.4, both before and after accident numbers in the peak hours are very high compared with the other times of the day. 76 of all the 293 accidents in the before accidents occurred in the afternoon peak hour. That corresponds to more than 25%. The morning peak hour also shows worrying figures of 49 accidents. It is not surprising that the afternoon peak has more accidents than the morning. In the morning, the people are mostly fresh, while they are fatigued and mentally and physically tired. In total, the afternoon and the morning peak hours represent 65% of all the accidents. The peak hours in the after period have also very high accident numbers. 99 of the 234 accidents occurred in the morning and the afternoon peak hours. Most of the roads have high traffic intensity throughout the peak hours and there are often long traffic jams where the cars move slowly or even halt. It was expected that the accident numbers would be higher in the peak hours as there is a relationship between the number of vehicles on the road and the accident occurrence. This is not linear though, because the traffic volume in the peak hour is normally 10 to 13% of the AADT, but here we see that the accidents in the peak hour exceed 25% of the total accidents of the whole day.

The accidents do not only occur in the day-time and the early hours of the night-time. They can occur anytime of the day. Here 17 accidents are recorded between 03 to 06 o'clock when most people would think no accident would have happened.

Comparing the accidents occurred in the before period to that occurred in the after period, 6 out of the 8 time groups show a reduction of the accident numbers. In total, 20% of the accidents are reduced from before to after. The only two time groups which accidents increased are after morning peak hour to noon time and in the evening from 9 o'clock to the midnight at 12 o'clock. Accidents increased in these times by 11% and 23% respectively. The time of the day is divided into 12 hours of day-time and 12 hours of night-time and then the accident numbers in the before and after period are compared. The accident numbers in the day-time was reduced by 22% and the night-time by 16%.

Table 5.7: How the number of accidents changed in terms of the time of the day.

Time of the day	Number of accidents		% change
	Before	After	
06 => 09	49	38	-22%
09 => 12	28	31	11%
12 => 15	44	23	-48%
15 => 18	76	61	-20%
18 => 21	38	25	-34%
21 => 00	22	27	23%
00 => 03	19	17	-11%
03 => 06	17	12	-29%
Day-time: 06=>18	197	153	-22%
Night-time: 18=>06	96	81	-16%
Total	293	234	-20%

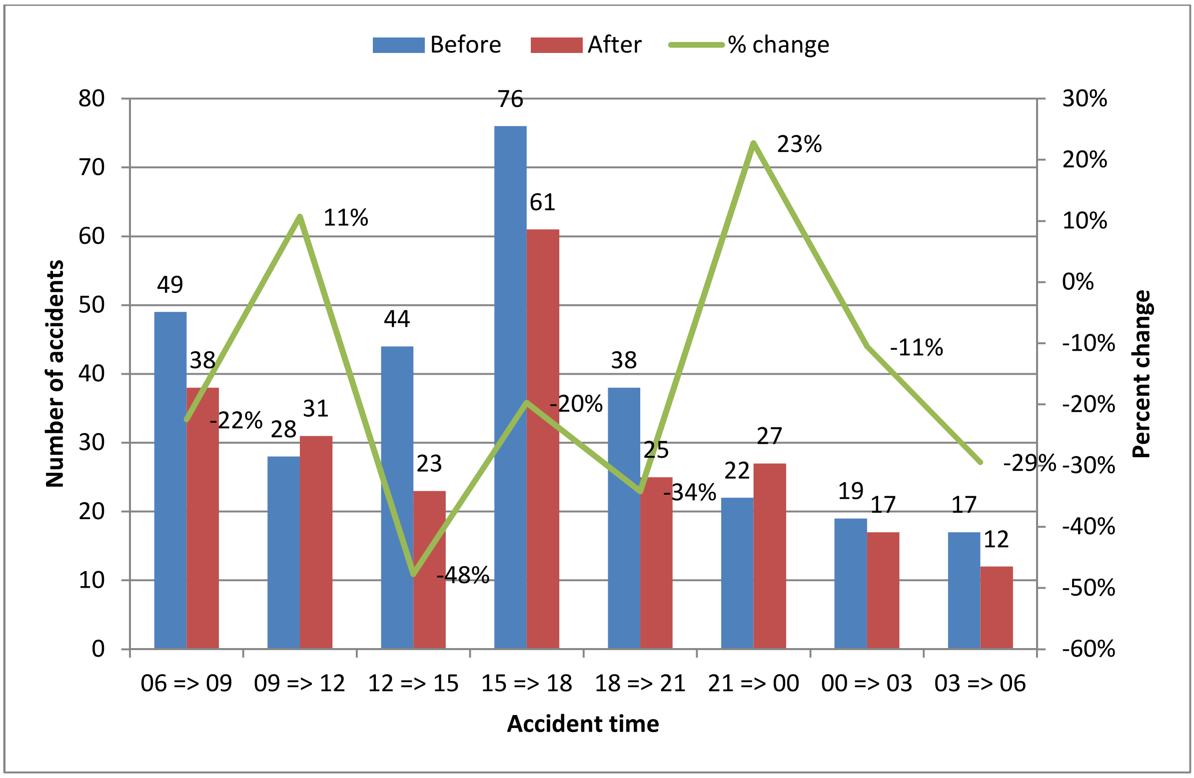


Figure 5.2

Accidents time of the day.

Chapter 6 – Discussion

Referring to the preceding chapter of the result, the establishment of the centerline rumble strips has led an accident decline of all the three analyzed crash types, total, injury and head-on-collisions. On average, the total accidents were reduced by 23%, while the injury and the head-on-collisions were reduced by 15% and 29% respectively. The mean effects of the injury and head-on collisions are homogenous meaning that the effect of the treatment measure can be generalized. However, the mean effect of the total accident is heterogeneous. This implies that the effect varies between the sites and cannot be generalized. As mentioned before, this heterogeneity is probably caused by the road design discrepancy. To check whether the heterogeneity is due to the road design or not, the sites are normally divided into groups and then the statistical calculations are once more performed. If this does not help in finding the cause of the heterogeneity, then there may be one or more outliers which affect the mean effect of the data set. Outliers are observations with extraordinary values which can cause dramatic differences on the result. In other words they are observations which their occurrences have very low probability. Outliers affect only the mean of the data set but they do not affect the median as it is a value that lies in the middle position of the data. For this reason many people choose to use the median as the typical average of data set.

From the two data set of the total accidents, there is a case (road number 348d) where the recorded before accidents have been 26 and after accidents 5. This produces very unusual difference between before and after period accidents. Consequently this is a possible outlier. One way to correct an outlier in a data set is to get rid of it all – to exclude that observation from the analysis. It is worth to see what happens to the result after this site is omitted. The result is presented in table 6.1:

Table 6.1: How the number of accidents changed in terms of the time of the day.

		All sites (no change)	Site 348d excluded	Site 401b excluded
Number of sites, (the samble)		32	31	30
Effect homogeniety		No	Yes	Yes
Best estimate (mean effect)		0,77	0,81	0,8
Accident reduction		23%	19%	20%
95% CI	**Upper bound**	4%	0%	-1%
	Lower bound	43%	-34%	-35%
90% CI	**Upper bound**	-1%	-3%	-5%
	Lower bound	-40%	-32%	-33%

As shown on table 6.1, when the two sites with the highest positive site specific effect and that with the highest negative site specific effect are removed from the analysis, a radical change has occurred on to the result of the analysis. In the first calculation, only site 348d was excluded from the analysis. Then Q-test statistic is performed. It is found out that $Q < Q_\alpha$ (42.89 < 46.19). This makes the assumption of the random variation of the fixed effects model valid. This means that the effect is homogenous and it can be generalized. The removal of site 348d has also affected the mean effect. Now the mean effect is 0.81 corresponding to 19% accident reduction instead of the previous 0.77 mean effect (23% accident reduction). This was expected because a site with a very high positive site specific effect was removed and then the mean effect is dragged to the side of the negative effect. The confidence interval of 95% shows bounds between 0% and -34%. This is also better significance effect. When 90% confidence interval is applied the bounds get closer to each other – it is even more significant. In the next calculation, site with highest negative site specific effect is excluded. The result is even better in terms of the homogeneity, the effect significance and even the mean effect. The accident is then reduced by 20%. This is reasonable because when these two unusual sites are removed their effect cancels out.

The result of the evaluation has also shown that there have been substantial changes in the number of accidents in the before and after period in terms of accident severity, time of the accident occurrence and the main accident situations. Most sites have had a positive accident change.

To my knowledge, there is not a study on centerline rumble strips evaluation conducted on Danish roads. But many previous international studies comply with the overall result of this study. All studies demonstrate that the centerline rumble strips treatment is a very effective measure to reduce the road traffic accidents especially the roads on the rural areas. Chapter 3 (the current state of knowledge) summarizes five of the many international researches that evaluated this treatment. Some of which have concluded that accident was reduced up to 55.2%.

The average total accident reduction of this study has been 20%. More positive accident reduction, close to that of the international studies, can be achieved if the sites included in the evaluation would have been more. The raw data received from the Road Directorate contained 62 sites. Only 31 were included in the analyses. Some of them were left out because the treatment was not old enough. Others were left out because of their type of the road. And others were left out because some information was missing such as the installation date. In the upcoming years, there will be more sites with centerline rumble strips to be evaluated. Therefore a study is suggested so as to prove the effectiveness of the treatment even better.

So as to avoid a possible overlap road safety measures, studies other than the effectiveness of the centerline rumble strips on the same sites are also suggested. It is essential to denote that there may be other measures which have also contributed the road safety improvement. An example can be black spot treatment. If black spot measure is implemented on same roads as the ones evaluated in this project, and then a study which is evaluating the black spot effectiveness is carried out, it may claim that black spot measure has reduced accident numbers by 20%. So the question is which of the measures have led the accident reduction? Or have they both contributed safety improvement? The two measures have probably reduced the accident together. It is therefore, important to consider overlap of measures by performing other evaluations on the road safety measures on the same roads (if there are any). It is not enough to multiply the C-trend factor with the numerator of the site specific effect formula and believe that this problem of overlap of measures was considered.

Regression to the mean effect factor, C_{RTM}, was set to 1 in the analysis as pointed out in the methodology chapter. The question one may wonder is: how will this affect the result? First of all, regression to the mean affect problem arises when there is a very unusual observation (very high or very low number of accidents). Yes, there was a case in the accident data which showed very unlike accident number in the before period compared with the corresponding after period site and of course the other before period sites. There was also another case where there was unusually low accident number in the before period and the corresponding site showed very high accident numbers. So the problem of the regression to mean effect is presumably there. When the statistical calculation was performed it showed that the effect was not homogenous which could mean that there was a regression to the mean problem. The main purpose of leaving out the regression to the mean factor in the formula of the site specific effect was that the lack of proper method which calculates the percentage or the factor of the regression to the mean. The regression problem is an individual problem and should be dealt with individually. In this study, it was chosen to visually find the sites those could cause the regression to mean problem and then exclude them form the analyses. After this was done the effect has become homogenous and the result can be relied on.

Chapter 7 – Conclusion

The centerline rumble strips treatment is a very effective road improvement measure for two lane rural roads. On an average, it can reduce the total accident numbers by 20%. This is; however, lower than the new accident reduction target (40%) of the latest action plan of May 2007. This means that, this measure only cannot achieve the desired target of accident reduction on the number of people killed, seriously and slightly injured.

When the accident data was collected and the descriptive statistics was carried out, it would be seen preliminarily that road safety improvement has been taken place. By comparing the three center estimators of the before and the after accident data, the mean, median and the mode, it was concluded that, at the first glance, the accidents occurred before the installation of centerline rumble strips were more than the accidents occurred after the installation of the rumble strips.

When the main inferential statistical analyses were performed, they agreed with the preliminary analysis of the accident data. The three analyses of the accident categories, total, injury and head-on accidents show an average accident reduction of 23%, 15% and 29% respectively. In the beginning, the effect of the total accident showed to be heterogeneous. But after two observations of outliers and possible regression to the mean effect problem were excluded from the analysis, the effect showed to be homogenous.

Further studies evaluating the effectiveness of the centerline rumble strips were suggested. It is not because that there are skeptics in their effectiveness but to show that they are more effective than they were concluded in this study. As some of the international studies suggested they can reduce accident numbers by up to 55.2%. Simultaneous or parallel studies other than the centerline rumble strips are also suggested. The parallel studies will take into account the possible overlap of safety measures. When these further studies are implemented the achievement of the desired accident reduction of the 40% is probable.

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