The Optimal Trigger Speed of Vehicle Activated Signs

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Abstract
The thesis aims to elaborate on the optimum trigger speed for Vehicle Activated Signs (VAS) and to study the effectiveness of VAS trigger speed on drivers’ behaviour. Vehicle activated signs (VAS) are speed warning signs that are activated by individual vehicle when the driver exceeds a speed threshold. The threshold, which triggers the VAS, is commonly based on a driver speed, and accordingly, is called a trigger speed. At present, the trigger speed activating the VAS is usually set to a constant value and does not consider the fact that an optimal trigger speed might exist. The optimal trigger speed significantly impacts driver behaviour.

In order to be able to fulfil the aims of this thesis, systematic vehicle speed data were collected from field experiments that utilized Doppler radar. Further calibration methods for the radar used in the experiment have been developed and evaluated to provide accurate data for the experiment. The calibration method was bidirectional; consisting of data cleaning and data reconstruction. The data cleaning calibration had a superior performance than the calibration based on the reconstructed data.

To study the effectiveness of trigger speed on driver behaviour, the collected data were analysed by both descriptive and inferential statistics. Both descriptive and inferential statistics showed that the change in trigger speed had an effect on vehicle mean speed and on vehicle standard deviation of the mean speed. When the trigger speed was set near the speed limit, the standard deviation was high. Therefore, the choice of trigger speed cannot be based solely on the speed limit at the proposed VAS location.

The optimal trigger speeds for VAS were not considered in previous studies. As well, the relationship between the trigger value and its consequences under different conditions were not clearly stated. The finding from this thesis is that the optimal trigger speed should be primarily based on lowering the standard deviation rather than lowering the mean speed of vehicles. Furthermore, the optimal trigger speed should be set near the 85th percentile speed, with the goal of lowering the standard deviation.

Keywords: optimal trigger speed, vehicle activated sign, vehicle mean speed, standard deviation, calibration, Doppler radar, driver behaviour, data analysis
**Included papers**

The thesis is based on the following papers:


My contributions to the papers were as follows:

**Paper I** – conducting the literature review, writing the manuscript and revising it.

**Paper II** – collecting data, processing the data, development of the data calibration method, writing and revising the manuscript.

**Paper III** – setting the experiment design, collecting data, analysing the data and writing and revising the manuscript.
# Contents

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I. Introduction

Excessive or inappropriate speed is often a significant factor for traffic fatalities. Therefore, a range of safety measures have been employed in order encourage drivers to adapt their speed to the current road and traffic conditions. A Vehicle activated sign (VAS) is one way to warn drivers that they are approaching the speed limit for a particular segment of road. The VAS signs measure the speed of passing vehicles and when a driver exceeds a particular threshold, display a warning message, e.g. ‘Slow down’ in combination with the current speed limit, (Walter and Knowles 2008). The threshold, which triggers the message to the driver, is commonly based on a vehicle’s speed, and accordingly, is called a trigger speed. At present, the trigger speed activating the VAS sign is usually set to a constant value that corresponds to the traffic agencies recommendation for the particular road segment. However, to our best knowledge, these recommendations do not consider the fact that an optimal trigger speed might exist, i.e. a trigger speed that has a significant impact on driver behaviour. It can be argued that VAS signs have a limited short term effect on driver behaviour and that excessive use of these signs might, in the long term, lead to a situation in which drivers tend to disregard the warnings. This might be the case when an inappropriate trigger speed is employed in the VAS signs. In other words, the effectiveness of the VAS on a driver’s speed is adversely affected by the inappropriate trigger speed of the signage. It should be noted that VAS belong to a much bigger class of signs known as variable message signs (VMS).

Given this background, the main objective of this licentiate thesis is to elaborate on the optimum trigger speed for VAS signs in order to modify driver behaviour over the long term. In particular, this thesis will cover previous studies on the effectiveness of the VAS, the procedure of the data collection and ultimately attempt to determine the optimal trigger speed of the VAS in order to reduce the mean and standard deviation of the speed of vehicles passing the VAS.

Studies concerning the trigger speed values of the signs have not been carefully examined. Nygård and Helemers (2007) and Nygård (2011) review the effects of the VAS and the VMS, in articles published between 2000 and 2009. The articles that were published during that period of time concentrate mainly on the influence of the sign upon human behaviour. The main conclusion drawn from their reviews is that relevant information that is displayed in the sign plays an essential

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role in influencing driver behaviour. Specifically, trigger speeds of this signs have not been emphasised in their reviews.

In addition, a large number of studies have been conducted to test the effectiveness of VAS in reducing vehicle speed and in improving safety. A frequent measure of the VAS effectiveness on driver behaviour is the reduction in the mean speed of vehicles as they pass the sign. However, some recently studies (Quddus 2013, MCMurtry et al 2009, Garber and Earhart 2000) have indicated a positive relationship between the standard deviation of vehicle speeds and the number of traffic accidents. Given this result, it is worth pointing out that the optimal trigger speed of VAS should have a combined effect on both the mean and standard deviation of vehicle speeds.

In order to determine the optimal trigger speed, accurate and unbiased speed data must be collected at the current VAS location. A commonly used method for the collection of speed and traffic information is a Doppler radar. However, the data collected by the Doppler radar, are sensitive to the calibration of the radar. In order to provide correct results, the radar should be mounted in an overhead position, pointing down toward roadway at approximately a 30 degree angle from the horizontal direction. Meanwhile, in the real world, the calibration of the radar is often done by subjective judgement and this might bias the collected speed information and subsequently, lead to incorrectly calculating the optimum trigger speed.

In this thesis, three specific research questions are investigated:

1. What is the trigger speed of the VAS signs that were used in previous studies and furthermore, how was the effectiveness of VAS signs on driver behaviour assessed?

2. How to handle the data collection procedure of VAS?

3. What is the effect of trigger speed on driver behaviour and what is the optimal trigger speed?

In order to answer the above research questions, the work in this thesis has been segmented into three phases respectively. In the first phase, a review study of the effectiveness of vehicle activated signs has been conducted. The review focuses on the parameters used for the assessment of the effectiveness of the signs. The parameters used for the configuration of the triggers speeds of the signs and the necessity of the signs to be related to traffic and weather conditions.

The second phase aims at collecting accurate and unbiased vehicle speed data from field experiments and solving the potential problems that might challenge the data collection procedure.
The collected data has been carried out at a test site by using Doppler radars. Additional calibration methods have been developed and evaluated to provide the experiment with accurate data.

Finally, in the third phase, a systematic data collection was done at two sites with an aim to find the optimal trigger speed in the mean and the standard deviation of the mean speed. The data collection was carried out whereby vehicle speed data were gathered whilst varying the value of the trigger speed threshold. This data collection was based on a complete randomized design. To obtain a comprehensive understanding of the impact of trigger speed on driver behaviour, this study is confirming two hypotheses: The first is that the change of the threshold value has an effect on vehicle mean speed; the second is that a change in the threshold value has an effect on the standard deviation of vehicle speed.

The research methodology described above attempts to present the appended papers that are attached at the end of this thesis. Chapter 2 summarises paper I. Chapters 3 and 4 summarise papers II and III, respectively. The rest of the thesis is organized as follows: Firstly, the state of the art review of the work carried out. Data calibration is described in section 3. Section 4 describes the optimal trigger speed. The thesis finally presents conclusions and proposes possible future studies in Section 5.

II. State of the art (paper I)

The previous research on variable messages signs (VMS) and vehicle activated signs (VAS) had been reviewed. The reason for including VMS in the review is the fact, that in majority of previous studies, the VAS, the main objective of this thesis, are considered to be a part of the VMS. The main research question which motivates this review is: What is the trigger speed of the VAS signs that were used in previous studies and furthermore, how was the effectiveness of VAS signs on driver behaviour assessed.

Several methods for measuring the effectiveness of the VMS and VAS are reported in the literature. Most frequently, the sign effectiveness is measured with the reduction of the vehicle mean speeds, using vehicle speed data collected by loop detectors, radars or by using micro-simulation techniques. In this context, the vehicle mean speed is usually examined. However, the vehicle mean speed might not always be a reliable measure of a sign’s effectiveness, as Kathmann
(2001) has showmen in his study. The author argues that the effect of the signs might not affect the average speed of the vehicles and instead, the whole vehicle speed distribution should be examined.

Another measure of the effectiveness that has been proposed in a handful of studies is the relationship between the presence of VMS and VAS signs and the number of traffic accidents. Taylor et al. (2002) presented a robust predictive model based on extensive accidents and speed databases. The authors deduce that the reduction in the number of traffic accidents was 4.5% to 7.5% for each 1 mph reduction in the mean speed of the vehicle. While Taylor et al. (2002) did not consider the severity of the traffic accidents, Nilson (2004) reports that the reduction of 1 mph in mean speed of the vehicle leads to a 6.6% reduction in all injury-causing accidents, a 0.7% reduction in accidents that cause serious injury and a 12.7% reduction in fatal accidents. The main advantage of using the relationship between presence of the signs and the traffic accident is that the direct impact of the signs on the traffic safety is measured. However, the drawback of this method is that the data collection needs usually to be done over a longer period, since traffic accidents are rather rare, e.g. Taylor et al. (2002) in their study use a database covering a 5 year period.

The third way of measuring the effectiveness of the VMS and VAS, proposed by some researchers, is by conducting interviews with drivers who have passed the signs. Luoma et al. (2000) argue that the effectiveness of the signs need not be assessed with only statistical measures, e.g. mean vehicle speed. Instead, other behavioural changes, such as the focus of a driver’s attention or cautious overtaking, might give a good estimate of the effectiveness of a sign. Another measure of the effectiveness, suggested by Charlton and Baas (2006) is the sign visibility and comprehensibility.

Conversely to the body of literature focused on the assessment of the effectiveness of VMS and VAS, fewer studies have attempted to deal with the technical configurations of these signs, in particular, the trigger speed. There is no clear consensus in the literature at what level the trigger speed should be set. Thus, Winnett et al (1999) reported a trigger speed being set to 4mph under the posted speed limit, Winnett and Wheeler (2002) 5mph above the posted speed limit and Mattox et al (2007) 3mph above the speed limit.

Lastly, a large number of studies have evaluated the effectiveness of the VMS and VAS on driver behaviour but only a few studies have considered the effects of these signs under different
road and weather conditions (Rämä, 1999; Rämä and Kulmala 2000; Luoma et al. 2000; Jiang et al. 2011). These studies reported a small beneficial reduction in mean speed but increases in the homogeneity of driver behaviour. In Rämä (1999), there was more effect on mean speed and standard deviation in summer than in winter.

The main conclusion from this review is that there is no clear evidence in the previous research on universally used standard settings for the trigger speed of the VAS. Furthermore, the previous research is rather inconclusive on the question of the relationship between the trigger speed value and the effect that trigger speed has on drivers under various road and weather conditions.

III. Data calibration (paper II)

The research question that motivates this chapter is: How to handle the data collection procedure of VAS? In this study, vehicle speed data was first collected and then the correction factor was determined using a mining procedure.

In order to collect vehicle speed data, a systematic experiment was designed. For this purpose, a test site in Mjälga, Borlänge was selected and equipped with a VAS and two Doppler radars. While the first Doppler radar was positioned on the same place as the VAS, the second radar was located either 100m ahead of the VAS, or 60m after the VAS. The rationale behind moving the second radar back and forward, in relation to the VAS, was to test the accuracy of the correction factor.

During the data collection stage, vehicle speeds were gathered using the two radars. After the data collection, missing data and outliers were detected. In the next step, the data was pre-processed by data cleaning and by data reconstruction. During the data cleaning, outliers and missing data, identified in the previous step, were removed, while in the reconstruction process, the outliers and missing data were completely constructed by filling in missing values and keeping all outliers. This step resulted in two different data sets, while the first data set contains the ‘cleaned’ data; the second data set contains the ‘complete’ data.

Subsequently, both data sets were employed in order to identify the correction factor. Contrary to the common practice, in this paper, the correction factor is based on distance. The calibration method is based on matching velocities and time recorded by two radars in order to calculate the travelled distance. The ratio between the travelled distance and the actual distance between the radars is the speed correction factor.
The calculated correction factors were compared to an experimental correction factor that was obtained by traveling a certain distance with the vehicle in cruise control mode.

The results of this paper indicate that the correction factor obtained from the cleaned data was superior to the correction factor retrieved from the reconstructed data. Additionally, the correction factor for a shorter distance (60m) was closer to the reference correction factor than the correction factor for the longer distance (100m).

IV. Optimal trigger speed (paper III)

The aim of this chapter is to examine if changes in trigger speed have effect on the mean and standard deviation of vehicle speed. Furthermore, the paper attempts to find the optimal trigger speed which yields the best compromise between reducing both mean speed and the standard deviation of vehicle speed.

In the previous chapter of this thesis, it has been shown that the setting of trigger speeds for the Vehicle Activated Signs and its effect were not thoroughly considered in previous research. Moreover, it was shown that the most frequent measure of the VAS effectiveness on driver behaviour is the reduction in mean speed of vehicles as they pass the sign. For the study conducted for paper III, the main research question is: What is the effect of trigger speed on driver’s behaviour and what is the optimal trigger speed?

In this paper, consistent and unbiased speed data were collected to assess how the VAS trigger speed affected driver behaviour. This consistency and lack of bias is dependent on gathering the data without influence from other secondary factors that lead to a misinterpretation of the results. To eliminate the effect of such factors, a complete randomised design (CRD) has been employed. This design is mainly based on the comparison of values of vehicle speed based on the different levels of the primary factor, which is the trigger speed.

In order to collect the data, two test sites in Borlänge, Sweden were selected. The first test site is referred to as Korsgård, the second test site as Mjälga. Both test sites are restricted with 40km/h speed limit and are notorious known for speeding. The sites were furnished with VAS and Doppler radars to collect vehicle speeds. The VAS used in the current study is also equipped with a data logger and a modem in order to be able to remotely alter the trigger speed settings of the sign. Such a setup facilitates alteration of trigger speeds, thereby permitting the study to compare the effect of
different trigger speeds on driver behaviour, particularly on the mean and standard deviation of vehicle speeds. However, connection problems sometimes prevented the trigger speed from being altered. When applying CRD, the data were collected 24 hours a day and the data collection was done in a period of 16 weeks. For each week, the trigger speed was randomly assigned to 85th percentile speed, speed limit plus 10%, 0km/h and 150km/h as well as some other values.

The collected data were analysed by both descriptive and inferential statistics. Mean speed, standard deviation and coefficient of variation were used in the descriptive statistics. The Bartlett test, the One-way test, the pairwise t and pairwise F-tests were done in the inferential part of the data analysis. While the Bartlett test was performed in order to check the homogeneity of the variances between trigger speeds, the One-way test was used to check the mean speed’s homogeneity, when the assumptions of equal variances were relaxed. Furthermore, the pairwise tests (t-test and F-test) were also used to perform a pairwise comparison for mean speeds and speed variances, respectively.

The results from the hypothesis testing showed that there was strong evidence of a difference in mean speeds and in speed variances between a trigger speed that is set to the 85th percentile and other trigger speeds. Apart from the inferential analysis, the effect of trigger speeds on mean speeds was not significant at either site. Conversely, there was a greater reduction in the number of speeders when the VAS was triggered at the 85th percentile. Thus, such results imply that with this trigger speed, there was approximately a 4% increase in the number of speeders who reduced their speed. Additionally, the standard deviation and coefficient of variation was shown to decrease when the trigger speed was increased. Meanwhile, the lowest standard deviation obtained was also when the trigger speed was set to the 85th percentile. Similar results were obtained at both sites. According to these results, an interesting finding was that the optimal trigger speed was approximately near the 85th percentile speeds, which had the desired effect of lowering the standard deviation. Another interesting finding was that standard deviation was high when the trigger speed was set near the speed limit.

V. Conclusions and future research
The review study showed that trigger speeds for VAS have not been carefully examined when studying the effectiveness of the VAS on driver behaviour. The work described in this thesis has
been concerned with proving the effectiveness of the trigger speed of these signs on driver
behaviour and ultimately determining the optimum value. Vehicle speed data were collected and
pre-processed by data cleaning and by data reconstruction. Further data based calibration methods
have been presented by matching the velocity of individual vehicles that were recorded by radar in
order to find the factor that correctly collected the data. The collected data were also analysed by
confirming the hypothesis that the change of the trigger speed has an effect on vehicle mean speed
and on the standard deviation of vehicle speed. This thesis searched for the optimal trigger speed
which provides both a reduction in mean speed and a reduction in the standard deviation of speed.

The following are the findings presented in this thesis:

• Optimal trigger speeds for VAS were not considered in previous studies. Additionally, the
effect that triggers speed has on drivers under various road and weather conditions were not
clearly stated.

• The correction factor for the radar obtained after data cleaning was much closer to the
reference correction factor than the factor obtained through data reconstruction.

• The correction factor for the radar obtained from the shorter distance was much closer to the
reference correction factor than the factor obtained through the longer distance.

• Setting the trigger speed relative to the speed limit is not a good practice. Standard deviation
of vehicle speed is high when the trigger speed is set near the speed limit

• The optimal trigger speed was near the 85th percentile speed, which had the desired effect of
lowering the standard deviation The trigger speed should be based primarily on lowering the
standard deviation rather than lowering the mean speed of vehicles

• The optimal trigger speed will need to be pre-determined according to the nature of the site
and to the traffic conditions. If there are no traffic data available, it is hard to identify which
trigger speed should be applied to the site.

Once the optimal trigger speed is known, an “intelligent” adaptable VAS sign might be developed.
Such a sign should reflect current traffic and road conditions. Such a VAS sign would derive its
trigger speed based on the data collected in the particular location. After moving to another
location, the data would need to be recollected and a new trigger speed would need to be
determined. This would mean that the VAS should have ability to ‘learn’ from previous conditions
and determine the optimal trigger speed. In this context, the next step is to develop an intelligent
trigger speed system for the VAS by using adaptive neuro-fuzzy inference systems (ANFIS) [6]. The idea of the system is to construct an initial fuzzy inference system whose membership function parameters will be further tuned or adjusted. The evaluation of the system will be done by a comparative study of statistical methods such as multiple linear regression (MLR), multiple nonlinear regressions (MNLR) and auto regressive integrated moving average (ARIMA). Budget and time constraints on the project did not particularly make it possible to have more than two test sites to be able to verify the proof of concept. The study will further collect more data at various sites for different speed limits. Furthermore, a systematic data collection will be the focus of the next stage in which traffic data will be integrated with weather data sources.

Regarding the data based calibration for the radar used in the data collection procedure; the results can be validated by another technique. A real time video surveillance might be appropriate. The benefit of video surveillance is that it can facilitate the detection problem where individual vehicles might be accurately detected by tracking their speeds, time when passing by the radar and accurately identify vehicles’ type.

Ongoing research includes the development of an intelligent algorithm that would help optimize the trigger speed of solar-powered Vehicle Activated Signs. Solar-powered Vehicle Activated Signs are VAS powered by batteries that are recharged by solar panels. Determining the trigger speed for these signs are more challenging due to the limited power capacity available to keep the sign operational. In order to be able to operate the sign more efficiently, the trigger should be efficiently set taking into account sign efficiency on driver behaviour and on power consumption. Therefore the intelligent algorithm will also determine the optimal trigger speed which is a compromise between speed reduction of vehicle speeds and power consumption of the VAS.

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References


**REVIEW OF THE EFFECTIVENESS OF VEHICLE ACTIVATED SIGNS**

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**Abstract**

This paper reviews the effectiveness of vehicle activated signs. Vehicle activated signs are being reportedly used in recent years to display dynamic information to road users on an individual basis in order to give a warning or inform about a specific event. Vehicle activated signs are triggered individually by vehicles when a certain criteria is met. An example of such criteria is to trigger a speed limit sign when the driver exceeds a pre-set threshold speed. The preset threshold is usually set to a constant value which is often equal, or relative, to the speed limit on a particular road segment.

This review examines in detail the basis for the configuration of the existing sign types in previous studies and explores the relation between the configuration of the sign and their impact on driver behavior and sign efficiency. Most of previous studies showed that these signs have significant impact on driver behavior, traffic safety and traffic efficiency. In most cases the signs deployed have yielded reductions in mean speeds, in speed variation and in longer headways.

However most experiments reported within the area were performed with the signs set to a certain static configuration within applicable conditions. Since some of the aforementioned factors are dynamic in nature, it is felt that the configurations of these signs were thus not carefully considered by previous researchers and there is no clear statement in the previous studies describing the relationship between the trigger value and its consequences under different conditions. Bearing in mind that different designs of vehicle activated signs can give a different impact under certain conditions of road, traffic and weather conditions the current work suggests that variable speed thresholds should be considered instead.

**Keywords:** vehicle activated signs; variable message signs; threshold trigger value; speed variation; traffic volume; mean speed
I. Introduction

Excessive or inappropriate speeds are often a reason for traffic fatalities. Therefore the primary consideration for traffic municipalities is to reduce speeding by either improving roadways infrastructure or setting on additional signage. Improving road infrastructure is more costly than establishing an additional signs. Therefore, vehicle activated signs (VASs) are recently being used in roadways to increase traffic safety and road efficiency. A VAS is a digital road sign that is mainly used for speed enforcement or to provide the road users with a warning about a hazard. Typically, VAS consists of radar that is mounted inside the sign to detect vehicle or driver speed. The sign displays a message when vehicle speed exceeds a pre-set threshold. It should be noted that VASs belong to a much bigger class of signs known as variable message signs (VMSs). Hence in the current work the terms VAS and VMS have been used interchangeably for the sake of simplicity.

A VMS is a digital board that displays one of a number of messages that may be changed as required in order to inform or warn travelers for a specific event. The message either indicates road and traffic conditions, alternates routes, construction activities or states the appropriate road speed limit. The signs are in general linked to a control center through one to one communication, a local network or radio link to provide real time information on the oncoming road. In the control center, a variety of traffic monitoring and surveillance systems shall extensively be done to provide the right information in order to be displayed to motorists. According to other researcher’s definitions, VMS was also known by various other names such as:

- Dynamic Message Sign, DMS
- Changeable Message Sign, CMS
- Electronic Message Sign
- Variable Speed Limit Sign, VSL

It should be noted that information displayed by a VAS is triggered on an individual basis and provides information targeted to a specific individual of the driver population as opposed to VMS which mainly provide information to drivers in general. Researches reporting the usage of VAS and the more general VMS have both been investigated in this review for the sake of completeness. This review examines in detail the basis for the configuration of the existing sign types in previous
studies and explores the relation between the configuration of the sign and their impact on driver behavior and sign efficiency.

Earlier studies reviewing the effect of variable message signs or vehicle activated signs had been reported by Nygårdhs and Helmers in 2007 [1]. Such studies have reviewed relevant work published between 2000 and 2005 and have mainly investigated the influence of VMS over human behavior. The authors stated that the effects of VMS signs on driver behavior showed more effect than fixed road signs due to some reasons. These reasons could be either VMS’s higher luminance and better contrast and VMS novelty or it could be derived from driver’s expectations of a more credible and relevant information posted in VMS than the static signs. Nygårdhs and Helmers illustrated that the perceived credibility of the message displayed in the sign play an essential role in effectiveness of the sign in driver behavior. Variable message sign should only show correct and immediate information that is relevant to the driver otherwise it is better to not show any message. The authors proposed as future research to investigate the effects of variable message signs that vary by showing always information compared to the sign that only show current traffic events. However, they did not clearly point the influence of adverse weather conditions on driver behavior.

In 2011, Nygårds updated the previous review by supplementing with studies during the years of 2006-2009 [2]. She mentioned only in her review that weather controlled variable speed limit can provide effect in reducing driver speed at various road conditions with no justification. Besides, she did not cover the weather effectiveness on driver behavior and how to assess it. However, she pointed that Variable Speed Limit shall only be triggered when conditions deteriorate. That means Variable speed limit sign shall work properly and reflects the actual conditions. Basically, Nygårds’ review was more directed to the recommended design of VMS and its reliability and relevance. Such work did not take into consideration the configuration of the sign and immediately relevant issues in assessing the effectiveness of the sign. However, the reliability of the displayed information is mainly related to the sign’s configuration. Due to the fact that the more the displayed information is reliable and accurate, the more drivers’ compliance increases. Therefore, once VMS or VAS is installed, the sign shall not be used as a simple communication device to display various safety messages or unnecessary warning for promoting road safety. The sign must have a solely purpose of providing essential travel advices to drivers. In order to decide whether the traffic advices shall be displayed on or not, most of VMS systems use algorithms based on some threshold
values such as traffic flow, occupancy or mean speed or combination of them. These threshold values shall be obviously dynamic and require fine-tuning because different locations in different time can yield different threshold values [3]. Finding a reasonable pre-set threshold value to trigger either VMS or VAS is challenging because an early or late activation of these signs can reduce their eligibility. Besides the reduction of sign eligibility provides to poor compliance between the driver and the established sign.

To apply right configuration on these signs is not a simple task and becomes a key target for transport agencies. The threshold should be set depending on road, traffic conditions otherwise the sign face the same problem as in the case of the static signs. Traffic agencies established VMS and VAS in several test sites to evaluate their effect on driver behavior and traffic efficiency but they did not carefully focused on the configuration of the sign in different road conditions. The main research question is how the threshold values were set on these signs and how the signs were configured? At which trigger threshold value should be activated to give positive effect on driver’s behavior? Can different threshold values give different impact under adverse conditions? This literature review aims to figure out the following statements:

- The effects of Variable message signs and vehicle activated signs on driver behavior proving the signs necessity to be related to various weather, road and traffic conditions
- The parameters used to configure the threshold values that were set on the established signs
- The parameters used to assess the effectiveness of variable message signs and vehicle activated signs

The rest of the paper is organized as follows. First give an overview about how the assessment of the effectiveness of VMS and VAS can be determined in general. Next the effects of variable message sign on driver behavior and headways are shown in section III. In section IV the effect and evaluation of variable speed limit is presented and summarized in Table 1. In section V the effect of vehicle activated sign is also discussed and summarized in Table 2. The paper finally presents conclusions and proposes possible future studies.

II. Assessment of the effectiveness of VMS and VAS

There are no universal criteria for measuring the effectiveness of variable message signs. One of the measures is the relationship of the sign to crashes. The collection of crash data correlated to
the presence of specific signage is valuable but crashes to a selected test site can be relatively rare. Sometimes may be required several years to determine whether the introduction of the sign had a beneficial effect or not [4]. Therefore the relation between vehicle speed and the frequency of injury collisions had been discussed and interested many researchers. Taylor et al. deducted that for mean speed between 25 mph to 35 mph, the reduction in collisions per 1 mph is 4% [5]. However, Nilson proposed another relation to estimate the collision reduction based on speed reduction. At 30 mph, he concluded that the reduction in speed of 1 mph lead to reduce by 6.6% in injury accidents, by 0.7% in serious injury accidents and by 12.7% in fatal accidents [6].

Another measure that had been used in the effectiveness is changes in drivers’ speed. This measure is not straightforward in the case for warning signs such as bend curves warning where the speed reduction is not required. The most often measure used in determining warning signs effectiveness is the degree of how much the drivers notice them according to their visibility and comprehensibility. This measurement can be obtained by recall or recognition question to drivers that had been passed recently the signs [4].

III. Effect of Variable Message Sign on driver behaviour and headways

A large number of studies had been established to test the effectiveness of VMSs in reducing vehicle speed and in improving safety on a work zone environment. Richard and Alex established a quasi-experiment to examine the effects of different safety messages displayed on VMS on driver’s attitudes and on-road traffic speed. The quasi-experiment was chosen on an inter-city Highway 2 between the cities of Edmonton and Calagary. Besides, a questionnaire survey was developed and managed to a sample of 97 drivers to report their responses to the messages displayed on VMS [7]. The results of the survey showed that a small proportion of the respondents reported that the messages increased their likelihood of obeying the speed limit. In addition, there was a small beneficial effect on driver’s speed. The safety messages in Richard and Alex study were not reflecting any traffic related information. Their messages were simply a reminder about traffic safety. The messages shown in VMS should only be activated when essential conditions deteriorate otherwise they led to a slightly noticeable effect on driver’s speed.

However, Jihzen et al. investigated VMS traffic guide information that was based on real-time detection of traffic flow and the actual conditions in Beijing Olympics. In their study, Jihzen et al.
introduced a logical structure of the traffic guidance VMS information system. The system was put into service and performed well during Beijing Olympic Games. The system collected the actual data from the road network, processed it and released timely traffic information to VMS display. The authors claimed to have achieved good practical effects but the assessment of the effectiveness of the system was not shown in this study. The information shown in VMS display was obtained after a complicated storage, processing and computational model. The time taken from the proposed model could lead to late release of the information where it could lead to decreases in VMS reliability.

Firman et al. determined the effectiveness of portable changeable message signs PCMS in rural highway work zones. An experiment was conducted in Seneca, Kansas in US to evaluate PCMS under two different conditions: (1) PCMS was switched on and (2) PCMS was switched off. The data was collected by two Smart Sensor HD radar sensor systems having the capability of data storage and wireless data downloading. Standard deviation, mean and standard deviation error mean were calculated and analyzed by using statistical software called the Statistical Package for Social Science (SPSS). The results for this experiment showed that when the PCMS was turned on, it reduced vehicle speeds by 4.7 mph over 500 feet distance on average. Besides, when PCMS was turned off, the average speed was reduced to 3.3 mph [8]. Firman et al. did not concern that there is a reduction in the average speed even if the sign is off. In this experiment, it was not mentioned when and how PCMS was activated. The activation of the sign could be a challenging task. Furthermore, the study did not measure what effect the speed reduction had in relation to the volume and time of day. Despite the fact that the time periods, especially peak hours or weekday, can have clearly consequences in the result.

There are a number of messages that may be posted in dynamic message signs, DMS but which type can be the most useful and effective one. Some researchers suggested that an active DMS that display warning messages could directly affect driver performance because warning messages attracted the attention of the drivers. Borello and Ornitz grouped different types of messages given on a DMS in three different classes. Based on this classification, the authors measured what effect the message of sign had on driver performance with the measure of speed. In order to test the immediate influence of the DMS on driver performance, Borello and Ortniz defined a cone of influence of the DMS. The cone of influence was defined as a distance between the minimum and
maximum line of sight for the sign to determine the best location of the speed detector for ideal readings. The cone was based on an angle of inclination of 7.5 degree in order that the driver may read the message in 918.0 ft [9]. By carefully setting the cone parameters, it could be easily excluded drivers who could not see the message in the DMS from the analysis.

Rämä and Kulmala investigated the effectiveness of variable message signs warning of slippery road conditions and a minimum headway sign on driver behavior. Driver behavior was measured in terms of speed and headways variations under weather conditions, road surface and traffic conditions. The data was collected by using loop detectors at three test sites in Finland. To examine the effects of driver adaption and any possible novelty, an after study was established within two winters. Driver behavior was monitored at three measurement points, 536-1,800 m upstream before the sign, 360-1100 m downstream after the sign and 7,670-13,000 m downstream. The operators at the Traffic Management Centre TMC classified the road surface conditions in three categories, good, possibly slippery and verified slippery. The TMC operators switched on or off the sign to flashing mode depending on the presence of slipperiness. Results showed that the VMS decreased mean speed by 1-2 km/h and increased the following distances. The positive effects were not found at all test sites. The effects were more significant before the sign than after the sign. However, at a distance 3-14 km after the signs, the mean speed increased slightly [10]. Rämä and Kulmala concluded that the variable message signs had other effects on driver behavior besides speed and headway.

Luoma, et al. designed a complementary study to investigate the other possible effect on reported driver behavior. In Luoma, et al. study, a combination of roadside and telephone interviews were done to drivers who encountered either of the signs that was used Rämä and Kulmala test sites. 2% of drivers who encountered the minimum headway sign declared that the sign had no effect on their behavior. Drivers reported other frequently effect of the slippery road conditions signs with a change in focus of attention, more concentration on their own driving, testing the road slipperiness and careful overtaking behavior. Many drivers informed that variable message signs improved their driving comfort. Luoma et al. found that the slippery road condition sign had more effects during black ice than during snowfall conditions [11]. Therefore, the authors proposed dynamic weather-controlled systems that can perform successfully in further study.
Rämä carried on another experiment on the Finish E18 test site to study the effect of weather-controlled variable speed limits and warning signs on driver behavior. The speed limits were automatically controlled by two road weather station in order to estimate the effects of road and weather conditions on speed. The road and weather conditions were classified as good, moderate or poor. These classifications were based on different parameters such as rain or snowfall, rain intensity, road surface, visibility and wind velocity. The main results from her study showed that the weather-controlled system decreased the mean speed and the standard deviation of speeds. The system had more effect on mean speed during summer season when the higher speed limits were allowed but weather conditions were not obvious, similar as winter conditions. Rämä reported that lowering the speed limit decreased the mean speed where the weather-controlled system increased the homogeneity of driver behavior [12]. The experiments done by the author were carefully established and analyzed. She mentioned that there is a need for a more advanced system to recognize adverse road and weather conditions and low frictions.

The effect of VMS signs on drivers' behavior can vary with the ages of drivers. Older driver are more risky for crashes in work zones claimed Heaslip et al. in their research study. The authors studied the effectiveness of the work zones features implemented in Greenfield, Manssachusetts by collecting speed and video data over a four-month period. Video data was used to be able to approximate the age of the drivers and their maneuvers. The results showed that VMS had a positive effect for all drivers regardless that older drivers’ speeds were obviously different than other drivers [13]. Heaslip et al. advised to develop advanced traffic analysis tools to get better understanding of driver behavior in work zone. They suggested the use of micro simulation and visualization techniques that should concern with new theory and structure by simulating expected driver behavior changes with other characteristics.

IV. Effect and Evaluation of Variable Speed Limits

Variable speed limits VSL are variable messages signs that display speed limits. The displayed speed limits are determined by VSL algorithms that are based on real time traffic data. The VSL algorithms can have different design and provide different impact depending on the type and the control objective of the VSL system. Jiang et al. designed three types of algorithms for activating VSL on. These algorithms were based on high flow, queuing and weather conditions. For high flow
conditions, the logic for determining new speed limit was retrieved from the speed-flow relationship curve, but for queuing conditions, the logic is done by reducing the upstream speed to a medium level speed level, between normal speed and the activated low speed limit. Jiang et al. did not present the algorithm that is based on weather conditions. However, the authors demonstrated the effectiveness of VSL in high flow and queuing conditions by using a micro simulation model. The results from their model showed that VSL was able to achieve speed harmonization for motorway sections with low ramp and could contribute to the reduction of secondary crashes [14].

Nissan and Koutsopoulosb focused on the evaluation of the impact of advisory variable speed limit VSL on motorway capacity. A motorway control system was implemented E4 in Stockholm. The system was equipped with an Automatic Incident Detection to detect serious disturbances in the traffic streams. When the system noticed the disturbance, it generated automatically a suitable set of advisory speed limits for the approaching traffic [15]. The new displayed speed limit was based on a comparison to two speed threshold with low and high values. The values of these two speed threshold are not clearly identified in this study while these values are the main elements in triggering the VMS sign. However, the results from this study showed that advisory VSL did not give any important effect after its implementation. Nissan and Koutsopoulosb concluded that the obtained result was related to the advisory system used in Stockholm. The system should be obvious to motorists that the recommended speed limit was based on the serious disturbance detected where the system did not seem to be focus in this point. Besides, motorists ignored the advisory speed limit if it was not motivated by the traffic situation.

A two stage variable advisory speed limit system was developed and implemented by Kwon et al. The system was established for only three week period in February to March at one of the I-494 work zones in Twin Cities. The proposed system used real-time measurements at both downstream and upstream speed levels. It tried to reduce the speed of the upstream flow to reach the same level as that of the downstream traffic. Therefore, the advisory speed limit was determined from a function based on both upstream and downstream speed levels. Kwon et al. reached a promising result in reducing the speed differences by 25% to 35% along the work zone area during the 6:00 to 8:00 a.m. periods on weekdays. The estimation of driver compliance level by correlating the speed differences in both upstream and downstream was 20% to 60% [16]. In this research, the effects of the system were only checked for a short-time period. The effects of the signs should be measured
on longer time period to study driver’s compliance. Weather conditions play an essential role in the long term effectiveness of the advisory speed limit where the authors excluded this factor from their study. Sandberg et al. investigated long term effectiveness of Dynamic Speed Monitoring Display, DSMD signs that were permanently installed in Minnesota, Washington and Dakota County. The study was conducted at speed reduction transition zones from a rural highway to urbanized area and was kept in one year duration. The overall results across all the test sites were clearly consistent in reductions in the 50th, 85th and 95th speeds averaging 6.3, 6.9 and 7.0 mph, respectively [17]. The authors mentioned that in order to draw conclusions for any long-term study the potential external influences other than the DSMS sign should be reviewed. However the mentioned review was not shown in their work. Simply they examined traffic speed and traffic volume with no check for the speed variation in relation with seasonal conditions. Sandberg et al. analysed the 24 hour average traffic speed and volume but vehicle speed could be extremely varied in rush hours than other time of the day. The variability of speeds during night time and daytime should also be analysed in their study. McMurry et al. studied the effects of Variable Speed Limit VSL signs at work zones in Utah. VSL signs were tested against the existing static sign for about 3 months. Night time standard deviation was analysed to examine the speed variation without construction interruption compared to daytime when work time was present. The results for this study showed that there were wide variations of average speed during the night time with regular static signs as compared to VSL signs [18]. Nevertheless the authors showed that night drivers and day drivers were more compliant to VSL signs than the regular static sign. However, the variability of speeds was only examined at short term but these variations might be very different at longer term. In this study, the speed limit posted in the sign at night time was 10 mph higher than daytime meanwhile 10 mph lower than the regular speed limit that usually posted on the road. The authors did not showed why the speed should be reduced by this amount and why the night posted speed in VSL could not be stepped back to the original speed limit. The effects of VSL on driver behaviour are summarized in Table 1.
Table 1. Effect of VSL on driver behaviour

<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Effect</th>
<th>Parameters used in the study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Richard and Alex</td>
<td>2010</td>
<td>Small beneficial reduction in mean speed and standard deviation</td>
<td>Traffic volume and speed for some days</td>
</tr>
<tr>
<td>Firman et al.</td>
<td>2009</td>
<td>Reduction in mean speed by 4.7mph and when VMS is turned on and in 3.3mph when VMS is off</td>
<td>Traffic volume and speed</td>
</tr>
<tr>
<td>Borello and Ornitz</td>
<td>2010</td>
<td>Type of messages have different effect on mean speed, standard deviation</td>
<td>Weekly average speed for each 20s.</td>
</tr>
<tr>
<td>Rämä and Kulmala</td>
<td>2000</td>
<td>1-2km/h reduction in mean speed and increasing the following distance in headways</td>
<td>Speed, headways, road surface conditions in three categories, good, possibly slippery and verified slippery.</td>
</tr>
<tr>
<td></td>
<td>1999</td>
<td>More effect on mean speed and standard deviation in summer season, increase the homogeneity of driver behavior</td>
<td>Speed, road and weather conditions in three categories good, moderate and poor.</td>
</tr>
<tr>
<td>Kwon et al.</td>
<td>2007</td>
<td>25% to 35% speed reduction during 6:00 to 8:00 peak periods</td>
<td>Speed, volume for every 30s.</td>
</tr>
<tr>
<td>Sandberg et al.</td>
<td>2008</td>
<td>Average speed reduction by 7 mph</td>
<td>Vehicle speed and volume</td>
</tr>
<tr>
<td>Nissan and Koutsopoulosb</td>
<td>2011</td>
<td>No significant impact</td>
<td>Vehicle speed and flow density.</td>
</tr>
<tr>
<td>McMurry et al.</td>
<td>2008</td>
<td>Variations in speed was reduced in general</td>
<td>Vehicle speed at day and night time</td>
</tr>
<tr>
<td>Jiang et al.</td>
<td>2011</td>
<td>Speed harmonization and better environmental impacts</td>
<td>High flow, queuing and weather</td>
</tr>
</tbody>
</table>

V. Effect of Vehicle Activated Sign

Automatic speed warning signs, vehicle activated speed limit sign, or Active speed warning sign were considered as Vehicle Activated Sign, VAS. In fact, VAS has a system that is activated by driver’s speed that exceeds a pre-set threshold. The sign had been developed and established in typical locations like dangerous entrances and curves, work zones and school zones. Different studies had been done in this area by presenting the effects of the use of VAS. Kathmann presented different approaches on how to assess the effectiveness of VAS. He pointed out that the approaches should be taken under two essential considerations that are important when assessing the
effectiveness of VAS. The first consideration was that the observations must be done in a way that cannot be discovering by the driver. The second one was that the measurement for collecting and analysing the data should be cost-effective. The approaches could be either an inductive loop measurement or other empirical measurements. As empirical measurements, Kathmann proposed three methods such as car following method, video camera surveillance and voice recording. Car following method is used by a test vehicle with Datron sensor to get speed profile along the way instead of local speed data.

Video camera surveillance and voice recording are used for analysing respective drivers braking behaviour and his familiarity with the road. Kathmann concluded that speed measurements should be collected before and after the installations of a VAS otherwise the assessment become difficult and time consuming. The best result reached from the methods was the car-following method [19]. Kathmann showed that speed reduction is not always based on the presence of VAS. Therefore there was a need to check the speed distribution instead of average speed. He suggested integrating data from different VAS sources. That would give better knowledge for assessing the effectiveness of VAS.

Winnett and Wheeler established a full scale study of the effectiveness of over 60 signs installations of different types of vehicle-activated signs on rural single carriageway roads. This study had been conducted by TRL for the Department of Transport. They aimed to assess the effectiveness of the signs on both driver’s speed and injury accident. Besides, they aimed to evaluate driver’s understanding of the signs [20]. Vehicle Activated signs was depended on the trigger speed or pre-set threshold that switches on the sign. The speed threshold was set at the 50th percentile speed detected before the sign was installed. That was supposed to target half of drivers. In other previous studies, the speed thresholds were set at between the 75th and 81th percentile speeds. In that case, the signs targeted a very small population. However, when the threshold were set at between the 20th to 30th percentile speeds, thus targeted more drivers. The effect of the sign is clearly related to the trigger speed value in order that activating VAS. An early or late switch on could provide a negative or positive impact on the sign. So, what is the most suitable threshold trigger speed for a specific site and how can be determined? The activation threshold speeds should be dependent on different time periods under various conditions. To find out the right trigger speed
that activates the sign, there is a need to analyse various trigger speed distribution in relation to average speed under diverse conditions.

In other study, Winnett et al. evaluated the effectiveness of an interactive fibre optic sign at a rural cross road. The main objective of this evaluation was in general to reduce speeds consistently and in particular target motorists at the top end of the speed distribution. The sign used was a warning sign with SLOW DOWN message, were switched on when driver’s speed exceeded 46 mph. In previous studies in TRL, Winnett et al. suggested that it is possible to control the traffic speed by varying the threshold. The threshold established in their study was fixed to 46 mph. That was chosen to warn driver travelling above 50 mph with 10% error margin on the detector used [21]. There was no basis why the threshold was fixed to 46 mph. VAS should only be activated when it should be activated, otherwise it could decrease its impact on the driver behaviour. In order to define the threshold of VAS, diverse potential factors should be checked.

In 2007, Mattox et al. conducted research study in South California DOT for development and evaluation of speed-activated sign by lowering speed in work zones. This study was based on a depth literature review of several speed reductions measures in work zones such as speed monitoring displays, changeable message signs with and without radar, vehicle activated signs. As a result of the assessment of these signs, it had been proven to provide remarkable effect in speed reduction, but due to their high cost, many transportation agencies did not established in all their work zones. The sign used in Mattox et al. research was vehicle activated sign, VAS which was the most cost effective sign among all other mentioned signs [22]. The predetermined speed threshold was set to the post speed limit with a 3- mph buffer. Results from this research study showed a reduction in mean speed, 85 percentile speeds and percentage of vehicles exceeding the speed limit. This study was only evaluated short term effectiveness. However VAS might lose its effectiveness over time as drivers become habituated to seeing them regularly.

The evaluation of effectiveness of the sign was established by studying before –after studies and concluded that the sign have an effect on reducing speeds, standard deviations or headways. The sign has its largest effect on drivers exceeding the speed limit excessively. All these evaluations were concerned when the sign is in operation but a few studies investigated the evaluation after removing the sign from the test site. Walter and Broughton observed the effect of speed indicator devices, SIDs after the sign is removed. SID is vehicle activated signs that display the real-time
speeds of vehicle passing the device. In the study, Walter and Broughton installed ten SID at ten sites in South London in 2008 across all weekdays with different level of traffic flow and with periods of installation that are randomly assigned to weekdays. They designed the experiment to be balanced as far as possible by reducing the possible effect of external factors on the results. Across all sites, an overall speed reduction was 1.4 mph [23]. The effect varied over time and differed across sites. SID showed a significantly effect on speeding drivers at all sites.

**Table 2. Effect of VAS on driver behavior**

<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Effect</th>
<th>Trigger speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mattox et al.</td>
<td>2007</td>
<td>Average speed reduction range 2.0-6.0 mph</td>
<td>3 mph over the posted speed limit</td>
</tr>
<tr>
<td>Winnett et al.</td>
<td>1999</td>
<td>Nearly 70% speed reductions for high end speeders.</td>
<td>46 mph for 50 posted speed limit</td>
</tr>
<tr>
<td>Winnett and Wheeler</td>
<td>2002</td>
<td>Mean speed reductions between range 1.2-13.8 mph</td>
<td>5 mph above the posted speed limit</td>
</tr>
</tbody>
</table>

However, there was no effect in speed after the sign was removed. Only a small reduction was lasting at those sites where the SID was in operation and had the most effect. Table 2 summarises the effect of VAS on driver behaviour and present the trigger speed value applied in the configuration of the sign.

**VI. Summary and Conclusions**

In previous studies, authors pointed out that the effectiveness of VMS is related to the credibility of the message displayed on the sign. The displayed message should reflect road, traffic or weather conditions and VMS should only be triggered when such conditions deteriorate. The majority of drivers travel at a speed they consider reasonable, and safe for road, weather and environmental conditions. Therefore, unnecessary activation of the sign can provide negative effect of the sign on driver’s behaviour. Additionally, the information shown in VMS were obtained after a long process in order to gather the traffic data, process it and compute an advisory message or a new speed limit. The time taken from this process could lead to late release of the information where it could lead to decreases in VMS reliability.
Weather conditions play an essential role in the effectiveness of VMS where most of the researchers excluded this factor from their study. There is a need for a more advanced system to recognize adverse road and weather conditions and low frictions. Therefore, dynamic weather-controlled systems that can perform successfully in further study were proposed by some authors.

To assess the effectiveness of VMS or VAS, vehicle speed and traffic flow are the most used data in the previous studies. These data were basically analysed by averaging the speed or checking the standard deviation in relation to a specific time per days or days of week. However, a reduction on the average speed is not always based on the presence of the sign. The sign should be placed at a site where it is not influenced by other factors such as junctions, roundabout or any traffic calming. That can lead to a misinterpretation of the results. The evaluation of the effectiveness of the VMS or VAS systems were conducted by using either empirical data from sensors such as loop detectors, camera or radar or by using micro simulation techniques. The empirical analyses were based on before–and–after VMS implementation on a specific test site. The results from this analysis were shown that VMS and VAS had an impact on driver behaviour in order on the effectiveness of both signs.

The relation between the design of VMS algorithm and the appropriate conditions are not clear in previous research studies [14]. Besides, for VAS, the trigger speed value was set with no basis. Authors did not consider the importance of the value of trigger speed on the impact of the sign on driver behaviour. The threshold value was set either 3 mph or 5 mph above the posted limit or 4 mph under the posted speed limit. Which consequence could lead if the sign was trigger by all vehicle speed or vehicle speed that is above the posted speed limit or under the posted speed limit? All the experiments were established by providing a constant threshold value under different conditions with no consideration for a dynamic threshold value.

**VII. Future work**

Developing dynamic activation threshold value has not been thoroughly investigated in previous studies. The idea is to establish a model that attempt to predict the appropriate activation threshold value to the corresponding traffic and weather situations. Therefore, a systematic data collection will be focused in first place where traffic data will be collected but by varying the value of threshold activation value. The data is archived by various threshold values. Four databases shall be
available for each threshold value: the database for daytime traffic; the database for night time traffic; the database for weekday’s traffic and the database for weekends. Meanwhile, the traffic data shall further be integrated with weather data sources. Besides, data is analysed partly with the help of descriptive methods which may describe, organize and present the raw data and partly with the help of association rules which find common relationships between attributes that may be difficult to discover. Another aspect is to extract the speed distribution pattern of the road speed traffic data finding the similarities between vehicle speed and time. The similarities between different attributes can be obtained by using k-means clustering algorithms.

References


Data based Calibration System for Radar used by Vehicle Activated Signs

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Abstract
The accurate measurement of a vehicle’s velocity is an essential feature in adaptive vehicle activated sign systems. Since the velocities of the vehicles are acquired from a continuous wave Doppler radar, the data collection becomes challenging. Data accuracy is sensitive to the calibration of the radar on the road. However, clear methodologies for in-field calibration have not been carefully established. The signs are often installed by subjective judgment which results in measurement errors. This paper develops a calibration method based on mining the data collected and matching individual vehicles travelling between two radars. The data was cleaned and prepared in two ways: cleaning and reconstructing. The results showed that the proposed correction factor derived from the cleaned data corresponded well with the experimental factor done on site. In addition, this proposed factor showed a more superior performance than the one derived from the reconstructed data.

Keywords: vehicle activated signs, Doppler radar, vehicle velocity, experiment, calibration

1. Introduction
A range of road traffic safety solutions have been recently developed and used by public traffic agencies to ensure safety and traffic efficiency. One such traffic safety solution being investigated by traffic authorities is Vehicle Activated Sign (VAS). VAS is a digital road sign that displays a
message when a vehicle’s speed exceeds a pre-set trigger speed. At present, most existing VAS systems are static in nature. These systems have a pre-set trigger speed which is set relative to the static speed limit applied on a specific road. In certain cases, simply setting the trigger speed relative to the speed limit may not be optimal for the existing traffic conditions, thus limiting the efficiency of the VAS [1, 2]. Hence it is necessary to develop an adaptive Vehicle Activated Sign system (adaptive VAS) which will respond to traffic and road conditions. The adaptive VAS system consists of two fundamental stages: The first one is to collect accurate and significant data; whereas, the second is to automatically find the suitable trigger speed based on that data. Since the performance of the sign is sensitive to the trigger speed the ability to accurately calibrate the sign is an important factor for VAS systems. The aforementioned data could be detected by many kinds of devices, such as loop detectors, cameras, radar guns and Doppler radars. This study is concerned with the data that is mainly collected by a continuous wave Doppler radar.

The problem of data collection might seem simple and easy to achieve. In reality the problem is complex for several reasons. Firstly, since the velocities of the vehicles are acquired from a continuous wave Doppler radar, the vehicle is not travelling toward the radar but is slightly inclined at an angle $\alpha$ (see Figure 1) [3].

![Figure 1. Relation between actual velocity $v_a$ and measured velocity $v_m$][3]

Therefore, the radar will not measure the actual velocity, but only the relative velocity in the direction of the beam. The cosine of this angle between the radar unit and its target determines the magnitude of the error. This error is known as the cosine error and it becomes significant when the angle to the roadway is large. The greater is the angle between the radar and the roadway; the lower is the indicated velocity [4]. The relationship between the measured velocity $v_m$ and the actual velocity $v_a$ is usually expressed by the following Equation (1) [5]:

$$v_a = v_m * \frac{1}{\cos \alpha}$$

(1)

Where:

$v_m$ is the velocity of the vehicle detected by the radar  
$v_a$ is the actual velocity of the vehicle  
$\alpha$ is the angle between the radar and the traveling direction of the vehicle
Secondly, a successful measurement requires a direct view of the radar towards the vehicles. If the radar is installed in a sidefire position, the radar must be located parallel to the roadway and face the coming traffic at an angle $\alpha$. The distance to the oncoming lane should be between 0.5 and 3 metres. The radar is usually mounted in a sidefire overhead position where the installation of the radar becomes more challenging. For this mounting, the radar must be set at a fixed height, so that its lower edge is 2.25 to 3.25 metres above the traffic lane’s ground. The radar must also be tilted to a 20° angle; otherwise the vehicles will not drive through the radar beam (see Figure 2). This installation is expected to be carefully set because precise alignment of the radar is the decisive factor in obtaining an exact velocity measurement and vehicle classification.

![Figure 2. Doppler radar mounted on a sidefire overhead position and tiled to 20 degrees.](image)

Setting the oncoming lane to a fixed height and distance can be done free from error, but eliminating errors due to the tilt of the angle of the vehicle is hard to achieve at the point of installation; measuring the angles accurately is problematic and requires careful measurement of road gradients and other factors. Thus, calibration has been set by subjective judgment rather than systematic judgment. In other words, the radar is typically placed at the site without a proper method and is simply set up “by eye”. A question raised in this paper is how calibration can be established with minimum equipment requirements in the field? Can a speed correction factor be derived from the available measurements collected by the radar? How can validation be completed through finding data driven by the correction factor? This paper proposes a systematic way to design an experiment for calibrating the radar with minimum requirements to be established in the field. The objective of this study is to perform a data driven calibration algorithm, which takes the data collected from two radars and derives the speed correction factor. The rationale behind using two radars is that no specialist or different equipment (or additional field personnel) are needed; once calibration has been done, the second radar can be redeployed to a new site.

The rest of the paper is organized as follows: At first, an overview about the calibration for a Doppler radar done in previous work is given in Section 2. In Section 3, data collection and experiment design is presented. Section 4 describes the calibration algorithm performed in this paper.
An experiment is presented in Section 5. The results are explained in Section 6. The paper finally presents conclusions and proposes possible future studies in Section 7.

2. Related work

There are several methods that have been used in radar calibration. A common method is a tuning fork that is tuned to vibrate at a certain frequency and placed in front of the radar. This method has been previously tested and proved as a stable and suitable standard for calibrating Doppler police radar guns [6]. Another study examined the uncertainties of different methods in calibration of speed enforcement down to road radar. The proposed methods were tuning forks, a vehicle’s speedometer, speed simulators, and a fifth wheel [3]. The most uncertain method regarding vehicle speed was a vehicle’s speedometer and the least uncertain was the laboratory speed simulator. Uncertainty in the tuning fork method was approximately the same as the laboratory speed simulator. Another study developed a radar calibration system of Doppler/range radars with high precision. The developed system provides information regarding several parameters, such as the Doppler frequency shift, the frequency measured with a universal time interval counter, the emulated speed, and the weather conditions [7, 8]. Due to the measurement error of frequency that directly affects the measured velocity, a new radar based velocity measuring system, based on a processor, was incorporated instead of calibrating the radar used in the their study. This system uses the Doppler principle based on underlying hardware design [9]. Furthermore, another study proposed a new vehicle speed and traffic flow measurement radar to get higher resolutions in speed and traffic flow management. This study is based on eliminating the interference of other vehicles on the road when detecting a certain vehicle [10]. A data fusion of Doppler radar with video camera had been proposed for a traffic surveillance system which was capable of automatically monitoring all vehicle speeds [11]. As seen, most of the previous work considered a calibration method based on either comparing radar frequency or developing new calibration systems. Most of the previous work did not consider a data driven calibration. Data driven calibration methods were used in various traffic models such as speed-density model [12] and time gap model [13] where the parameters of the models were mainly calibrated.

3. Data collection system and Experimental Design

A test site on Mjälga roadway in Borlänge, Sweden was selected for the experiment. The test site is located near Mjälga School, between Gyllehems roadway and Joel Alvén’s Street. No external factors, such as the presence of bends, junctions or roundabouts are present to affect the consistency of the data collection. The meaning of data consistency is that each vehicle which travels along the test site
should be present in the data set. Since the aim of this study was to calibrate the radar used in the adaptive VAS system, two main components form the data collection system: VAS and three Siersega radars. The VAS used in the current study displays two warning messages in succession. The first is a reminder of the posted speed limit, which is 40km/hr, which is followed by a “SÄNK FARTEN” (reduce speed) message. Typically the messages are displayed only when the vehicle speed exceeds a pre-set threshold speed, i.e. the trigger speed.

The Siersega device is an advanced traffic counter. It consists of a Doppler radar sensor integrated by a Flash RAM data memory, a real time clock, a serial data interface and a battery pack. Individual vehicle data was collected by the Siersega placed across the roads 100 m before the VAS (Position A), at the site of the VAS (Position B) and 60 m after the VAS (Position C) (see Figure 3). The device at Position A is labelled as $S_A$ and the devices at Positions B and C are labelled as $S_B$ and $S_C$ respectively. On each occasion that the Siersega recorded a time, the velocity, the direction of travel and the vehicle type for each individual vehicle for 24 hours a day for a whole week.

4. Calibration system

This section proposes a system for the calibration of the radar placed at the site of VAS using a matching between this radar with another installed at a certain distance. The main idea behind the usage of the second radar is to be able to calculate the velocity of each vehicle derived from the distance between the two radars and the travel time taken. The proposed system is mainly based on mining the data collected and finding the distance correction factor. The distance correction factor is the ratio between the actual distance and the distance derived from the two radars. Figure 4 is an overview of the proposed calibration system. Detection of the presence of missing values, outliers and the presence of a delay between the radars’ clocks are first explored. The data is cleaned and prepared in two different ways, either by removing missing values (data cleaning), or by filling the missing values with an estimated time and velocity (data reconstructing). For the two data sets, each individual vehicle is matched to calculate the correction factor that will be based on the distance travelled between the radars.
4.1 Data exploration

In ideal conditions, the radars should detect each vehicle and each vehicle should be visible to all of the three radars established on the road. The radars should be time synchronized where the individual travel time is the time difference between the synchronous radars. However, there can be a delay between the radars’ clocks due to an incorrect setup of the clocks. Despite the radars being synchronized initially, the clocks may be delayed due to disturbances in the radar detection of the vehicle. The most challenging disturbance is the arrival of vehicles from different directions at the same time and at the same position. This means that the radar may be occupied by another vehicle passing from the other direction. Another disturbance is the detection of the same vehicle more than once. These disturbances contribute to the presence of missing records in the data collected by the radar. Figure 5(a) presents a sketch showing vehicles and their corresponding times at different locations. Suppose Vehicle V is passing by Radars, $S_A$, $S_B$ and $S_C$ at time $t_A$, $t_B$ and $t_C$ and Vehicle V’ is passing by Radars, $S_A$, $S_B$ and $S_C$ at time $t'_A$, $t'_B$ and $t'_C$. Vehicle V’ is approaching from the opposite direction of Vehicle V. The travel time for V, i.e. time spent, between $S_A$ and $S_B$, is $t_{AB}$ and the travel time for V between $S_C$ and $S_B$, is $t_{CB}$. The same for Vehicle V’, the travel time for V’ between $S_A$ and $S_B$, is $t'_{AB}$ and the travel time for V’ between $S_C$ and $S_B$, is $t'_{CB}$. $t_B$ is the sum of $t_A$ and $t_{AB}$ and $t'_B$ is the sum of $t'_A$ and $t'_{AB}$. In Figure 5(b), when V and V’ arrive at Radar $S_B$ at the same time, $t_B = t'_B$, the radar detects either V or V’. Several cases of missing vehicles can be listed, but only two cases are presented here; missing vehicles by Radar $S_B$ (Case 1 and 2) (see Equation (2) and (3)).
Case 1: Vehicle V detected by Radar $S_A$ at time $t_A$ but missed by Radar $S_B$

$$t_B = t_A + t_{AB}$$

(2)

Case 2: Vehicle $V'$ detected by Radar $S_C$ at time $t'_C$ but missed by Radar $S_B$

$$t'_B = t'_C + t'_{CB}$$

(3)

Figure 5. Sketch of the detection problem (a) Vehicle V and V' arrive at time $t_A$ at Radar $S_A$ respectively at time $t'_C$ at Radar $S_C$; (b) Vehicle V and V' arrive at Radar $S_B$ at the same time $t_B = t'_B$

4.2 Data preprocessing

Real traffic data is generally:

- Incomplete data by the presence of missing individual vehicles
- Noisy data by the presence of outliers.

To eliminate the noisy data and repair the missing data, some initial tasks have to be made in the data preprocessing step [7]. One of these tasks is data cleaning. This process consists of two steps: detection and correction.

4.2.1 Detection Step

In this step, three types of detections are of concern:

A. Detection of time delay
B. Detection of outliers
C. Detection of missing values

A. Detection of time delay

The detection of a time delay is first extracted from the data set by using a numerical algorithm. The fixed point iteration method is one of these algorithms that can be used in order to obtain an estimate as to the time delay between radars. The algorithm converges at a fixed point under some conditions given by the theorem described by previous mathematical study [14]. Based on the aforementioned study, the proposed algorithm starts at any point and recursively approaches to an approximate solution. In this paper, an optimal time delay $\delta$ is applied by the following algorithm [15, 16]:

\[ \delta = \frac{1}{2} \left( t_B - t_A \right) \]
1. Start by an initial value to time delay $\delta$:
2. $\delta_k = (t_2 - t_1) \frac{v_1}{(v_1 + v_2)} - (t_3 - t_4) \frac{v_2}{(v_1 + v_2)}$
3. Choose threshold $\tau = 0.01$
4. Calculate the estimated distance, $x_2 = |((t_2 - t_1) - \delta_k)v_1|$
5. Derive expected error $\omega = \frac{|x_1 - x_2|}{\frac{1}{2} \frac{v_1}{v_2}}$
6. Calculate a new time delay $\delta_k+1 = |\delta_k - \frac{1}{2} \omega|$
7. If $|\delta_k+1 - \delta_k| \geq \tau$, then go back to step 3
8. If $|\delta_k+1 - \delta_k| < \tau$, end

Where $x_1$ is the real distance between $S_A$ and $S_B$
$v_1$ is the mean velocity for the first vehicle travelling between $S_A$ and $S_B$
$v_2$ is the mean velocity for the second vehicle travelling between $S_A$ and $S_B$
t_1, t_2 is the time recorded for the first vehicle by radars $S_A$ respective $S_B$
t_3, t_4 is the time recorded for the second vehicle by radars $S_A$ respective $S_B$

B. Detection of outliers

Next, the detection of outliers is mainly relies on an understanding of statistical data. Most of the outliers are usually detected by using either basic descriptive statistics, such as mean, median and standard deviation, or by visualizing the data using appropriate plots, such as scatter plots or boxplots. Both show the mean prevalence of the value in the data. It should be noted that any record that significantly differs from the mean is considered as an outlier. In this paper, outliers are records of vehicles traveling with much higher or lower velocity than the mean velocity of the data. For example, the common velocity of a motorcycle or truck differs from the common velocity of a car. Therefore, grouping data in smaller groups based on the type of vehicle helps in detecting outliers.

For Siersega $S_A$ $S_B$ and $S_C$, the types of vehicles are classified into four classes. The classification is dependent on the length of vehicles detected by the radar. They are as follows:

- Class1: Motorcycle (length<2m)
- Class2: Cars (length>=2 & length<6m)
- Class3: Trucks (length>=6 & length<9.5m)
- Class4: Long trucks (length>=9.5 & length<25.5m)
Based on this classification, the boxplot in the figure below shows how the outliers are detected. The main idea is to obtain only vehicles with minimum standard deviation from the overall mean velocity. Larger variations in vehicle velocity provide inconsistency in the correction factor that will be derived later in this study.

![Boxplot](image)

**Figure 6.** Vehicle velocities respective to Class 1 (motorcycle), Class 2 (cars), Class 3 (trucks) and Class 4 (trucks with trailers); (a) at radar $S_A$, (b) at radar $S_B$ and (c) at radar $S_C$

The first plots in Figure 6(a) are the velocities of vehicles respective to the four classes at Radar $S_A$ (100m before the sign). The second plot in Figure 6 (b) presents the velocities of vehicles respective to the four classes at Radar $S_B$ (at the sign located) and the last plot in Figure 6 (c) shows the velocities of vehicles passing Radar $S_C$ (60m after the sign). All the plots are clearly presenting that the presence of outliers mostly exist in Class 2. The outliers at Radar $S_B$ can therefore be considered as vehicles travelling under 30 km/h and vehicles travelling over 60 km/h. Next, it is seen in the histogram presented in Figure 7 that most of the vehicles passing Radar $S_B$ are travelling between 30 km/h and 60 km/h.

![Histogram](image)

**Figure 7.** Histogram for vehicle velocities; (a) at radar $S_A$, (b) at radar $S_B$ and (c) at radar $S_C
C. Detection of missing values

After the detection of the location of missing values and outliers in the data set, the data is corrected in two ways:

- Cleaning data: The data is cleaned by removing records that are detected as outliers and missing values. After this stage, the data contains only the records that are matched with the lowest vehicle variation.

- Constructing data: The data is completely constructed by filling in missing records and keeping all outliers. The main idea of the data construction is to build a complete data set without missing any individual vehicle. The best estimate of the missing value is derived from the time and velocity of the vehicle passing from the opposite direction.

4.3 Matching and correction factor

The basic idea is to find the velocity obtained by the radar by calculating the expected distance travelled by the vehicles. For instance, time records from Radar $S_A$ are matched to time records from Radar $S_B$. The travelled distances are extracted from the matched velocities and time recorded by both radars. The Speed Correction Factor; CF, is based on the estimated distance for each vehicle. CF is entitled by Equation (4) and (5). Additionally, the estimated distances are compared to the actual distance between the two radars. The time delay is included in order to find the travel time.

\[
x_m = v_i (|t_{Bi} - t_{Ai}| - \delta_{opt})
\]

\[
CF = \frac{1}{n} \sum_{i=1}^{n} \left( \frac{x_a}{x_m} \right)
\]

Where:

- $x_m$ is the estimated distance for each vehicle
- $x_a$ is the actual distance
- $v_i$ is the average speed for Vehicle $i$
- $t_{Bi}$ is the measured time for Vehicle $i$ recorded by Radar $S_B$
- $t_{Ai}$ is the measured time for Vehicle $i$ respective $i+1$ recorded by Radar $S_A$
- $CF$ is the correction factor based on estimated distance $x_m$
- $\delta_{opt}$ is the optimal estimated time delay derived between Radar A and Radar B
- $n$ is the number of vehicles
5. Analysis

The calibration system presented in previous section (see Section 4) is tested on two data sets:

- Data Set 1: Data Set 1 was collected by Radar $S_A$ and Radar $S_B$ where the distance between the radars is 100m
- Data Set 2: Data Set 2 was collected by Radar $S_B$ and Radar $S_C$ where the distance between the radars is 60m

As explained earlier (see Section 4.2.1), the optimal time delay between the deployed radars should be first noticed. Figure 8 shows the optimal time delay obtained from the numerical algorithm proposed in earlier section. Note that the optimal value is reached when the time delay is approaching the maximum value that the algorithm can provide.

**Figure 8.** (a) The optimal time delay between Radar $S_A$ and Radar $S_B$ respective to the number of iterations, (b) The optimal time delay between Radar $S_B$ and Radar $S_C$ respective to the number of iterations

![Figure 8](image)

**Figure 9.** Matching velocities for vehicles travelling between Radar $S_A$ and Radar $S_B$ (Data Set 1); (a) cleaned data (b)-complete data

![Figure 9](image)
6. Results and Discussion

Developing a calibration system that accurately detects and corrects vehicle velocities is the primary goal of this paper. To render the accuracy of this system, an experimental correction factor was employed and used to validate the newly developed system. The experimental correction factor which is considered as a reference correction is equal to 1.18. The experimental correction factor is based on the ratio between the actual velocity and the velocity detected from the radar. The actual velocity was derived by travelling a certain distance with a constant velocity. The constant velocity was obtained by driving the vehicle in cruise control mode. The actual velocity is the ratio between the travelled distance and the travelled time. The travelled distance was the distance between the radars. This distance was measured by a simple tape measure. The time spent in travelling the distance was recorded by a simple stopwatch/timer.

The results of the experimental correction factor and the proposed correction factors are depicted in Table 1. The proposed correction factor is performed on both data sets prepared on either cleaning the data or constructing the data. Note that in the table below, the distance between $S_A$ and $S_B$ is named as AB and the distance between $S_B$ and $S_C$ is named as BC.

From the experiment carried out in this paper, it is concluded that the correction factor obtained by removing missing values (data cleaning) was much closer to the reference correction factor than the correction factor obtained by filling the missing values with estimated time and velocity (data reconstructing). The correction factor for a shorter distance (Data Set 2) was even closer to the reference correction factor than for a greater distance (Data Set 1). In fact, the correction factor derived from a cleaned Data Set 2 is the closest to the reference correction factor and has the lowest normalised root mean square error (NRMSE) [17]. Normalised root mean square error is the square
root of the mean square error obtained from each correction factor. The latter means that a low NRMSE means a low error rate.

Table 1. Comparison between different correction factors obtained

<table>
<thead>
<tr>
<th></th>
<th>Data Set 1 (AB=100m)</th>
<th></th>
<th>Data Set 2 (BC=60m)</th>
<th></th>
</tr>
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<td></td>
<td>cleaned</td>
<td>complete</td>
<td>cleaned</td>
<td>complete</td>
</tr>
<tr>
<td>Correction Factor</td>
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<td>1.78</td>
<td>1.20</td>
<td>3.42</td>
</tr>
<tr>
<td>NRMSE</td>
<td>0.26</td>
<td>0.48</td>
<td>0.19</td>
<td>0.70</td>
</tr>
</tbody>
</table>

7. Conclusion and future work

In this paper, a data based calibration system was applied to accurately correct vehicle velocity collected by a Doppler radar and used on the adaptive VAS system. A data driven system entails the ability in preprocessing the gathered data and in matching individual vehicles to find out the correction factor for vehicle velocities detected by a radar. In fact, the correction factor is the ratio for the actual vehicle velocities to the measured velocities by the radar. In this study, the proposed correction factor, extracted directly from data collected by two Doppler radars placed at a pre-set distance apart, corresponds well to the true correction factor derived from the experimental calibration at the site. The proposed correction factor obtained from the cleaned data also showed more superior performance than the reconstructed data, indicating that filling the missing values with an estimated time and velocity provided an inaccurate data set. An estimation of time and velocity for missing values could be improved with an intelligent prediction algorithm to get further accuracy of the reconstructed data. However, the study reveals the correction factor for vehicle velocity which allows avoiding dealing with the mounting problem of the Doppler radar. The validation performed is rather a comparison with the experiment on site. Another type of validation needs to be established and explored to ensure the accuracy of the calibration system. Testing the system at other test sites also needs to be done in further studies.

In the near future, an adaptive fuzzy inference system can be developed to calibrate radar installation. The input to such a system can be the distance of the road, the mounting height and the tilted angle and the output is the correction factor. Also, a real time video surveillance algorithm can facilitate the detection of vehicles, the classification of vehicle types, the accurate counting of vehicles and the time difference between records. Using the real time surveillance algorithm, individual vehicles can be definitely tracked where many types of radar can be calibrated simultaneously. Monitoring and voice recording systems can be another way to calibrate the radar by
analyzing the voice signals detected from the traffic. A mobile application can be a good tool to calibrate the radar on site. A mobile phone application can make it easier to track the time and velocity at a certain location using the phone’s GPS. Finally, a VAS can be developed in a way that is automatically adapted to the location by using artificial intelligence techniques.

Acknowledgements

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References


Effectiveness of Trigger Speed of Vehicle Activated Signs on Mean and Standard Deviation of Speed

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Abstract

Excessive or inappropriate speeds are a key factor in traffic fatalities and crashes. Vehicle activated signs (VASs) are therefore being extensively used to reduce speeding in order to increase traffic safety. A VAS is triggered by an individual vehicle when the driver exceeds a speed threshold, otherwise known as trigger speed. The trigger speed is usually set to a constant, normally proportional to the speed limit on the particular segment of road. Decisions concerning the trigger speed largely depend on the local traffic authorities. The primary objective of this paper is to help authorities determine the trigger speed that gives an optimal effect on the mean and standard deviation of speed. The data were systematically collected using radar technology whilst varying the trigger speed. The results show that when the applied trigger speed was set near the speed limit, the standard deviation was high. However, the standard deviation decreased substantially when the threshold was set to the 85th percentile. This decrease occurred without a significant increase in the mean speed. It is concluded that the optimal threshold speed should approximate the 85th percentile, although VASs should ideally be individually calibrated to the traffic conditions at each site.

Keywords: vehicle activated signs, trigger speed, mean speed and standard deviation

1. Introduction

Speeding and speed variation have a direct impact on traffic safety in terms of the number and severity of traffic accidents (Piao et al. 2004). The relationship between speed and accidents has been extensively explored in transport studies, some of which focus on the relationship between vehicle mean speed and severity, while others have concentrated on speed variation and its
relationship to accident rates (Taylor et al. 2000; Aarts and Schagen 2006). Studies have also revealed a positive relationship between speed and accident rate (Quddus 2013), because a driver travelling at a higher speed has less time to react to hazards. In addition, the braking distance is substantially increased (Elvik et al. 2004). It has also been observed that mean speed is not always directly correlated with accident rate, whereas there is a positive relationship between speed variation and accident rate (Quddus 2013, McMurtry et al. 2009). Results from the aforementioned studies have attributed accident rates to vehicle mean speed and/or to the standard deviation of speed. Whilst all the work cited above is interesting, it is worth pointing out that accident rates largely depend on a combined effect of mean speed, the standard deviation of speed and other factors, such as flow and geometric characteristics (Garber and Earhart 2000).

The primary considerations for traffic safety are to reduce speeding, i.e. prevent vehicles’ speed from exceeding the speed limit, and also to reduce speed variation between vehicles. A range of road safety signs has therefore been developed and deployed to encourage drivers to adapt to the speed limit or to warn when approaching a hazard. Vehicle activated signs (VASs) are one of these signs that are widely used on roadways. Typically, a VAS consists of radar mounted inside the sign to detect vehicles and measure their speed. The sign displays a message when vehicle speed exceeds a pre-set threshold, which is usually set to a constant value that is often equal, or relative, to the speed limit on a particular road segment. Earlier studies show that these signs have a significant impact on driver behaviour by reducing drivers’ speed and improving traffic safety through reducing the accident rate, as well as the severity of accidents that do occur. Additionally, this leads to improved traffic efficiency, in reducing travel time and improving traffic conditions on the road, when it prevents congestion (Nygårdhs 2011). Although the results of the studies have indicated a reduction in mean speeds, speed standard deviation and headways, they do not provide a clear statement of the relationship between the trigger value and its consequences under different road and traffic conditions (Jomaa et al. 2013). Further, it has been observed that most authors did not consider the importance of trigger speed when determining the impact of the signs on driver behaviour. Some studies have been carried out without properly reporting the value of the trigger speed programmed into the signs; others set the sign to a certain static configuration within applicable conditions without providing a justification. The thresholds established in the latter were either set at 50\textsuperscript{th}, 75\textsuperscript{th} and 81\textsuperscript{th} percentile of the speeds measured before the sign was installed (Winnett and Wheeler 2002). In these cases the threshold was fixed to the posted speed limit with 10\% margin of error (Winnett et al. 1999), or fixed to the speed limit with a 3 mph buffer (Mattox et al. 2007). At this point it is worth mentioning that 50\textsuperscript{th} percentile speed is the speed at which 50\% of vehicles go at or below a certain speed limit.
The primary objective of this paper is therefore to study the effect of the trigger speed of a VAS on driver speed and standard deviation. This will be achieved by testing two hypotheses. The first hypothesis is that a change in trigger speed has an effect on vehicle mean speed. The second hypothesis is that a change in trigger speed has an effect on the standard deviation of vehicle mean speed. An additional objective is to search for the optimal trigger speed which yields the best compromise between reducing both the rate and severity of traffic accidents. The latter objective can be achieved by finding the trigger speed that provides both a reduction in mean speed and a reduction in the standard deviation of speed.

The rest of the paper is organised as follows. Section 2 describes how the experiment was designed and established to collect the data. Statistical analysis is presented in sections 3. The results are reported in section 4. Section 5 provides conclusions and suggestions for future research.

2. Data

2.1 Site Selection
Prior to setting up the experiment, the researchers carefully considered both the signage to be utilised and where that signage should be located; carelessness with regard to either of these two factors could lead to collecting data that is inconsistent or biased. The relevant literature within the field indicates that at least one of two factors, namely the notoriety of a given road segment for speeding or a high accident rate (where inappropriate speeds were the initial problem), ought to be considered when selecting a site in relevant experiments (Winnett and Wheeler 2002). Other criteria deemed relevant are listed as follows (Walter and Knowles 2008):

- The selected site should have existing static speed limit signs that are clearly visible
- The site should be located where there is a change from a high to a low speed limit
- The site should not be in close proximity to any traffic calming, sharp bends, roundabouts or pedestrian crossings
- The site should not be near intersections
- The site should have sufficient space to monitor driver behaviour before and after activating the VAS (approximately 100 m before the sign location, to give the driver sufficient time to react to the message, and approximately 100 m after the sign location to keep monitoring the driver)
- The site should be in close proximity to an external power source that can provide power to the sign. The presence of a lamp column would be a good option. Battery-powered signs are unreliable, particularly when VASs are used to study the effect of speed reduction
in relation to time of day and days of the week.

Based on the above, two test sites were selected in Borlänge, Sweden. The first is referred to as the Korsgård test site, which is located between the Tuna and Hugo Hedström roadways. The second is referred to as the Mjälga test site. A Google map screen shot marking both sites is provided for the sake of clarity (see Figure 1). Note that traffic flows in both directions and the posted speed limit is 40 km/hr at the test sites. Furthermore, both locations are notorious for speeding.

![Google Map of test sites](image.jpg)

*Fig1. Test sites chosen in the current study (Google Maps, 2014)*

2.2 Sign Selection

The sign used in the current study is a typical VAS powered with solar energy. The sign displays two warning messages in succession. The first is a reminder of the posted speed limit, which is 40 km/hr, followed by a “SÄNK FARTEN” (reduce speed) message. Typically the messages are displayed only when the vehicle speed exceeds a pre-set threshold, i.e. trigger speed (see Figure 2). Figure 2 shows when the VAS is turned off (a) and when the sign is active (b). The sign is equipped with radar and a data logger to detect and record vehicle speed. The sign is also equipped with a general packet radio service (GPRS) modem to facilitate communication to the radar and for authorised users to download and upload data. Note that it is possible to alter the radar settings remotely. Such a setup facilitates alteration of trigger speed, thereby permitting the study to investigate the effect of different trigger speeds on various driving speeds. Upon request the data stored in the collection module is uploaded to a web server for the user to download. As mentioned earlier, the VAS was powered by batteries recharged by solar panels. These panels
were not in use in this study due to their limited power capacity; they did not provide enough power to keep both the sign and the modem in operation. Furthermore, the site should be at least 200 m in length, as far away as possible from any traffic calming and not between the radar beacons that collect the data. The most challenging of these specifications was the power supply requirement, since this restricted the position and direction of the sign. At the Mjälga site, the VAS was set facing vehicles that were travelling in a north-westerly direction, whereas it was actually the south-westerly travelling traffic that was more often speeding.

![Figure 2](image.jpg)

*Fig2. Vehicle activated sign (VAS); (a) VAS is turned off, (b) VAS is active by displaying reminder messages about speed limit 40km/hr and “Sänk Farten”*

### 2.3 Experiment Design

A consistent and unbiased data collection is dependent not only on site and sign selection but also on gathering data without influence from other secondary factors that lead to a misinterpretation of the results. To study the effect of the VAS trigger speed on driver behaviour, the experiment design aimed to compare vehicle speed based on the different levels of that primary factor. However, this comparison is not straightforward, since driver behaviour can be influenced by other factors such as traffic intensity and road conditions. To eliminate the effect of such factors and to ensure the accuracy of the data, a complete randomised design (CRD) has been employed in this experiment. A CRD is a simple design that studies the effect of only one primary factor without taking into account any secondary factors, whilst test subjects are assigned at random to treatment levels of the primary factor (Yau 2013). At this point it is worth defining the experimental unit for the sake of uniformity. In the current study, each hour has been considered one experimental unit and trigger speed has been considered the primary factor to be assigned completely at random. To be able to further comply with the CRD type of design, randomisation and replication are mainly considered in the data acquisition phase (Gerald et al. 2012). As
mentioned above, the trigger speed is chosen randomly for each experimental unit and distinct experimental units are repeated with the same trigger speed. Due to a difficulty in changing the trigger speed every hour, a random trigger speed was assigned to a particular week. Then from each week, one working day was randomly selected for further investigation.

2.4 Trigger Speed Selection

Trigger speed thresholds such as 15th, 50th and 85th percentile speeds have been mainly used. Bear in mind that these percentiles reflect vehicles’ speed travelling at the specific test sites (as measured before the experiment began). For instance, the 85th percentile at the Mjälga test site is equal to the speed limit plus 25% of that limit, whereas the 85th percentile at the Korsgård test site is equal to the speed limit plus 30% of the limit. The chosen trigger speeds were extracted from vehicle speed data collected on a Monday before the VAS was deployed. Other trigger speeds, such as the speed limit plus 10%, were also tested – a trigger speed of the speed limit plus 10% being normal practice in Sweden. In contrast, the dominant practice in Britain is to use the 85th percentile as the trigger speed.

<table>
<thead>
<tr>
<th>Trigger speed basis</th>
<th>Trigger speed (km/hr)</th>
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<tr>
<td>Turn on to all traffic</td>
<td>0</td>
<td>Turn off to all traffic</td>
<td>150</td>
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<tr>
<td>Speed limit restriction</td>
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<tr>
<td>Extra trigger speed without basis</td>
<td>47</td>
<td>Extra trigger speed without basis</td>
<td>52</td>
</tr>
</tbody>
</table>

For control purposes, the experiment has included modes of operation where the VAS was triggered for all vehicles passing the sign (i.e. 0 km/hr as the trigger speed) and also turned off completely for all vehicles (by setting the trigger speed at 150 km/hr on a 40 km/hr road segment). Table 1 below summarises the trigger speed value in respect to its basis. Trigger speeds of 47 km/hr and 52 km/hr were tested in Mjälga without any particular basis, but simply in order to collect further data points for comparison.
2.5 Data Collection

As mentioned in the previous section, the VAS was equipped with radar and a data logger to record the speed of passing vehicles (see Section 2). To assess the effectiveness of trigger speed on driver behaviour, speed data were collected for each vehicle at three points on the road where the VAS was located. Therefore, three radars were needed for the data collection; 100 m before the VAS (Radar 1), at the sign (Radar 2) and 50 m after the sign (Radar 3). Radar 2 was installed within the sign; Radar 1 and Radar 3 were two additional radars. At the Korsgård test site, Radar 3 was not available, but at the Mjälga test site all radars were available. Therefore data were collected at only two points at Korsgård, but at three points at Mjälga.

Data were collected 24 hours a day. For each site, the VAS was installed for a period of four months. The study was designed such that VASs were installed on a range of weeks and for each week the sign would be activated with different trigger speeds. It is believed that month or day of the week are external factors that can have an effect on the results. Due to limitation of radar availability, this study did not consider these factors. At the Korsgård test site, data were collected from 1 September 2012 to 31 December 2012 and at the Mjälga site, from 1 May 2013 to 1 August 2013. It should be noted that technical difficulties with the radar, i.e. with its communication with the server together with uneven availability of equipment, were mainly responsible for the selection of the period of data collection and the difference in the length of time spent collecting data at the different test sites.

<table>
<thead>
<tr>
<th>Week</th>
<th>Date</th>
<th>Trigger speed (TS)</th>
<th>Week</th>
<th>Date</th>
<th>Trigger speed (TS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>47</td>
<td>21/11/2012</td>
<td>6</td>
<td>25</td>
<td>19/05/2013</td>
<td>0</td>
</tr>
<tr>
<td>37</td>
<td>11/09/2012</td>
<td>42</td>
<td>28</td>
<td>11/07/2013</td>
<td>40</td>
</tr>
<tr>
<td>46</td>
<td>14/11/2012</td>
<td>44</td>
<td>30</td>
<td>25/07/2013</td>
<td>44</td>
</tr>
<tr>
<td>48</td>
<td>26/11/2012</td>
<td>47</td>
<td>33</td>
<td>12/08/2013</td>
<td>46</td>
</tr>
<tr>
<td>49</td>
<td>05/12/2012</td>
<td>52</td>
<td>27</td>
<td>04/07/2013</td>
<td>47</td>
</tr>
<tr>
<td>46</td>
<td>13/11/2012</td>
<td>150</td>
<td>32</td>
<td>09/09/2013</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>24</td>
<td>13/05/2013</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>32</td>
<td>08/08/2013</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>22</td>
<td>27/05/2013</td>
<td>150</td>
</tr>
</tbody>
</table>

The collected data comprised the vehicle speed, the trigger speed and the date and time the vehicle passed the VAS. Due to the various factors that influence vehicle speed, a trigger speed
was randomly assigned to each week. From each week, one day was randomly selected for data analysis. Table 2 shows the selected week, selected day and selected trigger speed, respectively.

### 3. Statistical Analysis

In this study, the data analysis covered both descriptive and inferential statistics. Mean, standard deviation and comparative variation were used in the descriptive part and Bartlett’s test, one-way test, the pairwise t-test and the pairwise F-test were used for the data analysis (see Figure 3).

**Fig3. Data analysis carried out in the current study**

#### 3.1 Descriptive statistics

A large set of data was collected in this study. To convey the important aspects of the distribution of the data, some descriptive statistics were used: time mean speed to describe the central tendency; speed variation for the spread of the data; and coefficient of variation to describe both central tendency and spread of the data (Mousa 2005, Muchuruza et al. 2005). Speed can be defined either as time mean speed or space mean speed. Time mean speed $s_t$ is the measurement used in this study. Time mean speed is the average of spot speed $s_i$ or simply the average of $n$ vehicles passing a point during a certain period of time (Mathew 2012). Time mean speed $s_t$ is given by equation (1):

$$ s_t = 1/n \sum_{i=1}^{n} s_i $$

(1)

Speed standard deviation std is a measure for analysing speed variation and is approximately the square root of the speed variance of vehicle speed data. The speed variance is calculated by the sum of the squares for the difference between each vehicle speed and the mean speed of those vehicles (Kerns 2011). However, in this study the speed standard deviation is the preferred
measure rather than the variance, due to lower scaling in the standard deviation. The speed standard deviation of the sample is given by equation (2):

\[
\text{std} = \sqrt{\frac{\sum_{i=1}^{n} (s_i - s_t)^2}{n - 1}}
\]  

(2)

The coefficient of variation \(C_v\) is another appropriate way to measure the extent of variability in relation to the mean of the sample (SAS/STAT 2008). It is also defined as the ratio of the speed standard deviation \(\text{std}\) to the time mean speed \(s_t\). It is given by equation (3):

\[
C_v = \frac{\text{std}}{s_t}
\]

(3)

3.2 Inferential statistics

In this study, the data comprise information on vehicle speed across the entire year. These data cannot be collected easily, and a usual practice in cases like this is to collect a random sample, use diverse methods from inferential statistics and generalise the results to the entire dataset. A complete randomised design was adopted (described in the previous section), and inferential statistics were also used for hypothesis testing. In the statistical procedure of hypothesis testing, the researcher typically set up two hypotheses concerning the data, a null hypothesis and an alternative hypothesis. Under the null hypothesis it is assumed that there is no statistically significant relationship among the variables, whereas the alternative hypothesis challenges this assumption. The goal of hypothesis testing is usually to reject the null hypothesis in favour of the alternative hypothesis. The hypothesis testing procedure involves two additional parameters: a probability value \(p\) and a confidence level \(\alpha\). The \(p\)-value is the probability of the observed outcomes occurring under the assumption that the null hypothesis is true. The confidence level \(\alpha\) is the threshold value that the researcher selects to indicate at what point the null hypothesis will be rejected. If the \(p\)-value is less than or equal to \(\alpha\), then the null hypothesis will be rejected (Wackerly et al. 2008). For the analysis of changes in mean speed and speed variances between different trigger speeds, four types of hypothesis testing were applied – Bartlett’s test, one-way test, the pairwise t-test and the pairwise F-test. Bartlett’s hypothesis testing is used to perform the test on two or more samples, to check equality or homogeneity of variances (Dalgaard 2008). The null hypothesis for Bartlett’s test indicated that the speed variances between trigger speed values were equal.

The authors applied the one-way test to check for homogeneity in the mean speed between different trigger speeds that relax the assumptions of equal variances. The following null
hypothesis was tested using the one-way test: As with Bartlett’s test and one-way test, the pairwise t-test and the pairwise F-test were used to check variances and mean equality between different trigger speed levels, but only as a pairwise comparison. In the latter test, the comparison establishes which of the trigger speed levels differs from the others.

4. Statistical Results

The findings in this research have been separated into individual sections for the sake of clarity.

4.1 Descriptive statistics

As explained earlier (see Section 1), the main safety consideration is to reduce speeding and speed variation between vehicles. Lowering the average speed leads, in general, to a reduction in crash severity, and a reduction in the coefficient of variation leads to a reduction in crash rates (Taylor et al. 2000). This study attempts to determine if changing the trigger speed has an effect on reducing the average speed while simultaneously reducing the standard deviation of speed. Thus it is the authors’ intention that this study should help to derive the optimal trigger speed. In an attempt to establish the optimal trigger speed that would cause a reduction in the average driving speed, as well as coefficient variation, three types of relationship were explored. Figure 4 shows relationships between the proposed trigger speeds and mean speed (a), standard deviation (b), and coefficient of variation (c) at the Mjälga test site and Figure 5 shows the mentioned relationship at the Korsgård test site. At Mjälga, the mean speed increases when trigger speed increases but the standard deviation and the coefficient of variation decreases when trigger speed increases. The Korsgård test site shows the same trend of decreasing standard deviation and coefficient of variation with an increase in trigger speed. However, the effect of trigger speed on mean speed is not significant at this site. Mean speed did not vary in the same direction when trigger speed increased. Given the correlation between trigger speed and standard deviation as well as coefficient of variation at both test sites, the optimal trigger speed is based on reducing the standard deviation. One finding extracted from these figures is that there was a significant difference in standard deviation when the speed threshold was set to the 85th percentile (trigger speed set at 52 km/hr at Korsgård and at 50 km/hr at Mjälga), compared to a speed threshold set to the speed limit plus a 10% buffer (trigger speed set at 44 km/hr).
Fig 4. Relation between mean speed (a), standard deviation (b) and coefficient of variation respective to trigger speed at Radar 2 at Mjälpa test site

Fig 5. Relation between mean speed (a), standard deviation (b) and coefficient of variation (c) respective to trigger speed at Radar 2 at Korsgården test site
This finding is consistent for both test sites. A second finding is that when the trigger speed is set near the speed limit, the standard deviation is high. This holds at both test sites. However, the effect of trigger speed on mean speed was not as clear at the Korsgård site as compared to the Mjälga site, where the experiment started directly following VAS installation. At Korsgård there was neither a significant increase nor decrease in mean speed when the trigger speed was varied. This might indicate that the effect of the VAS, at least in terms of reducing mean speed, decreases with time, as the drivers recall the presence of the VAS and react differently than in the case of a recently installed sign. Therefore, it appears that trigger speed should be based primarily on lowering the standard deviation rather than lowering the mean speed. According to the preliminary results obtained at these test sites, mean speed and standard deviations differ from one site to the other. This suggests that the trigger speed has to be adapted to the selected site. Additionally, the optimal trigger speed should be near the 85th percentile in order to lower the standard deviation. In order to know the spatial range impacted by VAS, the same relationships are displayed at Radar 3 located 50 m after VAS but for downstream traffic at the Mjälga test site (Figure 6).

4.2 Inferential statistics – Hypothesis testing

Bartlett’s test was applied to determine whether the variance in vehicle speed is the same for all trigger speed levels, which in general are known as treatment groups. In order to determine mean speed similarity, the one-way test for equal means was also used, with a confidence level of 0.05.
The following hypothesis tests were applied to the data collected by Radar 2 at the Mjälga test site. Data collected at Korsgård were not examined in this analysis, since the results obtained from the descriptive statistics for this site were not as significant as those obtained for Mjälga. The outcome of both hypothesis tests was performed in R software and summarised in Table 3 below.

<table>
<thead>
<tr>
<th>Bartlett’s test</th>
<th>One-way test</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K$-squared statistic</td>
<td>153.6048</td>
</tr>
<tr>
<td>$p$-value</td>
<td>$2.2e-16$</td>
</tr>
</tbody>
</table>

In order to justify rejecting the null hypothesis, the values of the F-test and $K$-squared should be high and the $p$-value should be low. On both tests, the results are significant with an associated $p$-value that is very low, providing support for rejecting the null hypothesis that the variances and means are equal. The rejection of the null hypothesis in Bartlett’s test supports the alternative that at least two of the variances are different. A one-way test was also used for the alternative hypothesis to establish if at least two means are different. Probably not all the trigger speeds had mean and variance differences. Therefore a pairwise t-test and a pairwise F-test were performed. These tests are simply a pairwise comparison between group levels. In both tests, Bonferroni adjustment was included, in which the $p$-values are multiplied by the number of comparisons. Table 4 and 5 shows the probability $p$-value for equal means for all the possible combinations between trigger speed levels. In both tables (Tables 4 and 5), the results show that the $p$-value is lower than 0.05, enabling us to reject the null hypothesis of equal means and equal variances. There is therefore strong evidence of a difference in mean speeds and in variances between a trigger speed that is set to the 85th percentile (50 km/hr) and other trigger speeds.
4.3 Distribution of Vehicle Speeds

The distribution of speeds observed followed an expected bell-shaped curve (see Figures 7 and 8) for speed distributions at different radars at different test sites and with different trigger speeds. Some vehicles travelled slower than the 40 km/hr speed limit and some at or above it. Figure 7 shows the speed distribution at the Mjälga test site when the VAS was triggered at 40 km/hr and 50 km/hr, respectively. The Mjälga site had radars at three locations, i.e. 100 m before the VAS (Radar 1), near the VAS (Radar 2), and 50 m after the VAS (Radar 3). The solid line represents the speed distribution when the VAS was triggered by drivers travelling at a speed equal to or greater than 40 km/hr. The dashed line represents the speed distribution when the VAS was triggered at 50 km/hr.
Figure 8 shows the speed distribution at 100 m before the VAS (Radar 1) and at the VAS (Radar 2) at the Korsgård test site. Radar 3 was unavailable at this test site. In Figure 8, the VAS was triggered when a driver's speed was equal to or greater than 42 km/hr (solid line) and 52 km/hr (dashed line), respectively. As seen in both figures, the VAS has, in general, an effect.
on driver speed where the curves of Radar 2 shift to the left, indicating that drivers reduce their speed. In figure 7, the effect of trigger speed is even more apparent than in Figure 8.

At both sites, there were greater reductions in the number of speeders when the VAS was triggered with high value. VASs helped motorists travelling at high speed to reduce their speed to near the speed limit, while motorists travelling at low speed increased their speed to the limit.

The results presented in Table 6 shows that the percentages of number of speeders reduce their speeds to the speed limit. At Mjälga site, the percentage of speeders reducing their speed to the speed limit were 21% and 25% on setting the trigger speed to 40km/hr and to 50km/hr, respectively. At Korsgård site, the percentages of speeders reducing their speed were 13% and 15% on setting the trigger speeds to 42km/hr and 52 km/hr, respectively. Thus means that, at both sites, the numbers of speeders that reduce their speeds were approximately increased by 4% when setting the trigger speed to 85th percentile.

<table>
<thead>
<tr>
<th></th>
<th>Trigger speed (TS=40)</th>
<th>Trigger speed (TS=50)</th>
<th>Trigger speed (TS=42)</th>
<th>Trigger speed (TS=52)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Radar 1</strong></td>
<td>36%</td>
<td>42%</td>
<td>27%</td>
<td>25%</td>
</tr>
<tr>
<td><strong>Radar 2</strong></td>
<td>15%</td>
<td>18%</td>
<td>14%</td>
<td>10%</td>
</tr>
</tbody>
</table>

5. **Summary and Conclusions**

The effectiveness of trigger speed on mean speed and standard deviation were established in this study by collecting information on the speed of vehicles at two test sites. A systematic data collection was carried out whereby vehicle speed data were gathered whilst varying the value of the trigger speed threshold. This data collection was based on a complete randomized design. To obtain a comprehensive understanding of the impact of trigger speed on driver behaviour, this study confirmed two hypotheses: first, that the change of the threshold value has an effect on vehicle mean speed; second, that a change in the threshold value has an effect on vehicle speed standard deviation. The confirmation of these hypotheses leads to a straightforward statement that the trigger threshold should be considered a key factor when studying the effect of VASs on driver behaviour. The relationship between mean speed, standard deviation and trigger speed can help in deciding which trigger speed value has the greatest effect in terms of reducing speed (e.g.
crash severity) and standard deviation (e.g. crash rate). Theoretically, the optimal trigger speed should result in lowering both the mean speed and the standard deviation simultaneously, i.e. achieving a low coefficient of variation. In this study, the optimal trigger speed was near the 85th percentile speed, producing a lower standard deviation of speed by approximately 1 mph. However, this reduction is not apparently high but it is of much significance in terms of speeds distribution. Specifically, at both sites, the numbers of speeders that reduce their speeds were approximately increased by 4% when setting the trigger speed to 85th percentile. Thus indicate good traffic operations in increasing speed homogeneity between vehicles and in safety benefits by reducing traffic crashes. However, this study evaluated the safety benefits in term of reducing of mean speeds and standard deviation, not in terms of accidents. The 85th percentile speeds obtained from both test sites were not similar where both sites had the same speed limit (40 km/hr). Note that both 85th speed percentiles are significantly higher than the current practice in Sweden. Therefore the choice of trigger speed cannot be based solely on the speed limit at the proposed VAS location. VASs should be individually configured and adapted to the location and its traffic conditions, in order to achieve optimal effectiveness. The most interesting findings of this study are:

- Standard deviations of vehicle speed decreased as trigger speed increased at both test sites
- Standard deviation of vehicle speed was high when the trigger speed was set near the speed limit
- An initial recommendation is that if a VAS is configured with a static trigger speed, this should be set at approximately the 85th percentile. This recommendation is based on the relationship between the coefficient of variation and the trigger speed, where the coefficient of variation is low when the trigger speed is near the 85th percentile of a vehicle’s speed
- If there are no traffic data available, it is hard to identify which trigger speed should be applied to the site. Therefore future studies need to explore more test sites in order to investigate the relationship between site selections and trigger speed

At what speed the sign should be triggered depends on many factors, such as the prevailing speed limit, road geometry, traffic behaviour, the weather, and the number of hours of daylight. More research is required to study the trigger speed that offers the best compromise between speed reduction and power consumption. In addition, data collection should be expanded to test the effect of trigger speed with respect to time of day and day of the week or other factors such as traffic flow. Obviously to optimise the effect of trigger speed on drivers’ speed, VAS should be
further adapted to a greater diversity of traffic and road conditions. In the long term the goal is to develop an “intelligent” VAS which self-adapts to traffic conditions on site, in order to operate at the optimum threshold. Furthermore, this trigger speed should have the combined effect of reducing both accident frequency and accident severity.

Acknowledgments
The authors thank SafeX for their generous help in collecting the data, particularly in radar maintenance and sign movement from one site to the other. Our thanks are also extended to Westcotex for their valuable technical support for server communication with the radar and data logger, Borlänge authority for allowing us to change test sites and Vectura for providing radars for the experiment. Finally, we thank Intelligent Transport System, ITS Dalarna for supporting this research.

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