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Influence area of speed cameras: based on naturalistic driving data

Master’s thesis in Automotive Engineering

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Cover:
Figure depicting a typical fixed speed camera found in the U.K. (Image courtesy-KentOnline-https://www.kentonline.co.uk/kent/news/number-of-speeding-drivers-revealed-182106/) - printed here with the permission from <picturedesk@thekmgroup.co.uk>.

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[Abstract]
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Abstract

Speeding is a major problem worldwide contributing for a large number of crashes and injuries. In order to control the vehicle speeds, the traffic authorities have enforced speed regulations which are monitored by the speed cameras. However, these speed cameras tend to alter the driver behaviour affecting the vehicle kinematics. This thesis examines the influence area of such speed cameras on driver behaviour using naturalistic driving data. Several locations from the UK and Poland were selected for the analysis consisting of various camera types. Kinematic data of the vehicles passing through the selected locations were extracted and analysed for a pre-defined range of distance around the camera.

The study indicates that the driver behaviour was influenced by the presence of speed cameras. Drivers were found to reduce the speed before the camera and immediately started to increase the speed after the camera resulting in a V-profile in the vehicle speed. For the UK, the average speed drop before the camera was found to be 0.87m/s (3.13km/h) and the average speed rise to be 0.89m/s (3.2km/h) after the camera. The decelerating and accelerating distance were observed to be 182m before the camera and 166m after the camera respectively contributing to the influence area of 428m around the camera. In case of Poland, the average speed drop before the camera and the average speed rise after the camera were found to be 1.01m/s (3.62km/h) and 1.01m/s (3.64km/h) respectively. The deceleration distance and acceleration distance were found to be 194m before the camera and 125m after the camera respectively summing up for an influence area of 319m around the camera.

With the help of naturalistic driving data this study observes the behaviour from the driver's point of view for a fixed speed camera and an average speed camera. The behaviour from the average speed camera shows less variation in the speed when compared to a fixed speed camera. However, the results should be taken with caution as the number of cases are limited. Analysis of a larger number of cameras would give a definite result which can be an aspect for the future study. It would also be interesting to compare results from naturalistic driving study with an on-field study using external speed recording devices.

Key words: Naturalistic Driving Data, Driver Behaviour, Speed Cameras, Influence Area, Speeding

Contents

Preface

This report is produced as an outcome of the Master's thesis work equivalent to 30 ECT, carried on during 2018 at SAFER Vehicle and Traffic Safety Centre at Chalmers. This thesis constitutes the final requirement for the Master's degree in Automotive Engineering at Chalmers University of Technology.

At the first place, we would like to thank our Supervisor and Examiner Dr Selpi for her support, guidance and inputs at every phase of the thesis right from the start which was very valuable and helped us in reaching the intended objectives of the thesis. As this thesis is based on naturalistic data, SAFER served as a platform for providing us with required data. In this regard, we would like to thank Erik Svanberg and Helena Gellerman for providing us the access to the database and helping us extract the data. We would like to compliment SAFER for the supportive infrastructure which created a comfortable workplace during our thesis work. On the same lines, we would also like to thank all the people at SAFER for creating a friendly atmosphere during our work. We would like to thank our colleagues Gabriele Panero and Alexander Rasch for their friendly attitude in helping us during our work on database. We would also like to thank Sonja Laakso Gustafsson for helping us on the registration of our master's thesis.

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Akshay Srinivas and Vishal Bharadwaj Sringeri Manjunath Swamy

1 Introduction

Road traffic injuries have claimed about 1.2 million lives in the year 2017 globally according to the World Health Organisation(WHO) [1]. Speeding (driving faster than the posted speed limit) has been found to be a major contributor to the amount of road traffic crashes [2]. According to Royal Society for the Prevention of Accidents (RSPA) speeding alone has caused 11% of the injury collisions, 15% of the serious injuries from crashes and 24% of fatal crashes in the United Kingdom [3]. The consequences of speeding not only puts at risk the life of driver but also the lives of other road users like motorists, cyclists and pedestrians. It is more probable for a driver who is speeding to meet with a crash and with higher speeds the severity of the injury also increases since the occupant and other road users will be exposed to greater forces [2]. High speed scenarios also mean the drivers have minimal time to realise the threat and react to it and also delaying the time taken to come to a standstill. This not only takes away the comfort and safety boundary of the driver but also increases the chances of turning near crashes into crashes [3]. It is a simple understanding that if the number of speeding drivers are brought down, the number of crashes will also be reduced. The RSPA states that if the average speed can be brought down even by 1m/s (1.60 km/h) the accident rate can drop by 5% on an average when considering different type of roads [3]. This is where speed enforcement comes to play a huge role.

Speed enforcement has been an essential measure deployed by traffic bodies and authorities all over the world to curb speeding drivers by penalizing them. These penalties can vary from country to country and region to region. Penalties can be either monetary or suspension of driving license for a centain period of time depending on the severity of speed violation. The Mobility and Transport division of the European Commission states that certain countries make sure that severely penalised drivers undergo a driver improvement course [4].

There are many tools and measures that can be used for speed enforcement. Speed enforcement can be either automatic or non automatic. In non automatic speed enforcement the offenders are caught and penalized on the spot by police officers posted at the site. But this type of speed enforcement requires a large amount of human resource and is confined to time and place. When it comes to automatic speed enforcement, the speeding vehicle number plate is automatically detected by the camera. The offending vehicle’s driver in whose name the vehicle is registered will receive a fine through mail within a certain time period. However, technology used behind the number plate identification has changed drastically from the time when they were first implemented. This has helped the speed cameras to work with higher accuracy and range thus making the whole operation of speed enforcement highly efficient.

Previously conducted studies have shown that speed enforcement through speed cameras has been effective to a certain extent by forcing drivers to maintain speeds in the proximity of the speed cameras resulting in the reduction of crashes [5] [6]. These studies have been carried out either through questionaires or through speed measuring devices like radars and piezo sensors. This thesis studies the driver behaviour within the vicinity of the speed camera using naturalistic driving data (NDD) recorded from the United Kingdom and Poland. Naturalistic driving data is the data collected from a study which provides knowledge on the driver behavior by observing their day to day driving patterns with respect to the driving environment. This data is collected with the help of unobtrusive data recording equipments like cameras, sensors, CAN etc. [7]. The data recorded generally consists of real time information regarding various vehicle kinematics/dynamics and hence plays a significant role in the traffic safety/crash analysis by providing the actual information rather than information based on theoretical assumptions. The naturalistic driving data used in the current study is a part of the project called UDRIVE (European naturalistic Driving and Riding for Infrastructure & Vehicle safety and Environment) [8]. Compared to observations from outside (by radar and/or piezo sensors), NDD allows us to see from inside the vehicles (i.e., to see what drivers might have seen); this may help us to understand why the drivers reacted as observed.

As the present study includes the study of driver behaviour in the vicinity of a speed camera, it is expected that the results of this study could be useful for traffic authorities to plan the placement of the cameras and the type of cameras to be used.

Since this study involves analysis of naturalistic data, privacy issues should be considered. Sensor data and video recordings of the individuals (participating in the study) and the surrounding environment have to be handled in such a way to respect the privacy of the participants.

1.1 Objective

The aim of the thesis is to identify the influence area of the speed cameras and study how the driver behaviour is influenced by the speed cameras with the help of naturalistic driving data. The objectives set to achieve this are as follows:

- To review the literature related to effect of speed cameras and driver behaviour in the vicinity of the speed cameras
- To identify the segments of naturalistic driving data passing nearby speed cameras
- To analyze the influence area of the speed cameras from two countries (the UK and Poland) using the identified segments, also to take into account several types of cameras and accounting for the differences
- To analyse if factors like speed limit and infrastructure in the vicinity of the camera affect the driver behaviour

1.2 Scope

The current study is limited to data recorded by the same segment of passenger cars from the UK and Poland. The kinematic data used in the study are limited to longitudinal speed and acceleration. Only roads with speed limits equal to or greater than 50km/h were considered. In the present study speed camera locations with slow moving traffic have been left out and locations only with free flowing traffic have been considered.

2 Literature Review

This section deals with the literature review performed during the study. It includes the study about speed cameras, camera types and driver behaviour as well.

2.1 Speed Cameras

Speed cameras are used to curb the speed limits, register speeding offences and to identify the vehicle owners by capturing the vehicle registration numbers. Speed cameras are generally classified as fixed speed cameras (pole mounted) and mobile speed cameras (police vehicles). Fixed speed cameras can either measure speed from one fixed position or measure the average speed of the vehicle. There are various principles based on which a speed camera operates and thus accounting for their main classification. Mainly, the speed cameras are placed in locations where, the number of road crashes are relatively high, drivers tend to offend the speed limits, and in places where an evident relation between the number of crashes and speed was found [10].

Various studies have been carried out concerning the effect of speed cameras on the traffic safety. Most of the studies that have been carried out have found that there was a reduction in crash numbers in the proximity of speed cameras. According to the meta-analysis by Høye [11] fixed speed cameras reduced the number of crashes by 20% and KSI (Killed or Severely Injured) by 51%. However, in the same study average speed cameras were more effective than the fixed speed cameras in reducing the number of total crashes by 30% and 56% for KSI crashes. In another meta-analysis carried out by Ercke et al. [12], it was found that there was reduction by 33% in case of fatal crashes and 22% in personal injury crashes. A study carried out by Wilson et al. [2] from various parts of the world, concluded that there is a positive effect of speed cameras on road safety. It was found in their study that the number of serious injury crashes in roads with speed camera surveillance were reduced by 11% to 44% as compared to similar roads without cameras. Furthermore, in an evaluation by Gains et al., [13] in Great Britain, a significant effect of speed cameras on safety was found with a reduction of 22% in the number of personal injury collisions and KSI by 42%. Li et al., [14] finds that speed cameras were found to be effective in terms of reduction in accidents up to 200m from the camera and their effectiveness decreases with increase in distance from the camera.

According to De Pauw et.al [5], the choice to introduce a camera depends on the number of accidents, futhermore the seriousness of the accidents during the most recent 5 years and the nearness of critical spots in a ambit of one kilometer.

2.1.1 Types of Speed Cameras

Speed cameras are designed based on the fundamental principle of recording an image either by using a photographic film or through videotapes of vehicles passing by them. However, speed cameras are further classified based on their method of operation and working principle.

Fixed or single-spot speed cameras are permanently installed speed cameras which capture the vehicle's registration number along with the date, time, location, direction of travel, speed limit only if the driver exceeds the speed limit at that location. Whereas average speed cameras are placed at multiple locations (minimum of 2 cameras) along a single stretch of road. It calculates the average speed of the vehicle between the first camera and the last camera. The distance between the first and the last camera can vary from a few meters to several kilometers. Average speed cameras are also known as section control.

The types of speed cameras that are vital for the present study are explained below and the information was collected from the SpeedCamerasUK database [15].

2.1.1.1 Single spot Speed Cameras

Gatso speed cameras are one of the oldest and commonly used speed cameras that have been used across the United Kingdom. They were introduced back in 1992 for the very first time. These cameras are rear-facing cameras (i.e., they capture the image of the speeding vehicle only after it passes the camera). Radar technology is used to measure the speed of the vehicle and to trigger the camera into action on detection of over speeding vehicles. Gatso cameras make use of a powerful flash (main reason for being rear faced) while capturing the image of the vehicle, registration plate and white calibration lines painted on the road surface. The white calibration lines found near the cameras are used as a secondary measurement system. The distance between each line represents 5mph which can be used to ensure the speed of the vehicle. Gatso can differentiate the speed limits for each vehicle type (cars, caravans, HGVs) by measuring the length of the vehicle. Figure 1 depicts a Gatso camera and its secondary measurement system.

Figure 1: Gatso Camera (Image courtesy Google Maps)

2.1.1.2 Average Speed Cameras

SPECS average speed cameras are the most used average speed cameras. This camera is used to enforce speed limits on dual carriage ways and motorways. It is usually located at central reservations or at side of the road.

It uses an advanced technology known as ANPR (Automatic Number Plate Reading) instead of a camera roll. The cameras make use of infra-red technology to read the vehicle registration number day and night. It usually records the date and time stamp. With the help of ANPR the average speed of the vehicle is worked out between the cameras and if the speed is above the speed limit, a ticket will be issued to the driver automatically. Since it does not use a photographic film like the other cameras, there is no limit to the number of images it can capture. A typical SPECS avereage speed camera is as shown in Figure 2. Figure 3 depicts the concept of average speed cameras.

Figure 2:SPECS Average Speed Camera (Image Courtesy Google Maps)

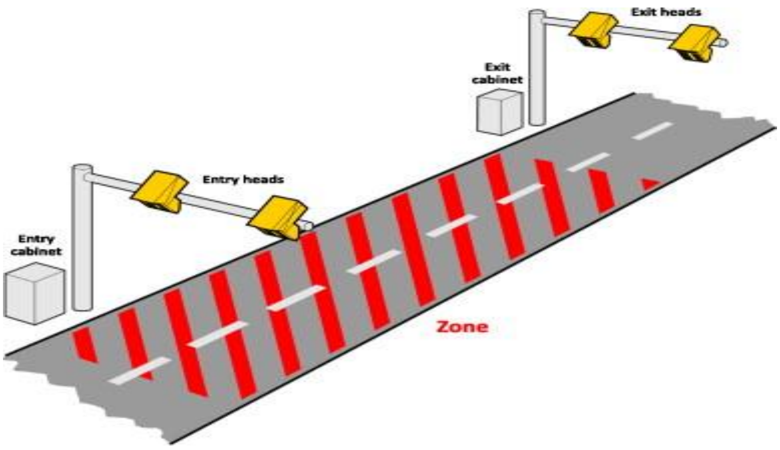

Figure 3: Diagram depicting the basic concept of average speed cameras (Image courtesy-RedSpeed International, in Soole, Fleiter & Watson, 2013)-printed here with the permission from <faa@acrs.org.au>.

2.1.1.3 Variable Speed Cameras:

The concept of variable speed camera was introduced to monitor the vehicle speeds on a motorway based on the existing traffic conditions on the motorway. They do not tend to enforce speed limits 24/7 but only when there is a necessity for it. If normally the speed limit for the motorway is 70 mph (113 kmph), it can temporarily be lowered down to around 50 or 60 mph (80 or 96 kmph). The temporary speed limits are controlled by operators at a control room. The speed limits are lowered down during peak hours due to congestion, crashes or bad weather. Only when the speed limits are lowered down the speed cameras are activated.

The type of camera that was placed by the local traffc authority for speed enforcement is called HADECS 3 cameras as shown in Figure 4. The HADECS 3 camera makes use of a non-intrusive dual radar for detecting speeding offences during all types of weather conditions. It also possesses additional features like positive vehicle identification, lane identification and vehicle position.

Figure 4: Variable Speed Camera (Image Courtesy-Google Maps)

2.2 Driver Behaviour

Various components like vehicle, road-infrastructure, environment, driver behavior forms an integrated or a complex relationship with respect to traffic safety. Based on statistical research, driver behavior is found to be a major concern amongst the above components [16]. According to [17] driver behavior was found to be responsible for almost 95% of the crashes studied. The complex interactions occurring in traffic affects the driver behavior. This change in behavior cannot be the same for all the drivers as this is influenced by the driver's perception of the scenario. In turn, these perceptions are influenced by the experience and the psychological characteristics of the individuals. Hence, the assessment of the driver behavior plays a vital role regarding traffic safety.

Several studies have shown that there are changes in the driver behavior near the speed cameras. Drivers tend to reduce the vehicle speed at the camera locations. According to De Pauw et al. [6] speeds decreased on an average of 3.97mph (6.38km/h) at camera locations. Also according to Gains et al. [13] various number of sites where the speed cameras were introduced, the speed was found to be dropped by 2.2mph (3.54km/h) or 6% on an average and 31% of overall reduction in the number of vehicles exceeding the speed limit. In the same study it was also observed that there was an overall reduction by 51% in terms of excessive speeding. Reduction in average speed can be credited to reduction in collisions. Taylor et al., [18] claims a reduction of 2-7% in collisions due to a speed reduction of 1mph.

However, such a speed reduction is associated with abrupt braking before the camera and sudden increase in speed after the camera. This is found to be a significant behavioral change in drivers resulting in a V-profile in the vehicle speed near the speed cameras [6]. This abrupt braking results in increased decelerations and was found to be responsible for an increase in rear-end crashes [19]. According to Lui et.al., [20], this abrupt braking was found to be significant around 300-400m before the camera. Similarly, speeding was found to be significant around 300-400m after the camera. Albeit different investigations have demonstrated that speed control with cameras is powerful in lessening the mishaps upto 200 meters after the camera, Daniele et al., [21] studied and demonstrated that by 200 metres after the speed camera, just 60% of drivers were still complying with the speed limit. It was also found in the same article that a difference of about 10km/h between the average speed at the camera and 200m away from it shows the effect of the camera on the driver's speeding behaviour.

3 UDRIVE

This chapter describes about the data set used for the study. It includes details of the UDRIVE data. UDRIVE is one of the European Naturalistic Driving Study projects that collects driver behavior data in naturalistic every day driving. The main intention being to analyze the drivers' risky driving behavior and driver distraction. The UDRIVE project aims to provide suggestions for traffic safety, driver training, driver awareness and road design. The results from the UDRIVE may be helpful in developing the driver behavior models and risk functions for traffic simulations. The study included drivers from the United Kingdom(UK), Netherlands(NL), Spain(SP), Poland(PL), Germany(GE), and France(FR);vehicle distribution in the UDRIVE data collection is as shown in Table 1.

Table 1:UDRIVE vehicle distribution

Type of Vehicle	Country	Number
Car	France	30
	Germany	20
	Netherlands	10
	Poland	30
	UK	30
Powered Two-wheelers	Spain	40
Truck	Netherlands	40
Total		**200**

The data was collected using Data Acquisition Systems (DAS) installed in the vehicles' trunk. The recorded data include video from seven-eight cameras, CAN data (data from the vehicle's own network), GPS data and acceleration data. Additionally, angular rate sensors and MobilEye smart camera which provides continuous data about the presence of other road users and their distance and speed relative to the instrumented vehicle, were also employed. The number of instruments connected to the respectective vehicles are shown in Table 2.

Table 2:Specification of DAS features per vehicle type from UDRIVE

Car	**Truck**	**Scooter**
7 cameras	8 cameras	5 cameras
IMU sensors	IMU sensors	IMU sensors
GPS	GPS	GPS
Mobil Eye Smart camera	Mobil Eye Smart camera	
CAN data	CAN data	
Sound level	Sound level	

The collected raw data is subjected to pre-processing. During this phase the raw data is enhanced with data like map data from digital maps. The data is then stored in MySQL database. Access to data is done through MATLAB scripts and an analysis tool specifically developed for UDRIVE called "SALSA".

This thesis study mainly focussed on the driving data recorded from the UK and Poland. These two countries were chosen particularly due to certain resources like camera database and camera maps were available. Geographic information (GPS), kinematic data (speed and acceleration) and data from the MobilEye was used to calculate the time gap between the subject vehicle and the lead vehicle.

4 Methodology

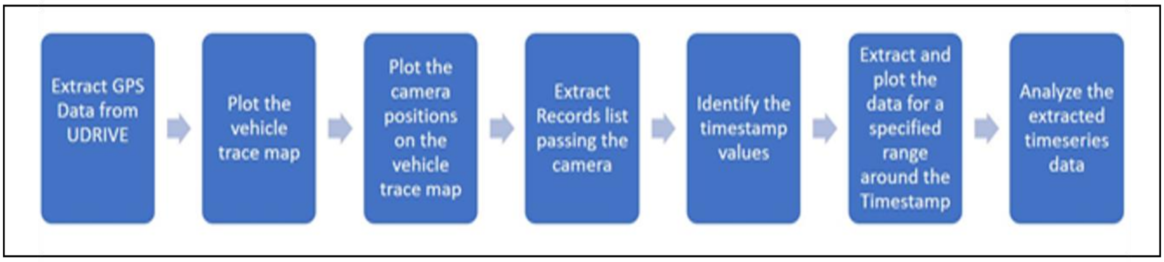

Figure 5: Basic design of the overall methodology carried out

The records were extracted from the UDRIVE for the year 2016. With the help of the GPS coordinates of each trip, a map that projects the vehicle trajectories was generated. The GPS coordinates of the selected camera sites were noted down from Google Maps (with help of Google Street View), which gave the approximate latitude and longitude values close to the camera. It is not possible to get the exact co-ordinates of the camera from the Google Maps. This is because the cameras are placed at a certain offset distance from the road. The camera position was plotted in the map that was generated using the vehicle trajectories. It was noticed that the camera position obtained from Google Maps were not matching accurately with the map developed using the vehicle trajectories, hence, with the help of obtained reference camera position and the vehicle traces a boundary was created. The extreme points of the vehicle traces were considered and given an offset on either side. The distance between the offset points was noted down and with the help of a MATLAB code the boundary was created. The distance between the offset points was considered as the radius of the boundary. With the help of a different MATLAB script, all the record names passing through this boundary were extracted. The same procedure (illustrated in Figure 5) was carried out for each of the camera locations of interest. Locations with considerable number of records were considered as explained below in Section 5.1.

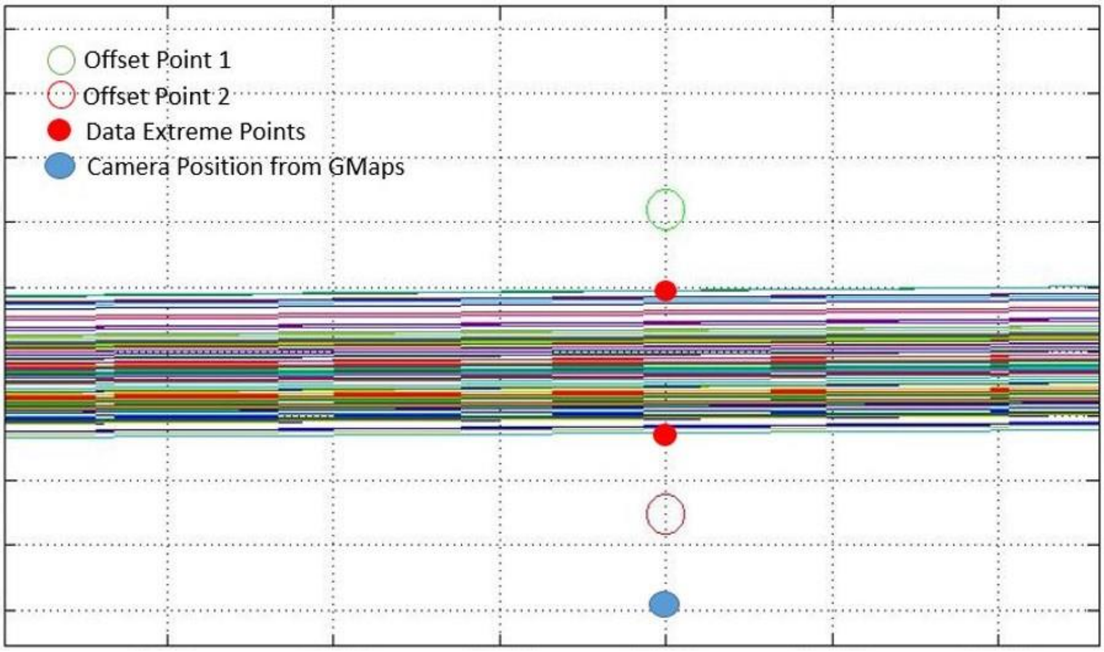

Figure 6 Placement of speed cameras on vehicle trajectories map

4.1 Camera Location Selection Criteria

Based on the vehicle trace map produced, the camera locations were located. Initially, the locations outside the city traffic zones were looked for, as the speed limits would generally be higher compared to roads within city limits. However, every such location couldn't be considered for the analysis due to certain limitations. Hence, selection criteria were set, which was based on the limitations. Hence, the locations were selected based on the following criteria:

- **<u>Number of records passing through the camera site:</u>** Some of the camera sites had a very few number of vehicle passes and hence had to be excluded from further study. The number of passes for the camera site was identified based on visual inspection of the vehicle traces plot.
- **<u>Speed Limit:</u>** Lower speed limit zones were observed to be concentrated in higher traffic congested areas. Hence, speed zones of over 40mph (64.37 kmph) were preferred initially for the location selection. However, due to lesser number of such high-speed zones, locations with a speed limit greater than 30mph (48.28 kmph) were also selected for the analysis.
- **<u>Road lane type:</u>** Roads with single directional traffic flow were preferred owing to the speed camera operation. Single directional traffic flow meaning the opposite lanes are separated by a median (physical barrier) in between. However, not many locations satisfied these criteria and hence, roads with bi-directional flow (without a median in between) were also selected.

Once the records were obtained for each location, each record was verified manually with the help of videos available in UDRIVE. Along with this the timestamp of the vehicle when it is in close proximity to the camera was noted down; this task was carried out manually. Timestamps at which the vehicles pass across the speed cameras are noted down and used as a reference for the segmentation of the data. Each segment consists of data 50s before and 50s after the camera.

4.2 Filtering of the records

The data for the records obtained from the UDRIVE lacked some of the factors like quality and insufficiency of information. Hence, this raw data was not suitable for the further analysis and had to be subjected to sorting/filtering based on the following parameters. Some of these parameters are chosen based on the requirements for the further analysis of the data.

- **<u>Signal Quality:</u>** Some of the records obtained from the UDRIVE contained faulty signals and hence such records were excluded from further study. Few of the records with sufficient data had poor quality video. Such records also had to be excluded because due to the difficulty in identification of timestamps near the speed camera. .
- **<u>Road lane:</u>** Roads with a physical barrier between the opposite lanes were preferred initially. However, due to lesser number of such roads with cameras, some camera sites with two undivided opposite road lanes (no physical barrier or separation in between) were considered as well. This was troublesome as

the speed cameras were intended to capture the vehicles of a particular lane (specified direction) only. This was a trouble as there was no visual separation in the vehicle traces plot. The camera radius couldn't be defined for such roads. This issue was resolved by the video analysis of records of such locations.

- **Timestamp values:** As mentioned earlier, each data segment is expected to contain data from 50s before the camera to 50s after the camera. This value was not suitable for few records which had a timestamp values lesser than 50s. Hence, such records were removed.
- **Time gap:** A time gap value of 0.5s was used for filtering the records. The reason for adopting time gap is to eliminate the influence of the vehicles in front. Very low time gap indicates the presence of other vehicles in the proximity (in front) of the subject vehicle. This affects the vehicle parameter profiles like speed, acceleration etc. This influence overrides the camera influence on the vehicle. Hence, a reasonable time gap of 0.5s was set as a lower limit. This value was found to be reasonable based on the video analysis from the UDRIVE. The records with time gap lesser than 0.5 s were rejected.

Based on the filtering criteria described previously, the overall records were further reduced, and the number of records rejected for different criteria is as shown in Figure 7.

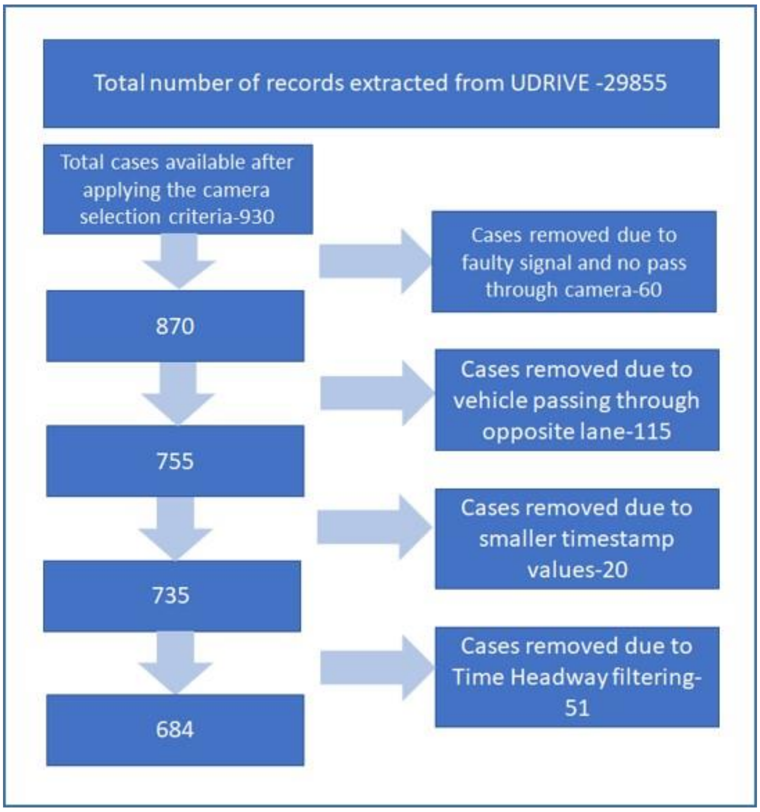

Figure 7: Flowchart depicting the filtering of records

4.3 Speed Profile Analysis

In this chapter the methodology used behind the speed profile analysis for the different types of speed cameras will be explained in detail. The speed camera types include single point cameras, average speed cameras and variable speed cameras. The influence of speed cameras on driver's behaviour will be assessed by considering the individual speed profiles of various drivers depending on the camera location site.

4.3.1 Single Point Cameras

In case of a single spot camera, the timestamps of 50 seconds before the camera and 50 seconds after the camera were considered, as explained in the previous section. Hence the speed of the vehicles for 100 seconds were extracted and plotted. Further, the average speed was calculated for the entire section(100 seconds) of data considering the speeds of all the drivers. This average speed was then used to convert the time values into distance values with reference to the camera position. Similar speed profiles were generated for 15 other locations.

It was very important to make note of a few other factors which can bear an effect on the driver's behaviour apart from that of a camera. For example, traffic signals, diversions, roundabouts, intersections, and change in posted speed. Some of these factors have been indicated in the plots in Section 5. A similar approach was carried out in the case of Variable Speed Cameras.

4.3.2 Average Speed Cameras

For the analysis of average speed cameras the selected data range consisted of kinematic data for approximately 50s before and after the first speed camera. Similarly, data for 50s before and after the second camera was collected. If the second speed camera is placed 50s after the first camera, a total of 150s of data was collected.

4.3.3 Continuous Speed Cameras

Continous Speed cameras are not a different type of speed cameras by any means. It is just two different single point cameras placed on the same stretch of road. Such an approach was considered to analyse the driving pattern across the cameras and compare the behaviour with the average speed cameras. The data considered for the analysis was for a total of approximately 100s which consisted of both the speed cameras but unlike the average speed camera, in this case the speed data for the second camera lies within the speed data of the first camera i.e., within the 50s after the first speed camera.

4.4 Influence Area Analysis

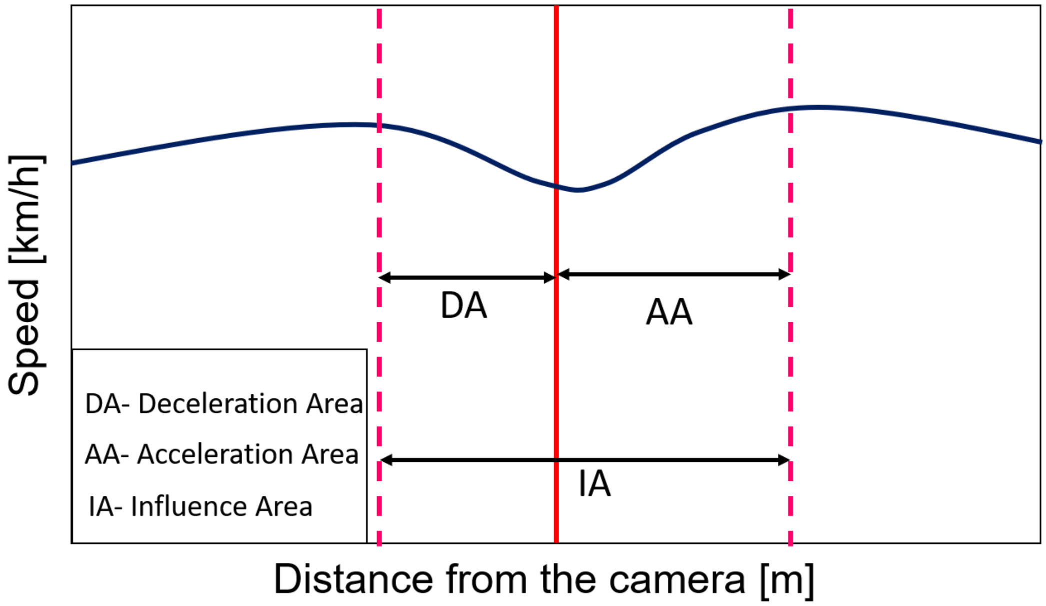

Figure 8 Sample plot depicting the Influence Area

The methodology to find the influence area of the camera is as depicted in the Figure 8. The influence area analysis was carried out by selecting a range of data points in the vicinity of the camera (from 300-500 m before to 300-500m after the camera). For the area before the camera, the distance from the point (called start point here) where the speed starts to drop until the camera was considered as the Decelerating Area. The speed at thestart point was also noted down and compared with the speed at the camera position to find the speed drop in km/h and in terms of percentage. Subsequently to calculate the influence area after the camera, the distance from the camera position until the point (called end point here) where the speed reaches a maximum speed and stabilises was considered to be the Acceleration Area. The speed at camera was then compared with the speed at the end point to find the increase in the speed in terms of km/h and percentage. The total distance from the start point to the end point was termed as the Influence Area.

5 Results

This section describes the results from the driver behaviour analysis near the speed cameras. This section is divided into two sub-sections. The first sub-section describes the speed profiles for the different types of cameras. The second sub-section deals with the analysis of the influence area of the speed cameras. A total of 11 single spot cameras were analysed (9 from the UK and 2 from Poland) and 1 average speed camera was analysed.

5.1 Speed Profile Characteristics

The pattern of the speed profiles near the speed cameras are discussed in this section. As the speed profiles were observed to be influenced by the speed cameras, a significant variance in the profiles were observed. The characteristics of variance in speed profiles was found to be influenced by the type of the camera in use and is described in the following sections.

5.1.1 Single Spot Camera

A speed profile for a single spot camera for one out of eleven locations studied is shown in Figure 9.

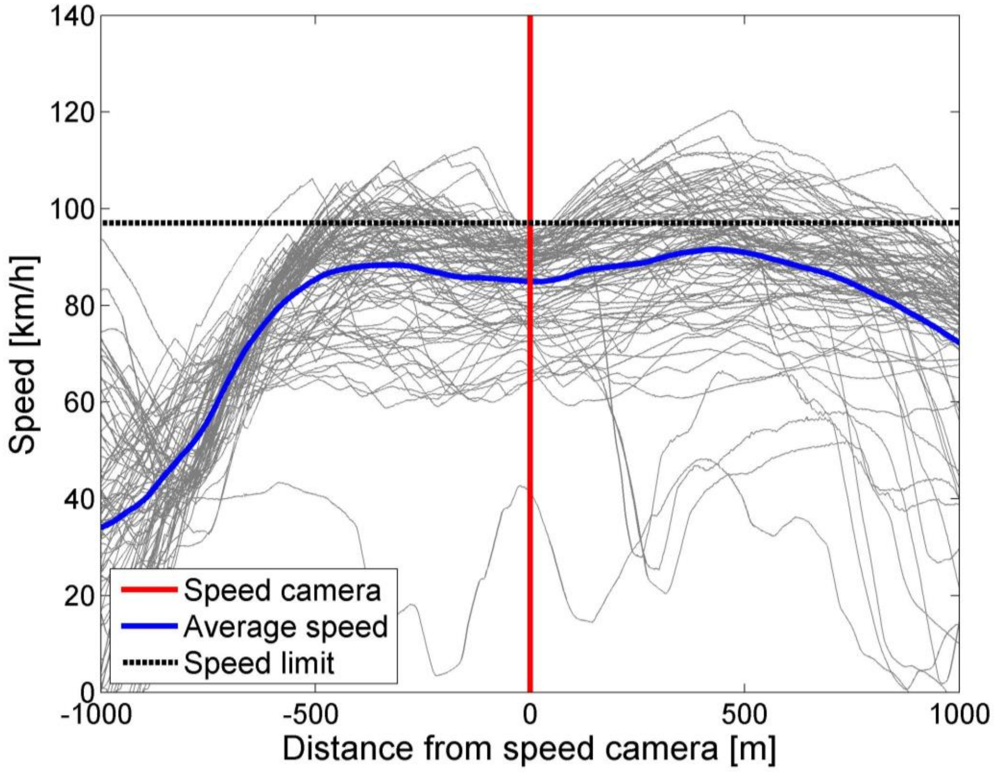

Figure 9: Speed profile for a single spot camera

A few locations with single spot cameras showed a nearly similar pattern in the speed profile. It is clear from Figure 9 that the drivers follow a particular driving pattern or behaviour near the speed cameras. Some of the drivers are seen to be exceeding the posted speed limit, slowing down in the vicinity of the camera (before the camera) and accelerating after the camera resulting in V-profile in speed. This effect of the camera on the drivers is called the kangaroo effect [9], which can be clearly seen from the average speed profile as shown in the same figure. The same speed profile analysis were carried out for the remaining 10 single speed camera locations as well. However, certain locations do not yield the same profile due to certain factors which will be explained in Section 6.1

5.1.2 Average Speed Cameras

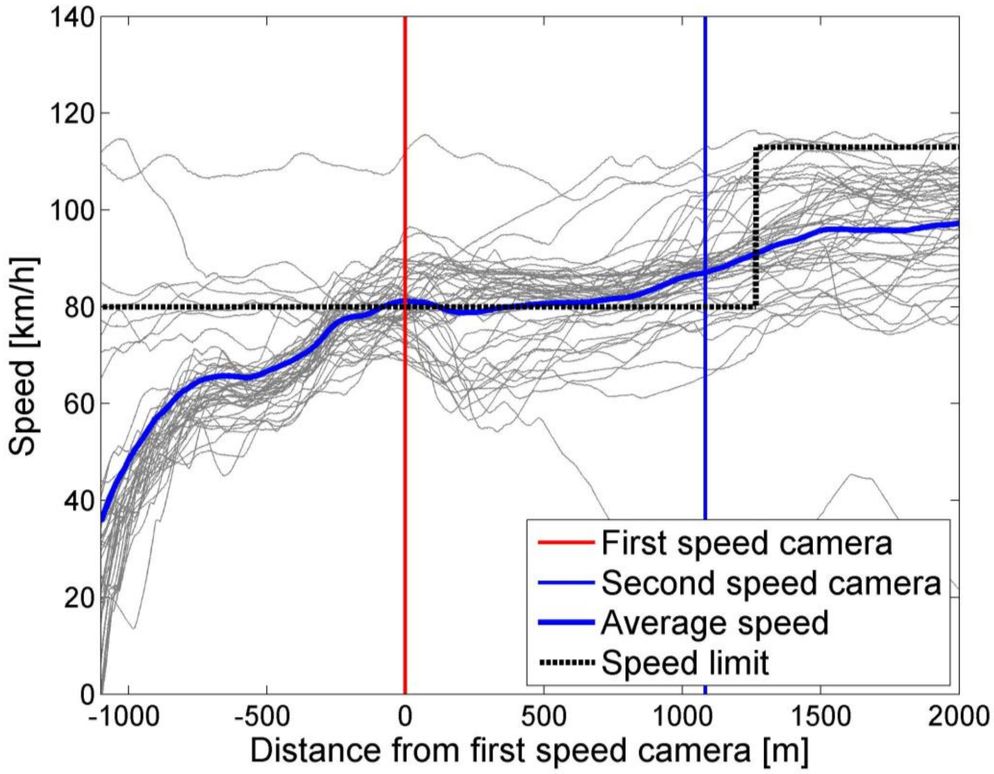

Figure 10: Speed profile for an average speed camera

A variation in the speed profile was observed in comparison with the single point cameras. The V-profile which was observed in case of single spot cameras was not observed here. The speed profile for an average speed camera is shown in Figure 10 . The low speeds that is seen before the first speed camera is due to drivers entering the motorway from a deviation.

The cameras were found to have influence on the speed profile for a particular section of road unlike the single spot cameras which typically influenced speed reduction at the camera spot. Drivers tend to reduce the speed after the first camera and try to maintain a constant speed. The reason for such a behavior might be attributed to the operating principles of an average speed camera. As these cameras monitor the average speed of the vehicle for a particular section of road, consisting of two or more cameras (two in the example shown in Figure 10), drivers tend to be conscious about their speeds for the section of the road covered by the cameras. Hence, a stable speed pattern (approximate) can be observed between the cameras.

5.1.3 Variable Speed Camera

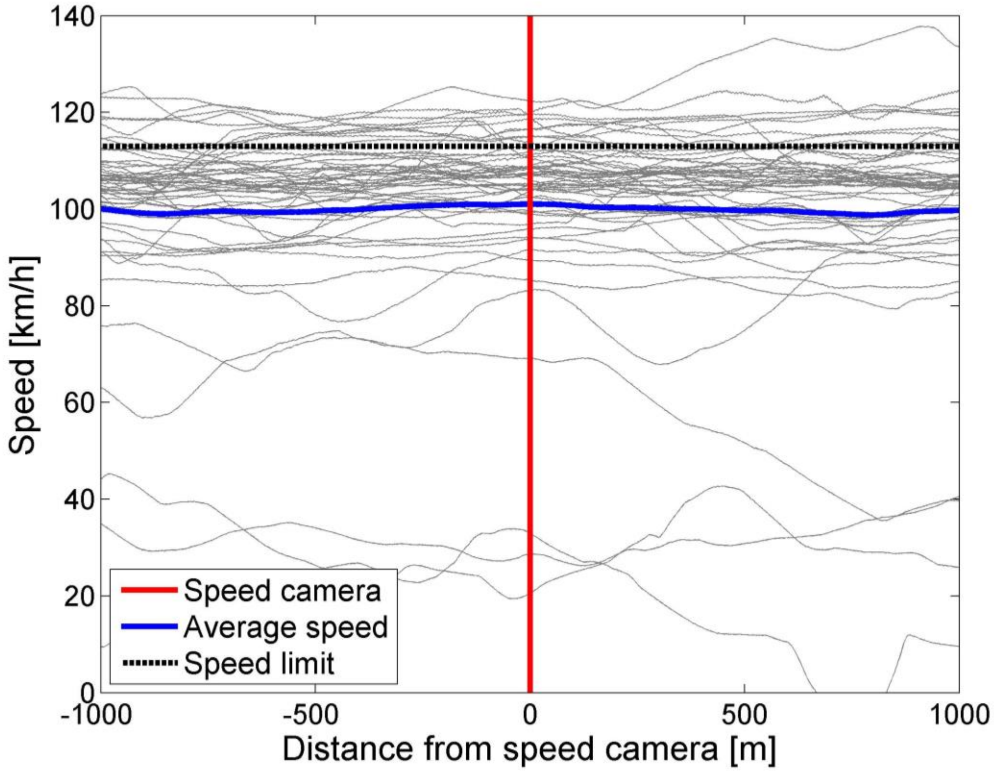

Figure 11: Speed profile for a variable speed camera

The speed pattern for majority of drivers was found to have no significant variations near the speed camera. There is no evident influence of the speed camera on the speed profile. The reason for such unaltered behaviour again owes to the operating principles of the camera. These cameras operate, or are activated, only when the speed limit is temporarily lowered. No change in the imposed speed limit during majority of the time of data collection could be the possible reason for such a speed pattern indicating no influence of the speed camera on the driver behaviour as shown in Figure 11.

5.1.4 Continuous Speed Cameras

The change in the speed pattern for both the cameras was found to be similar. An evident V-profile is observed in the proximity of both of the speed cameras as shown in Figure 12. For each of the continuous speed cameras, the drivers were found to react in the same way as in a single spot camera.

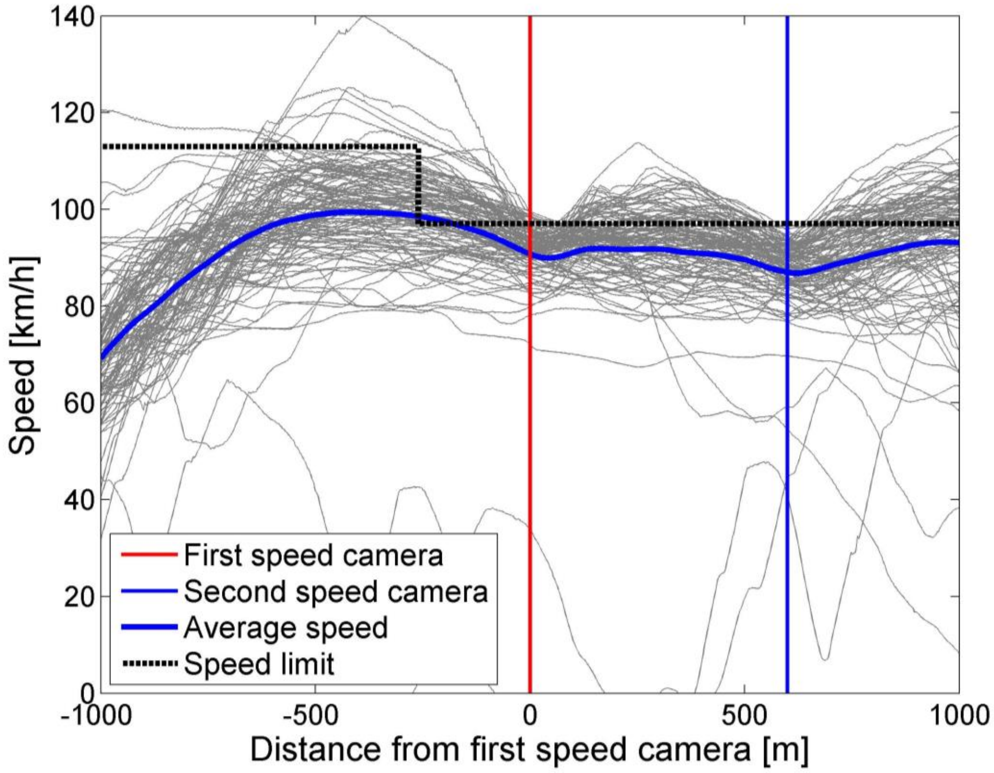

Figure 12: Speed profile for a continuous camera setup

5.1.5 Time Gap Comparison

To study the influence of time gap on the speed variation, a time gap value of 4 seconds was chosen. As depicted in Figure 13, speed drop was observed to be higher in case of time gap greater than 4 seconds and lesser in case of time gap lesser than 4 seconds with the values 1.23m/s (4.44km/h) and 0.79m/s (2.86km/h) respectively. As the time gap of greater than 4 seconds indicates a free flow of traffic (i.e., the driver can decide his/her own speed without any influence from the vehicle in front), the vehicle speeds were found to be influenced more by the speed camera compared to when time gap lesser than 4 seconds.

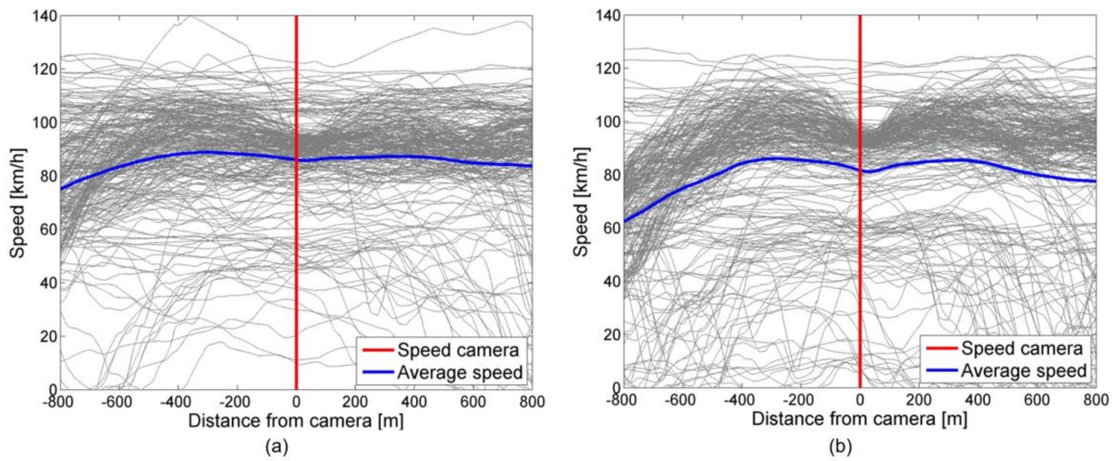

Figure 13: Time gap comparison, (a) being for less than 4 seconds and (b) more than 4 seconds

5.1.6 Acceleration Profile Characteristics

The overall mean longitudinal acceleration profile for all the locations in the UK combined indicated that the deceleration before the camera started from a distance of 108m before the camera and the acceleration distance to be around 81m after the camera summing up for an influence area of 189m. The deceleration before the camera was found to be 0.07m/s^2 and the acceleration after the camera was found to be 0.2 m/ s^2. The longitudinal acceleration profile indicated in the figure clearly shows that the speed camera has influenced the drivers to brake before the camera and accelerate after the camera.

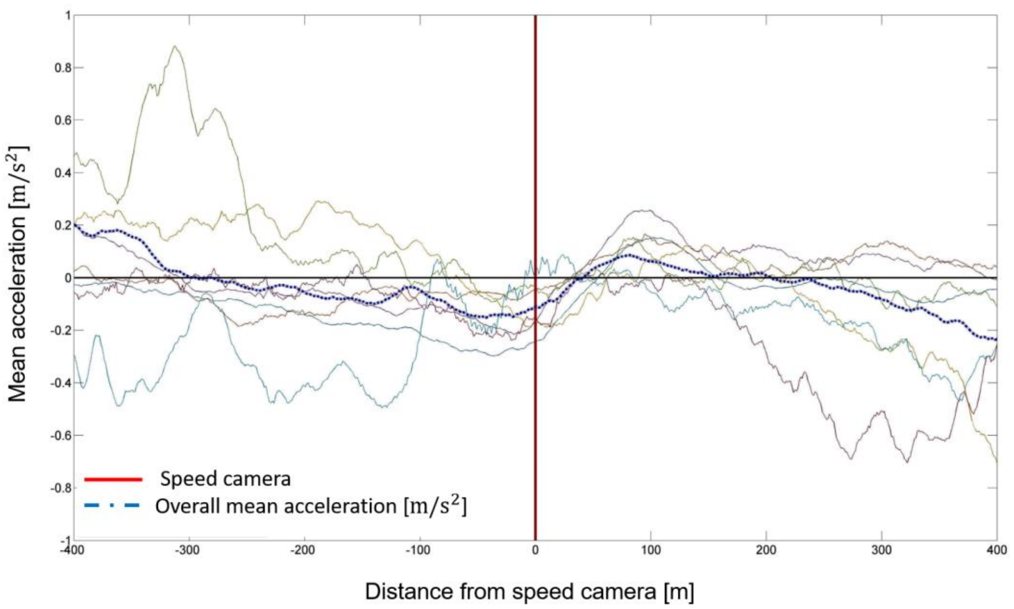

Figure 14: Acceleration profile for a single spot camera

5.2 Influence Area Analysis

In this section, the segment of the speed profile which is affected due to the presence of a speed camera is described. The influence area comprising of deceleration area and the acceleration area for different locations are shown in Table 3 and Table 4. Significant differences in the values were observed for different locations. The reasons for such differences might be the road infrastructure, posted speed limits and traffic conditions. Various road infrastructural elements like traffic signals and roundabouts were observed to influence the vehicle speeds, i.e., travel speeds were lowercompared to the travel speeds observed on the roads in absence of such infrastructural elements. On the same lines, posted speed limits were also observed to influence the vehicle speed profiles. Speed drops in presence of speed cameras on a higher speed limit roads were higher compared to lower speed limit roads. The median value for the decelerating distance, accelerating distance and influence area were found to be 182m,166m and 428m respectively for the selected locations in the UK. For Poland, the values were 194m,125m and 319m respectively.

Table 3: Influence area specifications for locations in UK

Location ID	Braking distance [m]	Accelerating distance [m]	Influence area in [m]	Speed Camera Type
1	262	166	428	Single Spot
2	303	364	667	Single Spot
3	316	434	750	Single Spot
4	182	399	581	Single Spot
5	62	114	176	Single Spot
6	130	145	275	Single Spot
7	300	151	451	Single Spot
8	56	223	279	Single Spot
9	79	85	164	Single Spot
10	260	128	388	Average Camera

Table 4:: Influence area specfcations from sigle spot camera locations in Poland

Location ID	Braking distance [m]	Accelerating distance [m]	Influence area in [m]
11	155	71	226
12	233	179	412

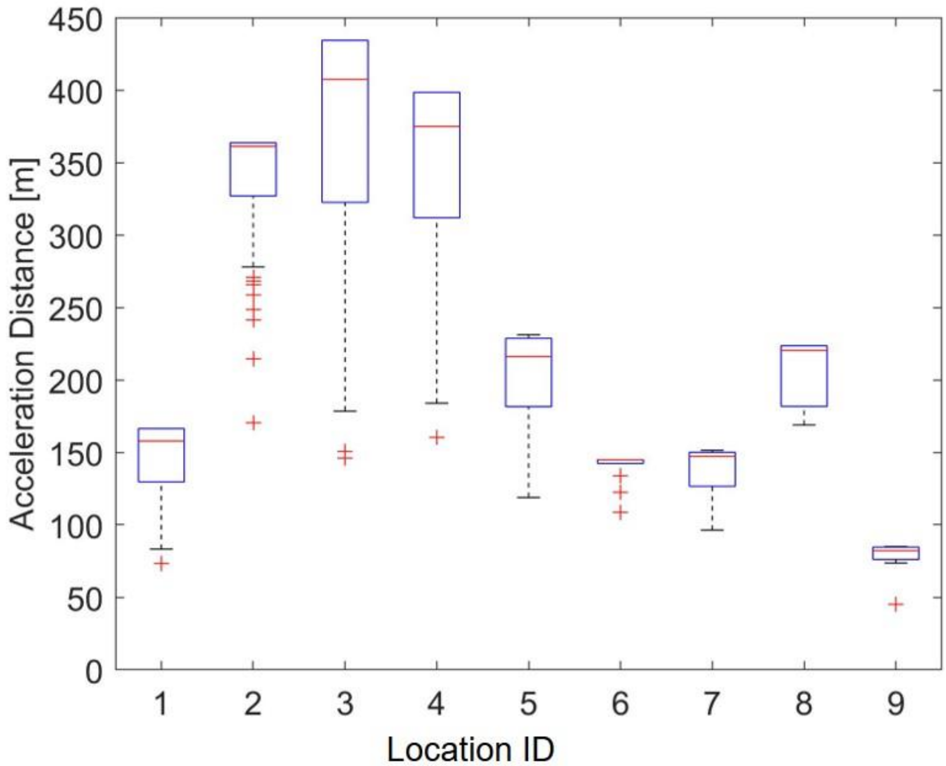

Figure 15: Boxplot depicting the variation in the acceleration distance for the single spot cameras in the UK

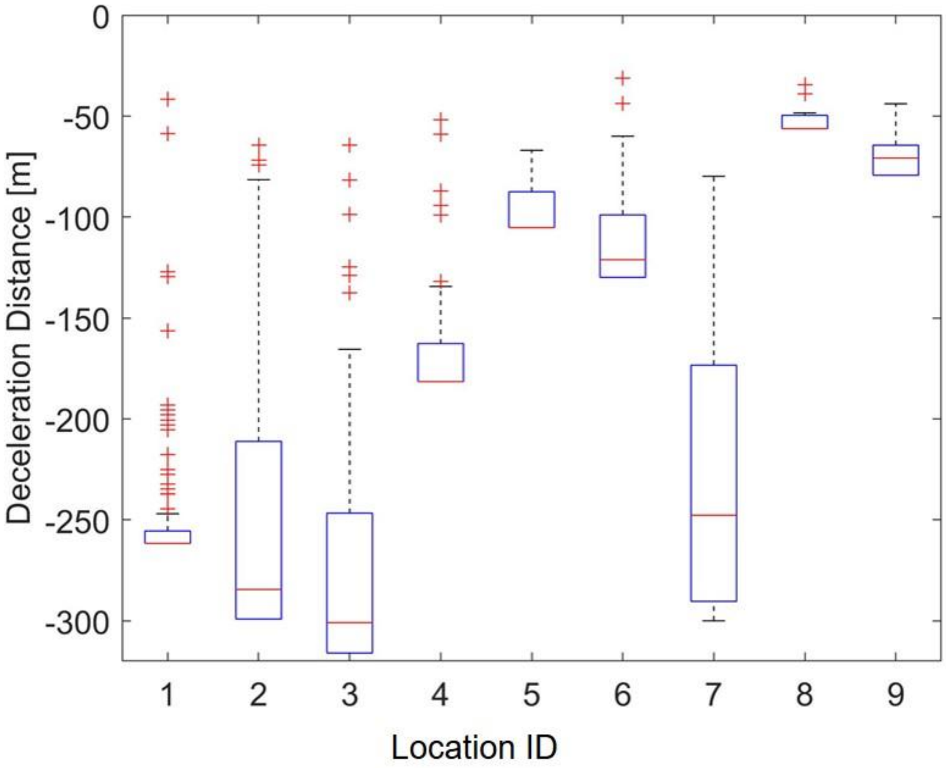

Figure 16:Boxplot depicting the variation in the deceleration distance for the single spot cameras in the UK.

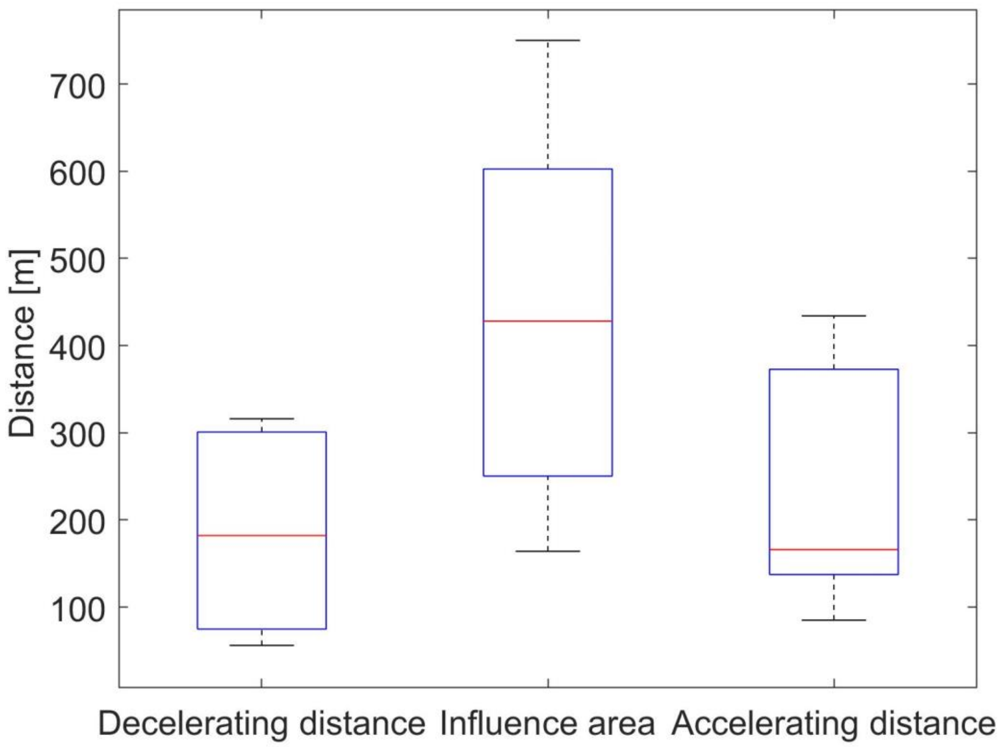

Figure 17:: Boxplot depicting the overall acceleration distance, deceleration distance and the influence area for the single spot cameras from the UK

5.3 Regression Analysis

The regression analysis were carried out to check if speed limit played a role in affecting the speed drop and the deceleration distance. The results from the regression analysis using the SPSS software are as shown in Table 5. The result is briefly presented in this section. The significance and the Pearson correlation are as shown in the table.

Table 5: Results from the regression analysis in SPSS

Dependent variable	Pearson Correlation (R)	R^2	Statistical significance (p)
Braking Distance	0.793	0.6288	0.009
Speed drop	0.612	0.3745	0.054

The results indicate that there is a strong linear correlation between the speed limit and the braking distance with the value of R equal to 0.793. The statistical significance value the "p" value for braking distance is 0.009 ($p<0.05$ is the condition which rejects the null hypothesis) hence rejecting the null hypothesis. Rejecting the null hypothesis means that there is a relationship between the two variables i.e., speed limit and the braking distance in this case. However, there seems to be a weak correlation between the speed drop and the speed limit. This evident from the "R" and the "p" values. These trends observed are with a small size of variables. It would be interesting to observe the trend with a larger count.

6 Discussion

In this chapter the results from the speed profiles, how the different types of cameras affect the driver behaviour and the influence area of the camera are discussed. Also the results from the influence area are compared to the previous studies. A total of 9 locations were considered for the analysis of single spot speed cameras, one location for the average speed camera and two locations for the variable speed cameras from the UK. Two locations were selected for the analysis of the speed profile from Poland.

6.1 Speed Profile

In this section the results from the speed profiles is discussed. The common behaviour of the drivers that could be observed from the data near the single spot camera locations were to decelerate before the camera to make sure they were within the posted speed limit and start to accelerate just as they passed the camera. This behaviour shows that few drivers did not wish to follow the posted speed limit in the absence of a speed camera which is evident from the variation of the average speed profiles before and after the speed camera location.

The average drop in speed for the nine locations from the UK was observed to be varying from 0.30 m/s(1.09km/h) to 2.17 m/s (7.83km/h) with the overall mean drop in speed found to be 0.87 m/s (3.13km/h). The huge margin in the variation is attributed to a couple of factors like posted speed limit at the camera site and the infrastructure in the proximity of the camera site. The speed drop does not solely depend on these factors individually but also as a combination of these factors. Similar reasoning applies to the average rise in speed as well, with the average speed rise values varying from 0.11m/s (0.4km/h) to 2.19 m/s (7.88km/h) and overall mean speed rise for all the locations from UK was 0.89 m/s (3.20km/h). The values for the overall mean speed drop and speed rise are very close to each other showing us that there is a similar pattern in the variation of speed before and after the camera. The results from the analysis carried out for the two locations from Poland show that the overall mean drop in speed was 1m/s (3.6 km/h) and overall mean rise in speed was 1.005m/s (3.61 km/h). Since these results are from just two locations it would be inappropriate to compare them with that of the UK However, during the video annotation for Poland it was observed that the drivers were more aggressive in terms of braking and accelerating in proximity of the camera. Unfortunately it was not possible to find more locations and extract braking related kinematic parameters to support this statement.

Previously conducted study by De Pauw et.al., [6] found that the average drop in speed of 1.2m/s (4.33km/h) and 2.34m/s (8.44km/h) for two locations in the Netherlands. The distance considered in the mentioned study is 2.5-3 kilometers before and 3.3-3.8 kilometers after the camera. The disparity in the results considering the mean drop in the speed for the mentioned study and for the present study can be attributed to the nature of study being totally distinct from each other. The mentioned study collected the vehicle speeds using Infra-red Traffic Logger and the drivers having no knowlegde about the speed collection. Also, the number of vehicles from which the kinematic data were collected were in thousands when compared to 30 drivers from the naturalistic study. Mountain.et.al [22], and Shin et.al.[23] found that at the camera sites an average of 11% speed reduction was found which according to a power model of speed could be expected to reduce injuries due to crashes by 18%.

The mean speed profile analysis for the average speed camera location showed a completely different behaviour of the drivers when compared to the single spot speed cameras. There was no evidence of the kangaroo effect in the case of average speed camera as the drivers try to maintain a constant speed level between the section of the two cameras. It is interesting to note down here that even though a few drivers/records are seen to be exceeding the speed limit, they are driving at a constant speed throughout the section. This behaviour can be due to the drivers' unawareness of the posted speed limit or a different percieved speed limit. During the analysis phase it was observed that there were a couple of average speed cameras placed further down the same road but with a higher speed limit, this could have contributed for the driver to percieve a higher speed limit. Another reason could be disability of the drivers to recognize the camera from a certain distance as compared to a single spot camera which has a more noticeable appearance. The mean speed of all the driver/records for the section between the speed cameras was 82.78km/h, exceeding the posted speed limit 80 km/h by a small margin. It can be said that average speed cameras have a better effect on the speed enforcement if the drivers have a better knowledge about the speed limits and the cameras made more recognizable. Previous studies have shown the average speed cameras or section control cameras to be more effective in terms of crash reduction in comparison with single spot speed cameras [11] [22].

6.2 Influence area

The influence area of the speed camera was analysed by using the average speed profile generated for each location previously mentioned. The deceleration distance and the acceleration distance add up to result the influence area. Observing the outcome of the deceleration and acceleration distances from the present study it can be said that the respective values vary from location to location drastically. For all the single spot camera locations from the UK the deceleration distance ranges from 62m to 316m with the mean value being 187m where as the acceleration distance ranges from 85m to 434m with the mean value being 231m. The speed limit in the vicinity of the camera affects the braking distance. The braking distance was found to be dependent on the speed limit. The reasoning for this dependency could be the fact that when the speed limit is on the higher side (for example 80-120 km/h), drivers usually need more time to slow down hence the braking or the deceleration starts from a farther distance. When the speed limit is on the lower side (for example 40-60 km/h), the drivers can slow down from a closer distance to the camera. Other factor like infrastructure (distance from the red light signals or roundabouts or the camera signboard to the camera) also affect the braking distance but they do not have an individual effect on these values but more of a combined effect. For example if the speed limit is on the lower side (40-60 kmph) and if there is a roundabout at a certain distance before the camera, then the presence of roundabout will further lower the speed of the vehicle thus decreasing the influence area of the speed camera.

The mean influence area in the present study was found to be 418m. But, according to a previous study conducted in China by Liu et.al. [20], the influence area was found be less than 1km. The deceleration distance was 300 to 400m before the camera and the acceleration distance was also about 300-400m after the speed camera. Again the mentioned study collected speed data directly at various distances from the camera sites. However, a similar study carried out by D. Falci de Oliviera et.al. [21] shows that drivers start speeding at a distance of 200m after the speed camera which matches closely with the present study. From the analysis carried out for two locations in Poland, the mean value for the influence area of the speed camera was found to be 319m. Studies conducted by Ziolkowski et.al. [23] for different locations in Poland show that the influence area of a speed camera is 286m, which in a way agrees with the present studies, considering the nature of the studies being similar. In the mentioned study the speeds were measured using a GPS data logger and a total of 4 drivers volountering.

Results from a study carrieed out by Alena Høye [24] indicates that the effects of speed cameras decrease with increase in the distance from the camera. The same author in a similar study states that the number of injury crashes decreased by 18% at a distance of upto 250m from the camera site. A study by Mountain et al. [22] where different sets of distances from the camera were studied in order to analyse at what distances the speed cameras had an effect on the drivers. The strongest effect according to the mentioned study was at 250m from the camera with 25% reduction in injury crashes. While considering 250-500m the reduction in crashes fell to 15% and further to 12% for 500-1000m. Also according to Hess [27], who analysed the effects of speed cameras at distances of 250m, 500m 1000m and 2000m found that the most significant effects were in close proximity of the camera with a 46% reduction in the injury crashes. As the distance increased to 500, 1000 and 2000m the effect decresed as reduction in injury crashes dropped to 41%, 32% and 21% respectively. Comparing to all these studies the influence area found from current study shows a positive approach towards the reduction in injury crashes if it can be linked with a crash database for future studies.

By observing and comparing the results between a single spot speed camera and an average speed camera, it does not make justice to place one type of camera over the other. Single spot speed cameras have been effective for a certain distance before and after the camera but fails to ensure that the majority of the drivers are compliant with the speed limits 231m after the camera. Speed cameras can be placed at frequent intervals in order to overcome this practice by the drivers but at the same time the investment and operational costs could soar up.It is a good option to place mobile speed cameras immediately after the influence area of fixed speed cameras, but this will require a large human resource and can be confined to time. It would be logical to place non-operational speed cameras at frequent intervals to make the drivers feel that they are being monitored. In the U.K. cameras have been shut down in the past due to insufficient funds, but their stuctures were left intact so that the drivers assume cameras are still active and adhere to the speed limits [28]. While speaking about the average speed cameras, it can be said as the major solution to the problems of the fixed speed cameras. Average speed cameras encourages the drivers to cut down on speed over a larger sections of road and also influence the driver behaviour drastically. The results from the literature review carried out for the current study showed that average speed cameras have a better effect on speed reduction and thus injury crash reduction when compared to the fixed speed cameras. Although the data analysed here suggests that the average speed of the vehicles passing through the two cameras had a marginally higher speed than the posted speed limit, —one can see that the average speed cameras take the kangaroo effect out of the picture and bring in less variation of vehicle travel speed. Previous studies carried out by Wegman et al. [29] shows that the acceleration and deceleration effect caused due to the fixed speed cameras have an adverse effect on the traffic flow. This issue can be eased out by implementing average speed cameras which also helps in reduction of travel times especially during the peak hours as suggested by Cascetta et al. [30].

Therefore, it would be logical to install average speed cameras on motorways and expressways where usually the speeds are high and would require speed monitoring over a stretch of the roadway. On the other hand, single spot speed cameras could be used for speed monitoring across a particular spot or junctions on the roadways. Certain junctions like schools, hospitals and pedestrian crossings would require single spot cameras.

7 Conclusion and Limitations

7.1 Conclusion

Speed cameras are observed to influence the driving behaviour of the drivers as shown by the variation in the speed profiles. In case of single spot cameras, drivers are found to drop the speed before the camera and increase it after passing the camera resulting in a V-profile in speed called the “kangaroo effect”. On the other hand, the average speed cameras were found to be responsible for a consistent speed profile for an entire section of road covered by the cameras. The drivers were found to drop the speed at the first camera spot and tried to maintain a consistent speed through to the final camera spot. Hence, average speed cameras are best suited for a speed controlled section of road compared to single spot cameras which are more suitable for a very short speed reduction zones. No influence on the speed profiles were found in the presence of (inactive) variable speed cameras. Hence, the driver behaviour is greatly affected by the type of camera in use. The posted speed limit was observed to influence the braking distance before the camera. The decelerating distance was found to be larger when the speed limits were on the higher side (for example 80-120 km/h).

7.2 Limitations

7.2.1 Small Amount of Data/Camera Location Fulfilling Filtering Criteria

The dataset used for the study consisted of few locations in the UK and Poland. However, when the camera locations were identified and chosen from the Google maps and verified for the vehicle passes and other filtering criteria described in Sections 4.1and 4.2 were applied, most of the locations had to be removed and the overall number of locations reduced. For Poland, the final number of locations dropped down to just three which is not sufficient to represent the general variation in speed profile for the entire country.

7.2.2 Small Number of Drivers Passing Through Each Location

In most cases, the speed pattern for the location was observed to be very similar. A possible reason for this was the small number of drivers passing through each selected camera location. Due to this, the overall trend of the speed variation depended on the driver with maximum passes. In a few locations, almost all the records belonged to a single driver. Owing to this limitation, it is difficult to generalise if the driving pattern observed here will be representative of a wider population of drivers.

7.2.3 Small Size of Suitable Data due to Naturalistic Study

Since the data used here is from a naturalistic driving study, the analysis had to be based on the availability of data i.e., the analysis had to be performed with reference to the vehicle traces already available unlike the experimental study which could have been set to be performed on the locations required for the analysis with large enough number of drivers.

8 Future Work

The study could be performed with more number of drivers and locations enhancing the results which could help in better interpretation of the results. With more data, the analysis becomes more representative and indicative compared to a small amount of data.

Currently, the study is based on the variation of speed alone. The study could take into account various other parameters like brake activation signals and brake pressure signals to depict the exact braking behaviour of the drivers.

Various other influential parameters like weather conditions and lighting conditions could be integrated to the study as these parameters have a significant influence on driving behaviours.

The study could be extended to various geographical regions to know the similarities or differences in driving pattern. This could help in understanding the influence of local cultures on driving behaviour.

As discussed earlier the influence area found in the current study matches closely with the previously carried out studies which showed reduction in the level of injury crashes. It would be interesting to relate the current study with the crash database in those regions to cross check if the speed cameras have been effective to an extent or not. This will also help in better placement of the cameras in the future.

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