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School of Transportation Sciences

Master of Transportation Sciences

Master's thesis

Acceleration / deceleration behaviour in the vicinity of speed cameras / speed section control

Jean Felix Tuyisingize

Thesis presented in fulfillment of the requirements for the degree of Master of Transportation Sciences, specialization Traffic Safety

SUPERVISOR :
Prof. dr. Tom BRIJS

MENTOR :
Mevrouw Jana HOREMANS

2022
2023

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ABSTRACT

This study investigated the impact of speed enforcement devices, specifically Average Speed Section Control (ASSCs) and fixed cameras, on acceleration and deceleration events within their vicinity. The research employed advanced statistical and Geographic Information System (GIS) analysis methods to uncover patterns of driver behavior in relation to these enforcement systems.

The findings confirm the null hypothesis, indicating a notable concentration of events within a 600-meter radius of enforcement devices, suggesting their influence on driver behaviors within a specific range. However, the majority of these events are of low severity, suggesting that drivers may not significantly alter their speed upon encountering these devices. This could be attributed to several reasons such as drivers maintaining safe speeds or the usage of real-time in-vehicle intervention systems. The complexity of driver behavior is also highlighted, indicating the potential influence of factors like traffic density, road conditions, weather, time of day, and driver characteristics.

Further, the study highlighted that high-severity events often occurred outside speed enforcement zones, particularly around intersections, indicating these as potential hotspots for drastic speed changes. These findings call for a broader perspective on traffic safety interventions, beyond reliance on speed enforcement devices. However, the study acknowledges certain limitations, such as its reliance on secondary data and specific geographical focus, which may impact the broad applicability of the findings. Additionally, the severity of speed modification events was also categorized into low, medium, and high, which could oversimplify the continuum of speed changes and potentially mask trends within each category.

This research contributes valuable insights to traffic safety and driver behavior literature, illuminating the complexity of driver behavior and the potential influence of factors beyond the presence of speed enforcement devices. Future research directions may employ various categories of events severity, and may also explore the role of in-vehicle technologies, driver characteristics, and a broader set of environmental variables in driving behavior and traffic safety.

Key words:

Average speed section control (ASSC), Fixed camera, Acceleration and deceleration events, Real-time interventions, speeding, virtual camera site.

ACKNOWLEDGMENTS

I would first like to express my deepest gratitude to my supervisors, Prof. Dr. Tom Brijs, and Ms. Jana Horemans, whose expertise, understanding, and patience, added considerably to my experience as a postgraduate student. Your constant guidance, constructive criticism, and inspirational discussions have undoubtedly been instrumental in shaping this research.
I am incredibly grateful for the generosity of the Transportation Research Institute (IMOB) and the team behind the i-Dreams project for providing the crucial data which made this research possible. Your dedication to open research and the advancement of knowledge is deeply appreciated.

A heartfelt thank you goes to my colleagues and fellow students at Hasselt University. Your support, encouragement, and friendship made this journey not only more manageable but also more enjoyable.
I also wish to acknowledge the role of [any other person or entity that has helped in your research or writing process for example, any editors, proof-readers, or funding bodies].

Lastly, but by no means least, I extend my deepest gratitude to my family and friends. Your unwavering faith in my abilities, along with your love and support, were the pillars that kept me standing throughout this demanding journey.

The completion of this thesis would not have been possible without the support and patience of all of you, and I am eternally grateful. Please note that while I am profoundly appreciative of all the assistance and support I received, any errors or shortcomings in the thesis are entirely my own.

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List of abbreviations

A&D: Acceleration and Deceleration
A/D: Acceleration/Deceleration
AASHTO: American Association of State Highway and Transportation Officials
ASSC: Automated section speed control
BD72: Belgian Datum 1972
CSV: Comma Separated Values
EPSG: European Petroleum Survey Group
ETSC: European Transport Safety Council
FHWA: Federal Highway Administration
FMCSA: Federal Motor Carrier Safety Administration
GIS: Geographic Information System
ID: Identity
IMOB: Instituut voor Mobiliteit (The Transportation Research Institute)
ND: Naturalistic Driving
NHTSA: National Highway Traffic Safety Administration
OSM: Open Street Map
QGIS: Quantum Geographic Information System
SARTRE: Social Attitudes to Road Traffic Risk in Europe
SPSS: Statistical Package for Social Sciences
WGS84: The World Geodetic System 1984
WHO: World Health Organization

1. INTRODUCTION

1.1. Background information

Excessive speed is the cause of many road accidents and their consequences. Globally, 10 to 15% of all accidents and 30% of all fatal crashes directly result from speeding or inappropriate speed (Wouter V. & Brecht P., 2020). The Royal Society for the Prevention of Accidents (RSPA, 2021) declares that driving speed becomes excessive when it fails to align with the road speed limit, road sight distance, weather and road conditions, and other road users(World Health Organization (WHO), 2004). Higher speeds make it harder for drivers to see and react to what's happening around them. It also makes it harder for cars to stop and eliminates the driver's safety margin, converting near-crashes into crashes (RSPA, 2021;WHO, 2004). Research indicates that an increase in average traffic speed corresponds to an increase in crashes, with severe crashes witnessing a more significant surge. Conversely, reducing the mean traffic speed almost always reduces the frequency and severity of accidents (Nilsson Goran, 2004; Ms Anna Vadeby, Blair Turner, 2018; Elvik et al., 2004). According to Nilsson's power function, a 1% change in speed can lead to a 2% change in injury crash frequency, a 3% change in severe crash frequency, and a 4% change in fatal crash frequency (Cameron & Elvik, 2010).

Furthermore, the drivers whose speeds exceed the average speed of the surrounding traffic by 10% to 15% are considerably more likely to get involved in an accident. In contrast, a reduction of one mph in average speeds could decrease the accident rate by around 5%, with the percentage varying slightly depending on the type of road: a) 6% on main urban roads and residential roads with low average speeds; b) 4% on medium-speed urban main roads and lower-speed rural main roads; and c) 3% on higher-speed urban main roads and rural single-carriageway main roads (RSPA, 2021). The choice of driving speed is influenced by several factors including the driver's motivation, attitude, risk perception, and acceptance, the probability of police control, the vehicle's technical condition, and the characteristics of the road and its surroundings (Kubera et al., 2019). Given the profound link between excessive speed and traffic accidents, controlling vehicle speeds has clear public health benefits (Jones et al., 2008).

To this end, many governments have developed advanced speed monitoring technologies, utilizing fixed and portable cameras and Average speed section control systems, which have been shown to reduce the overall number of crashes by 20%. According to a study conducted in Flanders-Belgium, it was observed that the introduction of speed cameras led to a significant reduction in driving speeds. On average, the speeds decreased by 6.4 km/h at locations equipped with these cameras (Pauw et al., 2014). The study further revealed a substantial decrease in speed limit violations. The probability of drivers exceeding the speed limit decreased on average by 80%, while the likelihood of drivers surpassing the speed limit by more than 10% fell by an impressive 86%.

A separate study by Pauw et al. (2014a) investigated the efficacy of two automated section speed control systems installed on a motorway in Flanders-Belgium. The study found notable changes in driver behavior following their implementation. Specifically, there was an approximate 5.84 km/h reduction in average speed. Furthermore, the study revealed a 74% decrease in the likelihood of drivers exceeding the speed limit, with an even more dramatic reduction of 86% in instances of drivers surpassing the speed limit by more than 10%.

However, despite the positive effect of the speed camera and ASSC in their vicinity, studies revealed that the speed in other uncontrolled areas remains high (Pauw et al., 2014). This is a manifestation of a phenomenon known as the "Kangaroo jump" or "V-profile" behavior around camera/ASSC areas. This phenomenon results from the drivers' tendency to reduce their speed dramatically within a few hundred meters before the camera. Once they have passed the camera, they rapidly accelerate to recover their original speed, typically within a distance of less than one kilometer from the camera's location .

Recognizing and understanding patterns of speeding behavior are fundamental to formulating effective measures to prevent excessive road speeds. In this context, the current study explores the impact of speed enforcement devices, specifically cameras and Average Speed Section Control (ASSC) systems, on driver behaviors, particularly in terms of acceleration and deceleration rates. By evaluating these dynamics, the study aims to shed light on the relationship between the presence of speed enforcement technologies and the resulting driver responses, thereby offering crucial insights that could inform strategies for improved speed management on our roads.

1.2. The problem statements

Higher driving speed is one of the basic risk factors in traffic (Aarts & Van Schagen, 2006). Speeding is a major problem worldwide, contributing to 10-15% of road crashes and 30% of fatal injury crashes (Wouter V. & Brecht P., 2020). The consequences of speeding put the driver's life at risk and the lives of other road users like motorists, cyclists, and pedestrians. Elvik et al. (2004) showed that driving at a higher speed than the posted speed limit increases the chance of being involved in a crash and increases the severity of the crash. Additionally, it leads to higher collision speeds and consequently to severer injury. According to Cestac et al. (2012), higher driving speeds provide less time to process information and act on it, making the braking distance longer. In that context, the possibility of avoiding a collision is smaller. Notwithstanding the negative consequences associated with speeding, many drivers still speed. The SARTRE 3 survey revealed that twenty-four percent of car drivers reported violating the speed limit often, very often, or always on motorways (SARTRE consortium, 2004).

To control vehicle speeds, governments and traffic authorities enforced speed regulations through speed cameras and speed section control, which monitor all vehicle speeds and detect plate numbers to levy penalties. However, studies revealed that speed limit violations are prevalent, even on motorways with speed cameras (Montella et al., 2012). The problem with speed cameras is that they alter driver behaviors, and their effect declines with increasing distance from the speed camera location (Kubera et al., 2019).

Montella et al. (2012) showed that drivers decelerate short distances before the camera and vigorously accelerate above the speed limit just after passing by the camera. The

sudden decelerating near cameras causes the drivers to try to make up for lost time after passing it, and they do this by speeding up resulting into a phenomenon known as the "Kangaroo jump" or "V-profile" around camera/ASSC areas. This intentional speeding ahead of the camera zone increases crash risks and severe injury consequences in zones without cameras (Kubera et al., 2019); (Montella et al., 2012).
In the journey to find the best solution, studies revealed that higher compliance with speed limits might be achieved through a better communication and information strategy for road users before implementing the speed control system (Montella et al., 2011). However, limited empirical studies looked into the acceleration and deceleration (A&D) behaviors in the vicinity of the speed control devices, by employing A&D severity.
Many often focused on identifying the effect of speed control devices to crash reduction by employing speeding data. Contrarily, the primary aim of this research was to explore and elaborate on the influence of the presence of cameras and ASSC systems on the variations in acceleration and deceleration behaviors demonstrated by approaching drivers.
Drawing on Naturalistic Driving data, the study delivers comprehensive insights into these driving behaviors, specifically focusing on the trends in acceleration and deceleration in close proximity to speed cameras or ASSC systems. Additionally, this study discusses its potential limitations and suggests some recommendations for future research. Furthermore, the study also discusses alternative measures to study the drivers behaviors in the vicinity of the speed camera or ASSC. The results of the study will contribute to the field of transportation sciences and could inform policies and strategies for improving road safety. The study's findings may be useful for transportation planners and policymakers in identifying effective speed control measures that improve driver behavior, reduce accidents, and improve road safety.

1.3. Aim of the study and research questions

Speed limits are essential for ensuring safe driving and a crash-free route. However, some drivers' journeys are marked by excessive speeds (High acceleration) and high deceleration. Such behavior can be influenced by several roadway factors, including the presence of speed management devices (cameras). Given the significance of determining factors that can alter the drivers' behavior, this study aimed to investigate the relationship between the speed management devices and Acceleration/Deceleration behaviors. More specifically, the study assessed whether the presence of speed control measures (cameras or Average Speed Section Control) results in a change in behaviors of approaching motorists by influencing their acceleration and deceleration severity.

The study research sub-questions:

- What is the issue with speeding?
- Why do drivers exceed the speed limit?
- Are the acceleration and deceleration behaviors altered by the presence of the speed camera/ASSC
- What are the factors to consider when analysis the influence of the speed management devices to the A/D events?.

- Could in-vehicle data recorders be a valuable data collection method to study driving behavior in the vicinity of speed cameras?.

The study further tested two hypotheses:

Null hypothesis (H0): “*The presence of speed cameras or Average Speed Section Control influences the high frequency of acceleration and deceleration events in its vicinity”*. This hypothesis predicts that the spatial positioning of speed cameras significantly impacts driving behaviors, resulting in a phenomenon known as the "Kangaroo Jump" or "V-Profile" in the camera's immediate vicinity (Pauw et al., 2014). This concept arises from the view that drivers, aware of the camera's presence, alter their usual driving patterns to avoid speeding penalties. Typically, this alteration manifests as an abrupt deceleration as they approach the camera, followed by a subsequent acceleration, resembling a 'V' pattern on speed-time graphs, hence the name "V-Profile". In effect, the study aims to examine how the presence of camera/ASSC shapes the patterns of vehicular A&D in monitored sections of the road. Through the lens of naturalistic driving data, we intend to gain a rough understanding of these behavioral shifts.

Alternative hypothesis (H1):*”The presence of speed cameras or Average Speed Section Control has no significant effect on frequent acceleration and deceleration events in its vicinity”.* The alternate hypothesis in this study predicts that the presence of speed cameras or ASSC systems does not notably influence high frequency of acceleration and deceleration events in the immediate vicinity of these systems. This would mean that drivers maintain consistent driving behaviors, irrespective of the presence of these monitoring systems, and hence, acceleration or deceleration events are not specifically associated with these devices. In other words, this could suggest that speed management systems might not necessarily alter the occurrences of abrupt speed changes.

2. THEORETICAL FRAMEWORK

2.1. Speeding and crashing risks

Speeding has a strong correlation with crashing risks. Several research efforts undertaken in the last few decades have shown a close correlation between speed, road crash frequency, and severity (Reagan et al., 2013). According to Wouter V. & Brecht P. (2020), the risk of a collision increases dramatically as the speed increases. This rise in crash risks is attributable to a motorist needing constant time to react to unexpected situations. In traffic, drivers, on average, need about one second to react to an unforeseen event and choose an adequate response this is called the reaction time. At high speeds, reaction time to unexpected events is shorter, maneuverability is reduced, and stopping distance increases. (Ms. Anna Vadeby, Blair Turner, 2018). It is estimated that 10 to 15% of all accidents and 30% of all fatal crashes directly result from speeding or inappropriate speed. The driving speed becomes excessive when a motorist exceeds the stated speed limit; and inappropriate when a driver drives too fast for traffic, infrastructure, weather conditions, or other factors.

(Elvik, 2009; Cameron & Elvik 2010) show that a change in average speed tends to have a larger effect on crashes and crash severity. If on a particular road, the average speed of traffic increases, the number of crashes will increase, with severe crashes increasing to a larger extent. However, when the mean speed of traffic is reduced, the number of accidents and the severity of injuries will almost always decrease (Elvik et al., 2004). According to the power function Nilsson as a rule of thumb, a 1% change in speed results in approximately a 2% change in injury crash frequency, a 3% change in severe crash frequency, and a 4% change in fatal crash frequency(Nilsson Goran, 2004). Elvik (2011) also confirmed the negative effects of speed in Norway by claiming that the number of deaths would decrease by 20% if all drivers adhered to the speed limits. In addition to average speed on the road, vehicle speed differences also affect crash frequency. The larger the differences, the higher the crash rate (Ms Anna Vadeby, Blair Turner, 2018). The figure 1 illustrates the Relationship between the percentage change in speed and the percentage.

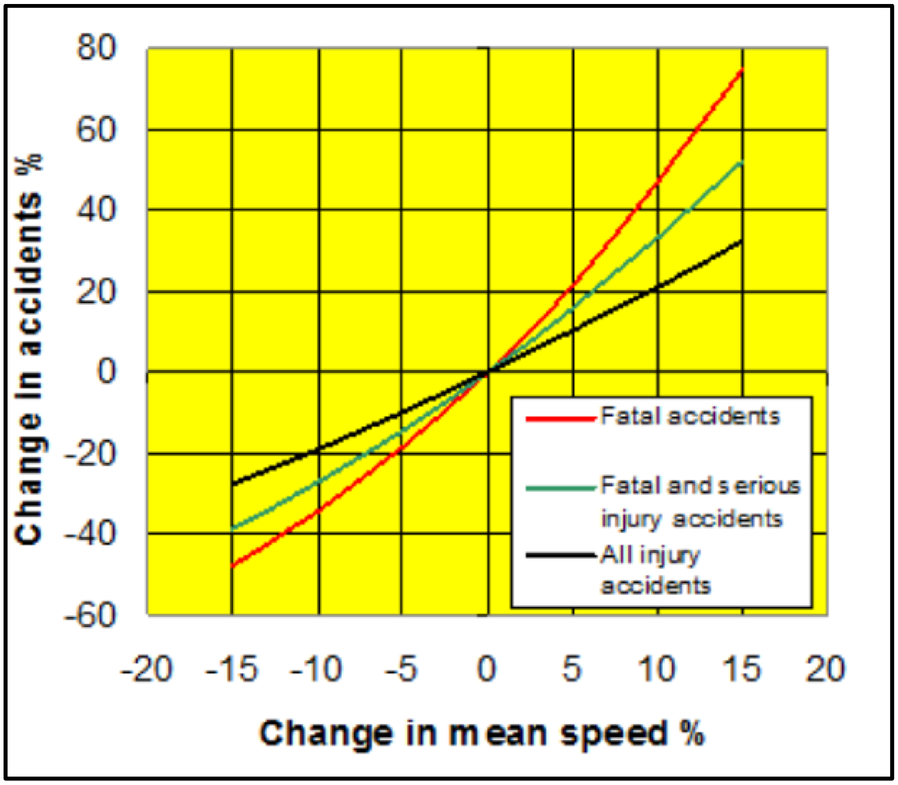


Figure 1: Relationship between the percentage change in speed and the percentage change in crashes rate

Source: Nilsson (2004)

2.2. Excessive speeds and inappropriate speed

The speed is excessive when it exceeds the posted speed limit. For example, if the limit is 60km/h and the driver drives at 70km/h. Whereas, The speed becomes inappropriate when the driver is within the speed limit but too fast based on the prevailing road conditions. For example, in poor weather, road surface conditions, poor visibility, or high pedestrian activity (ETSC, 1995), (RSPA, 2021). Inappropriate speed contributes to around 12% of all injury collisions reported to the police, 13% of crashes resulting in serious injuries, and 24% of collisions resulting in death. This distinction is crucial because a speed limit only defines maximum speeds as the limit. Then, it is up to each motorist to choose what speed, within the limit, is appropriate (ETSC, 1995).

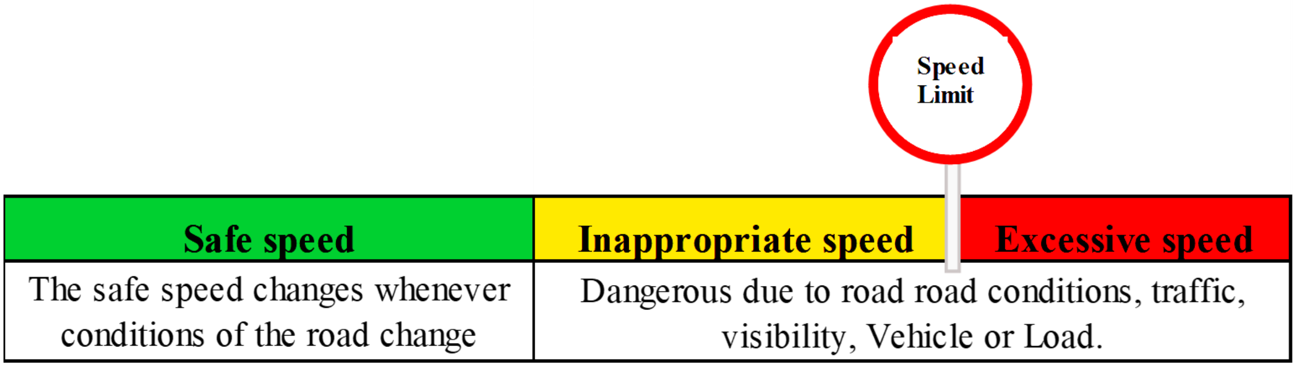


Figure 2: Inappropriate speed vs. Excessive speed

Source: www.drivingtests.co.nz

Safe speed is a speed at which the vehicle can cope with the road conditions, and the driver can steer the car without causing undue danger to other road users (or themselves). Darren Cottingham (n.d) showed that safe speed changes frequently with road conditions. For example, a sharp corner, rain, fog, ice, and sunstrike cause the safe speed to decline.

2.3. External factors that influence the speed choice

Understanding the relation between speed behavior and the influencing factors offers clues for appropriate countermeasures against inappropriate and excessive speed (Aarts et al., 2011). Vehicle speeds depend on factors relating to drivers, vehicles, and the roadway environment (Kanellaidis, 1995), (ETSC, 1995). speed may be constrained by drivers in choosing to drive at a speed they consider safe and comfortable. Social pressure from other drivers, length of trip, underestimation of the speed limit, inattention to operating speed, and positive feelings about driving fast could influence their choice (Richard et al., 2014). Social pressure seems to obligate many drivers to follow the traffic flow and consider it necessary to stay out of everyone's way and avoid cars stacking up behind them. In addition, drivers can end up going too fast because they are paying less attention to their speed due to traffic flow, the power of the vehicle, or other in-vehicle distractions such as music. Moreover, speeding could occur due to drivers' attitudes where they feel good because of their speeding enjoyment. These attitudes seem to reflect thrill-seeking or sensation-seeking behavior (Richard et al., 2014).

The speed choice can further be motivated by the state of the physical road infrastructure and its environment. The road geometry, sight distance, the availability of speed reduction elements, the road width, the width and a number of lanes, road sign and marking information, weather conditions, and the speed limit's credibility are crucial factors influencing driving speed (ETSC, 1995) (Edquist et al., 2009); (Aarts et al., 2011). A short sight length only reduces speed if the sight is blocked over a longer distance; short disruptions of the sight length do not have any effect. Respectively, the width of the road and lanes influence the speed, whereas wider roads have higher speeds (Aarts et al., 2011). The environment of the road can affect the driver's behavior in the choice of driving speed which can therefore affect crash rates. Given that, road surface conditions may be one of the most important factors affecting the driver's perceptions in choosing

the appropriate speed. Drivers often choose a lower speed on roads with rough and narrow surfaces (Edquist et al., 2009). When the road is wider, drivers may increase speed and make dangerous overtaking. Road signs and markings are expected to provide the driver with the correct or needed information about the appropriate speed. Going over the speed limit can also happen unintentionally, especially where signs are not detected: compliance is much easier when the limit makes sense (Fuller et al., 2008).
The reliability of a speed limit might also be questioned. When a speed limit lacks credibility, it is viewed as too low, and individuals are likely to speed. A high-credibility speed limit is regarded as sensible or suitable in light of the road and its immediate surrounding features. Incredible speed limits may have a negative impact on the entire speed limit system and the acceptance of other traffic laws (Aarts et al., 2011). Police enforcement might be another external speed-affecting element. The impact of police enforcement on speeding behavior is undeniable and may be highly significant. The presence of speed enforcement in the road network substantially impacts the likelihood of choosing a speed. However, speed enforcement needs constant investment to remain at a similar level of compliance (Aarts et al., 2011).

Table 1: Summarized factors affecting Speed choice (External factors).

Road related	Traffic and environment-related	Vehicle-related
Width Gradient Alignment Surroundings Layout Markings Surface quality	Density Composition Prevailing speed Weather Surface condition Natural light Road lighting Traffic signs Speed limit Enforcement	Type Power/Weight ratio Maximum Speed Comfort

Source: European Transport Safety Council (ETSC).

2.4. The driver-related factors Influencing the speed

There are a range of driver-related factors that can influence a driver's decision to speed, including social norms, attitudes toward enforcement, peer pressure, gender, and age. By understanding these factors, policymakers and educators can work to develop more effective interventions aimed at reducing speeding and improving road safety:

i. The motivation to save time: Many drivers reported driving faster when late for an appointment or meeting. Thus, not surprisingly, being in a hurry is associated with speeding, faster acceleration, hard braking, dangerous overtaking, and tailgating (Fuller et al., 2008).
ii. Driver's emotional state: Recent evidence has shown that the driver's emotional state can influence speed choice. Feelings of anger are associated with aggressive driving,

speeding, penalties for speeding violations, and crash experience (Fuller et al., 2008).

iii. Driver's Beliefs: Some drivers may speed because of the belief that their driving capability and confidence protect them. Another factor that may be influencing his driving attitude is the tendency of some drivers to see themselves as more experienced than their average drivers (Gershon et al., 2018)
iv. Peer influences: A driver's behavior might highly be influenced by peer pressure from passengers in the vehicle (Eisenberg et al., 2014). According to Fleiter et al., (2012) the chance of speeding may rise if passengers encourage the driver to do so or show displeasure when the driver complies with speed limits. Peers can also encourage speeding if the driver believes they will find speeding to be attractive (Fleiter et al., 2012).
v. Risks perceptions: In some cases, motorists may speed because they underestimate the negative consequences of speeding for themselves and others. Drivers often think that they can speed safely (Corbett et al., 1999). Further, drivers often underestimate the risk that speeding poses to themselves compared to drivers otherwise like themselves, which may influence their tendency to speed (Hatfield et al., 2006). Even though the enforcement influences speeding, drivers' underestimation of their chances of being booked for speeding may reduce the value of fines (Hatfield et al., 2006).
vi. Attitudes toward enforcement: Motorists' opinion of the appropriateness of speed limits and corresponding penalties will likely influence their decision to speed. If a driver perceives law enforcement as being unfair or excessively punitive, they may be more likely to speed in order to avoid getting caught. Additionally, if people perceive fines for speeding as mere revenue collection, they may be less likely to adhere to regulations (Hatfield et al., 2006; Murray et al., 2007).
vii. Social norms: A driver's perception of what is socially acceptable behavior can influence their likelihood of speeding. For example, if a driver believes that others in their social group frequently speed, they may feel more pressure to conform to this norm (Cordellieri et al., 2016).
viii. Gender: Research has suggested that gender can play a role in speeding behavior, with male drivers being more likely to speed than female drivers (Cordellieri et al., 2016). Extensive research in the field of traffic safety has often emphasized the role of gender in driving behavior, particularly in the context of speeding. A considerable body of evidence suggests that male drivers exhibit a greater propensity to speed compared to their female counterparts (Kumfer et al., 2021).
ix. Age: Younger drivers, are more likely to engage in speeding behavior (Cordellieri et al., 2016). Research has consistently shown that drivers under the age of 25, are more prone to engage in risky driving behaviors, such as speeding (Kumfer et al., 2021). This predisposition can be attributed to several factors that intertwine with the psychological and sociocultural aspects of this age group.

2.5. Understanding acceleration and Acceleration Vs. speed

While the terms 'speed' and 'acceleration' are often used synonymously in the context of vehicular driving, they bear distinct meanings and implications for road safety. Speed, a scalar quantity, is defined as the rate of change in an object's position, commonly measured as distance traversed per unit of time. It carries a magnitude but no specific direction. When speed is associated with direction, it transforms into velocity. Velocity, a vector quantity, determines the rate of displacement of an object in a specific direction within a set time frame, holding both magnitude and direction (Joshua, 2018).

Acceleration, on the other hand, describes the rate of change in velocity, or the change in speed or direction per unit of time. A vehicle moving at a constant speed, irrespective of the rate, exhibits zero acceleration. For example, a jet traveling straight at 800 miles per hour demonstrates zero acceleration despite its rapid motion, due to the constancy of velocity. The acceleration isn't dictated by velocity at a specific time, implying that a vehicle's velocity can change rapidly irrespective of its speed (What Is Acceleration?, Khan Academy, n.d.).

Furthermore, the concept of 'high acceleration' defines a vehicle's capacity to rapidly reach high speeds, such as transitioning from 0 to 60 mph within a brief duration. Conversely, 'speeding' refers to a vehicle's ability to sustain high speeds under standard driving conditions. Both acceleration and speed are crucial components of road safety, as excessive speed or acceleration amplifies the risk of accidents and injuries (Acceleration vs velocity, n.d).

In summation, speed and velocity relate to an object's rate of motion, with velocity providing additional directional information. Acceleration pertains to changes in velocity, which can be incited by alterations in speed or direction. Understanding these distinctions is pivotal for promoting safe and responsible driving behaviors. Additional details are illustrated in Table2

Table 2: Acceleration vs. Speed

Characteristics	Acceleration	Speed (Velocity)
Nature	Vector	Vector
Calculated with	Velocity	Displacement
Components	Velocity, Time	Distance, Time and direction of motion
Average	Velocity/Time	Displacement/Time
Unit	m/s^2	m/s
Equation	A=V/T	V=D/T

Source: www.diffen.com

- Calculating acceleration: Instantaneous acceleration is the change in velocity "dV" divided by the duration of the interval (dt): $\frac{dV}{dt}$ i.e. the derivative of the velocity vector as a function of time.

- Average acceleration over a period of time is the change in velocity ΔV divided by the duration of the period (Δt): $\frac{\Delta V}{\Delta t}$

As illustrated in Table3, if the direction of acceleration is in the same direction as that of velocity then the object is said to be speeding up or accelerating. If the acceleration and velocity are in opposite directions then the object is said to be slowing down or decelerating:

Table 3: Acceleration and Deceleration vs. Vector direction

Event	Description	Vector Direction and change in magnitude
Initial Acceleration	When the vehicle starts moving in forward direction	Displacement: Forward/Increasing Velocity: Forward/ Increasing Acceleration: Forward constant
Initial Deceleration	When the moving vehicle decelerates to a stop	Displacement: Forward/ Increasing Velocity: Forward/Decreasing Acceleration: Backward/ Constant
Reverse Acceleration	When the vehicle is accelerating to reverse backward	Displacement: Forward/ Decreasing Velocity: Backward/ Increasing Acceleration: Backward/ Constant
Reverse Deceleration	When a reversing vehicle is decelerating	Displacement: Forward/ Decreasing Velocity: Backward/ decreasing Acceleration: Forward/ constant

Source: Source: www.diffen.com

2.6. Normal/Maximum acceleration or deceleration

Acceleration and deceleration are fundamental aspects of driving. Many researchers have analyzed vehicle acceleration characteristics and determined that the acceleration rates actually applied by drivers varied widely from driver to driver and also depended on the type of vehicle, the prevailing traffic, and weather condition (Long, 2000).
While these actions are standard parts of driving, excessive acceleration or deceleration often referred to as 'high-severe' can be a sign of aggressive driving and increase the risk of accidents (Fancher et al., 1998). However, the normal acceleration rates of passenger cars are rarely equal to the maximum value because drivers seldom apply the maximum acceleration capabilities of their vehicles except in emergencies (Wang et al., 2004). According to Long (2000), maximum acceleration and deceleration (A/D) are most frequently engaged at intersections or during incidents necessitating rapid deceleration, such as impending crashes. The acceleration rates at signalized intersections are influenced by various factors, including vehicle characteristics, intersection geometry, any obstructions, and drivers' attitudes towards speeding.
Contrary to what might be intuitively perceived, high acceleration or deceleration rates do not necessarily denote high or low speeds. The Two-phases-model as discussed by Wang et al.,(2004), suggests that drivers tend to exhibit higher acceleration rates at lower speeds and vice versa. Supporting this, a study by Bham and Benekohal (2002)

which evaluated and compared various acceleration models with field speed profile data, found that acceleration rates typically move from zero at the car's start, peak at a certain point, and then decrease back to zero at maximum speed.

Furthermore, the required distance and time for deceleration maneuvers differ among vehicles, and are influenced by the initial speed or 'approach speed' at which drivers begin to decelerate (Bokare & Maurya, 2017). Higher approach speeds necessitate longer deceleration distances, and the 'critical speed,' at which maximum deceleration is achieved, varies depending on both the vehicle type and the approach speed. A higher approach speed correlates with a higher critical speed, suggesting that drivers aim to reach their maximum deceleration rate faster when operating at higher speeds, particularly when an immediate stop is needed. In other words, the maximum deceleration rates tend to rise with an increase in a vehicle's maximum speed.

2.7. Areas of high acceleration and deceleration on the roadway

Areas of high acceleration and deceleration on roadways can be dangerous for drivers and passengers, as they increase the risk of accidents and injuries (Ragnøy, 2011).. Several studies found that areas near signalized intersections, roundabouts, and speed breakers were the most significant high acceleration and deceleration areas (Lee, 2022). Here are some examples of areas where acceleration and deceleration are common:
Intersections: Intersections are one of the most common areas where drivers need to accelerate or decelerate. As drivers approach an intersection, they may need to slow down or stop if there is traffic or a red light. When the light turns green or the way is clear, they must accelerate to move through the intersection and continue on their journey (Lee, 2022). Additionally, drivers may decelerate and accelerate at intersections due to the various acceleration and deceleration performances between vehicle types. (Mondal et.al, 2020).
On-ramps and off-ramps: Are areas where drivers need to accelerate or decelerate to merge onto or exit the highway. When entering the highway, drivers need to accelerate to match the speed of traffic and merge safely. When exiting the highway, drivers need to slow down and decelerate to exit safely (FHWA, 2018).
Hills: Driving up or down a steep hill can require acceleration or deceleration to maintain a safe speed. When driving up a hill, drivers may need to accelerate to maintain their speed, while when driving down a hill, they may need to decelerate to prevent their vehicle from going too fast (NHTSA, 2014).
School zones: Are areas near schools where drivers need to slow down to reduce the risk of accidents involving children and then accelerate when they exit. In school zones, drivers may need to decelerate to a significantly lower speed, that could allow to watch for crossing children (AASHTO, 2020).
Work zones: When driving through a work zone, drivers may need to slow down and then accelerate again when they exit the zone. Work zones can be hazardous because they often involve narrow lanes and changing traffic patterns (FMCSA, n.d).

2.8. Technological measures for speed enforcement

One way to influence driving speed is to set the speed limit. However, driving above the speed limit is quite a common phenomenon all over the world. Over time, different studies revealed different strategies and possible solutions to non-compliance with the speed limit. Hale (1990) suggested the two main alternatives be helpful if the speed is hard to control. These alternatives include: (i) to take the choice of speed away from the driver through the use of automatic speed-governing devices or built-in limits in engine design); (ii) to indirectly influence the speed and driving behavior of drivers. Besides infrastructure design measures, several researchers proved technological measures to be crucial in speed enforcement (Aarts et al., 2011). Technology offers the possibility of immediate feedback on inappropriate speed choices by means of variable message signs that selectively display warning messages and could be accompanied by vehicle license number detection (ETSC, 1995).

2.8.1. Single-point camera and its effectiveness

In locations with high crash rates linked to excessive vehicle speed, fixed or mobile speed cameras are an effective intervention for lowering road traffic crashes and associated fatalities. (Jones et al., 2008). Speed cameras are generally introduced at sites identified based on high rates of speed-related collisions. They work by recording an image of vehicles passing them above a set trigger speed. Speed cameras may also change the culture of speeding over extended periods (Pilkington & Kinra, 2005). According to a study conducted in New Zealand, the speed camera is attributed to the reductions in personal injury crashes of up to 32% in urban and 14% in rural areas (Keall, Povey, & Frith, 2001). In Canada, speed cameras were shown to be connected with a 9 percent reduction in collisions and a 2.8 km/h drop in mean speeds at locations where they were installed (Chen, Meckle, & Wilson, 2002). A meta-analysis of ten research on the local impact of speed cameras in seven European nations revealed a 19% reduction in injury-causing crashes (Elvik, 2002).

A speed camera pilot project in the UK indicated that the installation of cameras resulted in a 41% reduction in fatalities or severe injuries and a mean speed reduction of 10 miles per hour in the vicinity of the camera (Gloag, 1993). Later, in 1995, an investigation of ten police forces operating cameras at 174 locations found a 28 percent drop in crashes and a 2.4 mile/h decrease in speeds at the operational sites compared to the time before camera installation (Hooke, Knox, & Portas, 1996). Notwithstanding the reputed efficacy of speed cameras in speed enforcement, they must be supplemented by other road safety measures such as traffic calming and anti-speed and anti-drunk driving education programs. (Pilkington & Kinra, 2005)

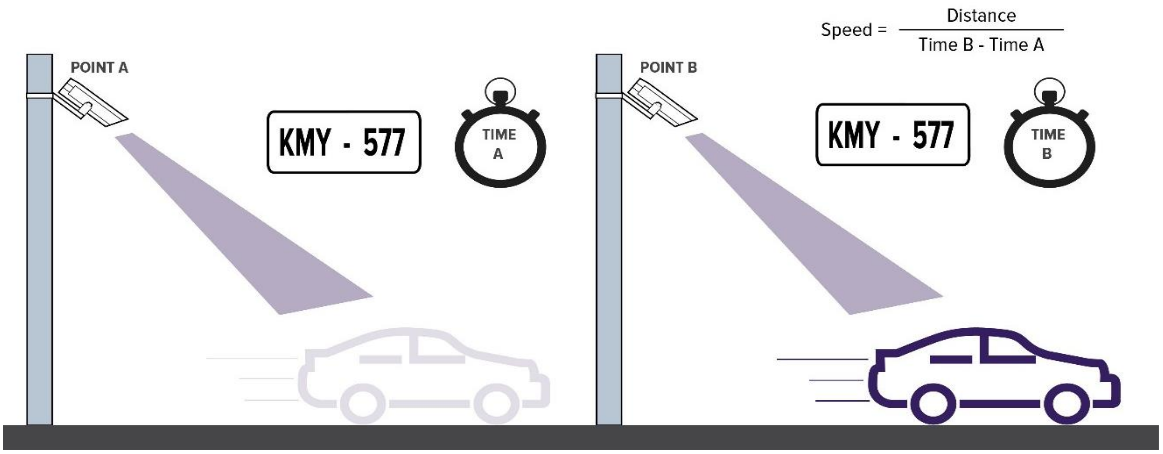
Figure 3: Single fixed camera

2.8.2. Average Speed Section Control

Average Speed Section Control (ASSC) has been identified as an effective countermeasure to reduce speeds and improve speed limit compliance. The benefit of this enforcement system is the registration of the average speed at an entire section, which would lead to high-speed limit compliances and, subsequently, a reduction in vehicle speed variability, increased headway, more homogenized traffic flow, and increased traffic capacity (Pauw et al., 2014). The system consists of two sets of cameras for each lane, placed at the entrance and exit of the controlled section. The vehicle is identified when entering the enforcement section through the license plate registration and again when leaving it. The system recognizes speeders and tickets them based on the assessment of the average time used by the vehicle to cover the distance of the section (Pauw et al., 2014). Studies that looked closely at the efficacy of ASSC in Europe by Soole et al. (2013) discovered that it was linked to high compliance rates with posted speed restrictions. In that study the offending rates were less than 1% and associated with a reduction of up to 90% in the proportion of vehicles exceeding the speed limit. In addition, the speed variability was reduced, which resulted in more homogenized traffic flows, improved traffic density, and reduced journey travel times.

Another study conducted in Italy found that ASSC is acknowledged to have contributed to the significant reduction of 22% in the crash frequency from 2004 to 2013 (La Torre et al., 2019). In Norway, Ragnøy (2011) studied three road stretches with ASSC. The sections had a length of 5 km to 9.5 km, all with a speed limit of 80 km/h. A before- and after study of the speeds showed a decrease for all three treated locations, with higher effects for roads with a higher driving speed during the before period. From an initial average speed of 76.7 km/h, 88.5 km/h, and 89.4 km/h, the speed decreased by 2.7 km/h, 10.2 km/h, and 8.8 km/h, respectively. Furthermore, higher speed decreases were found at the entrance and the exit of the section, compared to the middle of the section. An analysis of the speeds downstream after the exit of the section showed that the speed was influenced for at least 1000 m after the exit.

Figure 4: Automated/Average Speed Section Control



2.8.3. Real-time in-vehicle intervention systems/ Intelligent Speed Assistant

An intelligent speed assistant(ISA) is a useful device to reduce inappropriate speed and contributes to an increase in road safety (Vlassenroot et al., 2007). ISA system can warn the driver about speeding, discouraging the driver from speeding or preventing the driver from exceeding the speed limit (Connelly et al., 2002). Various studies like Várhelyi (2002) and ETCS (2025) categorize ISA devices into three types depending on the intervention each can provide. 1) An informative or advisory system will only give the driver feedback with a visual or audio signal. 2) When the speed limit is overruled, a supportive or warning ISA system will give direct feedback with visual, auditory or haptic pedal. In other words, the pressure on the accelerator pedal will increase when the driver attempts to drive faster than the speed limit. 3) A mandatory or intervening system will totally prevent the driver of exceeding by exerting a counter-force whenever the driver tries to depress the pedal beyond a pre-set speed limit (active gas pedal) or just does not respond beyond the speed limit (dead throttle)

Advisory or Informative systems
Implementing the in-vehicle speeding warning message system is essential in reducing drivers' operating speed. According to the simulator experiments conducted by Yan et al. (2016) aiming to investigate the impacts of the in-vehicle audio speeding warning message system on drivers' speed performance. It was found that the audio warning system could significantly reduce the probability of speeding over 20% of the speed limit. However, the effectiveness of in-vehicle warning systems seems controversial among researchers. Based on the study conducted by Várhelyi (2002), in-car information on the current speed was found to have the lowest positive effects on speed limit compliance. On the contrary, the system might distract the driver and produce mental overload in complex driving situations, increasing the accident risk. In his research, the effectiveness of warning systems was underrated for not taking control over drivers' inputs except by simply providing drivers with real-time information of how fast above the speed limit they are driving. He argued that the best safety effect would be expected from the intelligent gas pedal and automatic speed limiter. According to the study conducted in Australia (Creef et al., 2016), to evaluate the effectiveness advisory ISA. Its results demonstrated that advisory or informative systems has the potential to promote road safety by increasing compliance with speed limits in Australia. The Advisory ISA system is acknowledged to have reduced speeding by 89% of trial vehicles. The median probability of speeding was also reduced by almost 30%.
Intelligent gas pedal/ automatic speed limiter/ Active acceleration pedal

A mechanism that prevents drivers from exceeding the current speed limit. With that system, the vehicle's performance is not affected at speed levels below the speed limit. This system has demonstrated, among other things, high reductions in mean speeds and speed variance, which make it ideal for trafficking safety intervention (Adell, 2007). Several studies were conducted worldwide to study the effect of the ISA system on speed change. The study was conducted in Belgium(Ghent) on 37 vehicles equipped with the ISA system (Active Accelerator pedal). The result of the study proved a decrease in speed by 10% in the 90km/h zones and a decrease from 45.9% to 42.8% in the 30 km/h zone (Vlassenroot et al., 2007). According to the study conducted (Adell, 2007) on 281 vehicles in Sweden (Lund), they proved the effectiveness in decreasing drivers' speed and their risk of being fined for speeding. However, besides the system's positive effects on safety, some drivers find it a threat. In Sweden, drivers reported the system increased their workload, and their emotional state deteriorated. They showed an increased feeling of obstructing other drivers and reduced driving enjoyment (Adell, 2007).

2.8.4. Speed feedback signs (Dynamic display signs)

Dynamic display signs measure the speed of approaching vehicles and communicate the speed to the drivers in the digital display. When coupled with the posted speed limit, the real-time permits drivers to compare their driving speed to the legal speed limit. The system displays the operating speed and the message associated to the detected speed (Yan et al., 2016). The message is addressed to the driver, informing him/her to slow down. Donnell and Cruzado (2008) researched the use of speed feedback signs (Speed minders) in Pennsylvania. In that research, the speeding behaviors were evaluated before and after implementing the dynamic display signs. The results indicate that the speed minders were effective in reducing approximately 10 km/h of mean passenger car speeds at all sites when the devices were deployed. The study also tested the speed change behaviors after the removal of the system. At the locations where the speed minders were deployed, the observed mean speeds generally increased in the week after the speed minders were removed from the site. The Center for Transportation Research and Education at Iowa State University (Hallmark et al., 2015) conducted a national demonstration project to evaluate the system's effectiveness in reducing speed and crashes on curves. The study found a decrease in average mean speeds up to 10.9 miles per hour. According to the study, far fewer cars exceeded the posted or advised speed, demonstrating that the signs successfully lowered high-end speeds and average and 85th-percentile speeds.

2.8.5. Mobile speed enforcement vans

Mobile speed enforcement vans are vehicles equipped with technology such as radar or laser devices that measure the speed of vehicles, and Automatic Number Plate Recognition (ANPR) cameras that can capture images of speeding vehicles. They are commonly used to monitor speed at various locations, such as in work zones or areas where speeding is a particular concern (WHO, 2020). The vans are usually parked in a designated area, and the technology inside the van is used to measure the speed of passing vehicles. When a vehicle is found to be speeding, the ANPR camera captures an image of the vehicle and its registration plate. This information can then be used to issue fines or penalties to the vehicle owner.

According to a study by the European Transport Safety Council (ETSC), mobile speed enforcement vans are an effective way to reduce speeding and improve road safety. The study found that in areas where mobile speed enforcement was used, drivers were less

likely to speed, resulting in a decrease in the number of road accidents and fatalities (ETSC, 2017). Another study by the University of Leeds found that the use of mobile speed enforcement vans resulted in a significant reduction in the number of crashes and injuries on roads (Broughton et al., 2010). The study also found that the presence of mobile speed enforcement vans had a positive impact on driver behavior, with drivers becoming more aware of speed limits and more likely to comply with them.
Overall, mobile speed enforcement vans have been shown to be an effective way to improve road safety by reducing the number of speed-related accidents and encouraging drivers to comply with speed limits. However, the effectiveness of this technology may depend on factors such as the location of deployment and the level of enforcement.

2.9. Limitations of speed camera and Average section speed control

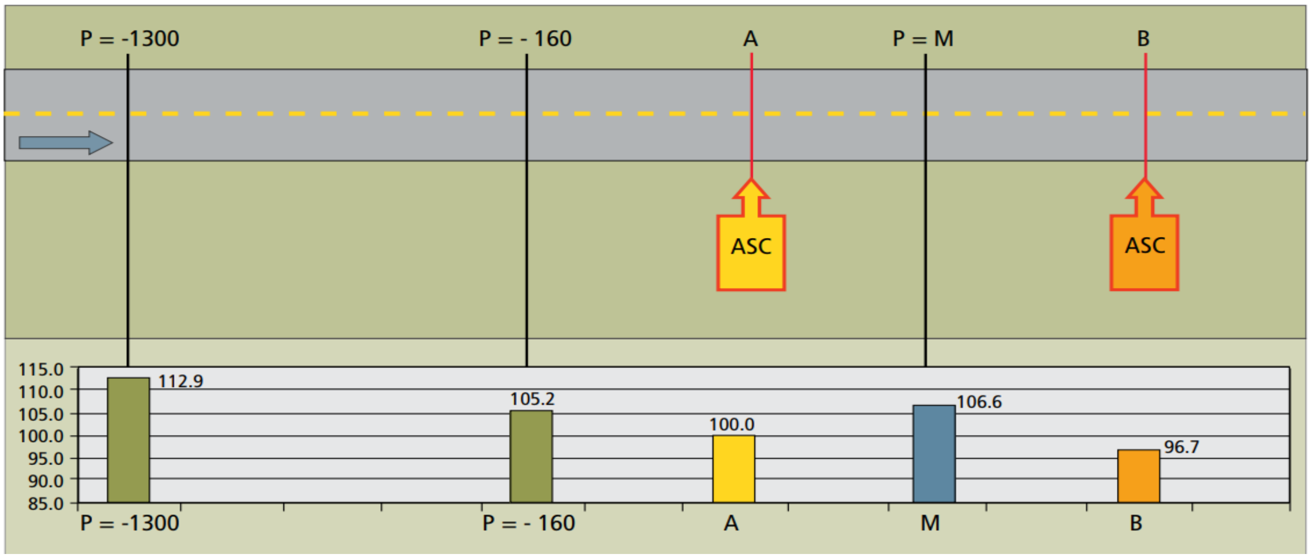
Speed enforcement using cameras and average speed section control (ASSC) has several limitations that affect their effectiveness in reducing speeding on the roadways. One of the main limitations is the limited coverage of these systems, which can only detect speed-limit violations in a small fraction of the entire road network due to the high cost of installation (Elsagheer Mohamed et al., 2021). As a result, these systems are usually installed in fixed locations, which may not capture speed-limit violations that occur in other areas of the road.
Another limitation of speed enforcement using cameras is that fixed-camera sites become widely known, and manipulating the cameras becomes a social norm (Elsagheer Mohamed et al., 2021). Additionally, the visibility of cameras and warning signs can lead to manipulating behavior among drivers who slow down only at the camera locations to avoid detection(Corbett et al., 1999). Such manipulation has even become worse with anti-camera technologies, social apps, and detectors that have been developed and used to warn drivers about the location of speed cameras (Elsagheer Mohamed et al., 2021). These technologies allow drivers to slow down at camera locations and overspeed in other uncontrolled segments, thereby defeating the purpose of speed enforcement.
Furthermore, the accuracy of average speed section control can be affected by several factors, including changes in road conditions, weather, and traffic density (Elsagheer Mohamed et al., 2021). These factors can affect the accuracy of the speed measurements, leading to false positives or negatives.

2.9.1. Analyzing limitations and influence of Speed Camera/ASSC Enforcement on driving speed based on empirical studies.

According to the study conducted in the UK and Poland (Srinivas et al., 2018), drivers were found to reduce their speed before the camera and immediately increase their speed after the camera. That study found the average speed drop before the camera to be 0.87m/s (3.13km/h) and the average speed rise to be 0.89m/s (3.2km/h) after the camera (Srinivas et al.,2018) in the UK. Then, the average speed drop before the camera and the average speed rise after the camera were 1.01m/s (3.62km/h) and 1.01m/s (3.64km/h), respectively in Poland. The deceleration and acceleration distance was found to be 194m before the camera and 125m after the camera, respectively, summing up for an influence area of 319m around the camera.

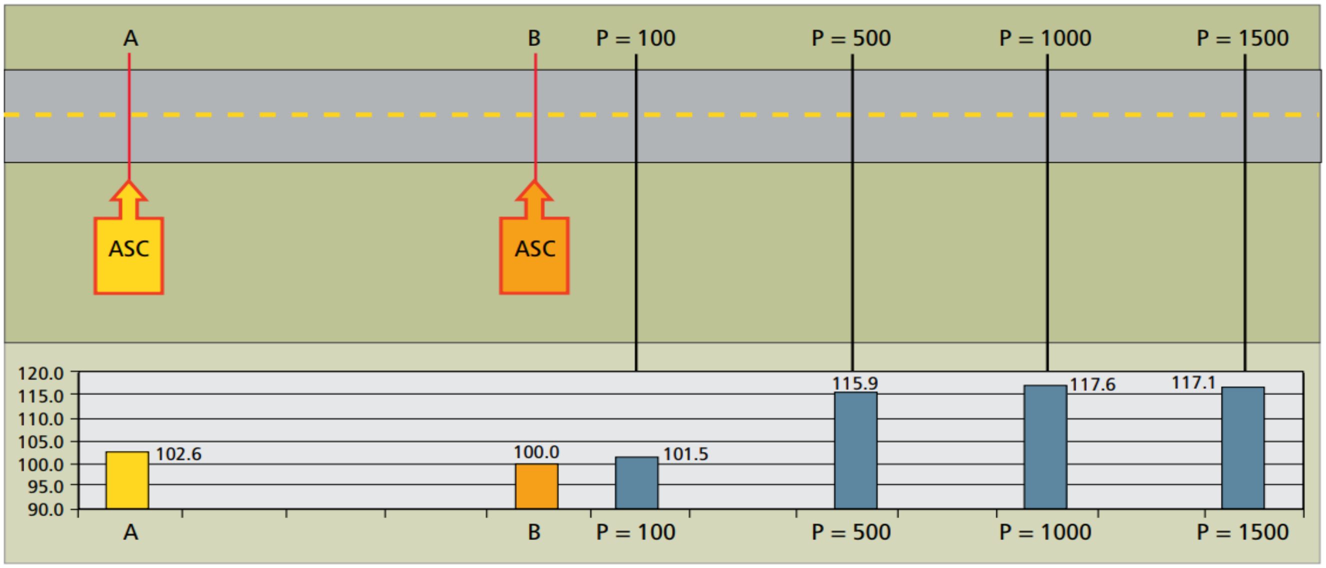
Based on the results of the evaluation of ASSC conducted in Norway by Ragnøy (2011), some manipulations of the cameras were detected before entry in the controlled zone (Camera A), within the controlled zone, close to the exit (Camera B), and after passing the last camera. Figure 5 illustrates the scenario before entry and within the controlled zone. In that illustration, Point P=-160 indicates a distance of 160 meters before point A. P=-1300 indicates the distance before the first camera, and Point P=M indicates a point within the section of the road between A and B.

Figure 5: Deceleration before the first speed camera



As it is shown in figure5, the speed at point P=-160 relative to point A was 105.2, or 5.2% higher than at point A. This means that a deceleration occurs during the last 160 meters approaching the first camera's position. At a distance of 1,300 meters before point A, the speed is 112.9, or around 13% higher than at point A. After passing camera A, the speed progressively increased and was eventually reduced when approaching camera B positioned on the exit. The illustration in figure 6, after the exit of the controlled section, shows the high acceleration.

Figure 6: Acceleration after passing the last camera



The figure shows the relative driving speed at the points P=100 meters, P=500 meters, and P=1,000 meters relative to the speed at point B. Figure 6 shows that the speed limit compliance was achieved when passing the camera at point B and was maintained for at least 100 meters after camera B. Then the speed increased again and reached 115.9 at point P=500, equivalent to 15.9% higher compared to the speed at point B. After an additional 500 meters (P=1000), the speed increases further to 117.6. This level remained almost constant until point P=1500.

2.9.2. Analysis of possible causes and effects of non-compliance with the camera/ASSC.

According to Figure 5 and Figure 6 as illustrated above, it was evident that the presence of the ASSC influenced driving behavior. However, braking just before the camera and subsequent acceleration is dangerous. When the traffic volume is high, and vehicles follow each other at close distances, this could increase the probability of rear-end collisions. Such braking may be due to the fact that the motorist became aware of the camera too late and/or is often the case for motorists with automated speed enforcement warning devices. The high acceleration after passing the fixed camera or the last point of ASSC is influenced by the fact that the motorists become relatively sure that there will be no more cameras immediately after passing the last camera (Ragnøy, 2011).
The driver's confidence of knowing the location of speed enforcement points is the key contributor to the camera manipulations. In that regard, undermining that confidence in knowing the whereabouts of fixed-site cameras might reduce the incidence of decelerating and accelerating and might bring about lower speeds generally (Corbett et al., 1999). Notwithstanding the driver's knowledge of the camera location, (Corbett et al., 1999) also revealed the manipulation influenced by the camera's perceived efficacy. An underestimation of the perceived efficacy of installed cameras could lead to a lower perceived threat of detection elsewhere and result in speeding.

Some studies revealed that non-compliance with the ASSC can vary with time. An evaluation of the driving speed after installing ASSC at the A3 motorway in Italy showed high non-compliance with the speed limits. This non-compliance was 50.5% directly after the installation of ASSC and 57.4% one year after the installation (Montella et al., 2012b). After that period, another study was conducted on the same road by Cascetta et al.(2010), and found a reduction in non-compliance from 57.4% to 17%. The authors stated that differences in traffic conditions and the function of the territory could partly justify these differences. Nevertheless, they indicated that also the enforcement strategy is an important difference and that a better strategy of communication and information to the road users and an increased level of enforcement in the follow-up of offenses could achieve higher compliance with the speed limits.

The authors emphasized the need to change drivers' perceptions of themselves as being better or safer drivers and to help them understand that they are not exempt from the safety message that cameras send (Corbett et al., 1999). Besides the above-defined manipulation of cameras, Ragnøy (2011) identified another limitation of speed camera enforcement. In his study, it was found impossible for the camera (ASSC) to calculate the average speed for vehicles that are not recognized by both cameras. That makes it impossible to impose any sanction on this group, either.

2.10. Techniques mostly used by drivers to avoid detection while speeding

Drivers believe in and use a range of techniques to avoid being booked for speeding. Several studies were conducted worldwide to identify drivers' habits and reactions to speed enforcement measures. According to the study conducted in Sydney by Hatfield et al. (2006), Several people were reported engaging in practices to reduce their chances of being booked while speeding. The study found the main driver's techniques to avoid speed tickets: "slowing down when you see police or a camera, speeding if the traffic around you is speeding, taking back streets, and avoiding known locations of police or cameras. Driving at certain times of the day was also practiced by 6.9% of the Sydney sample and 5.0% of the rural sample, with the most common and consistent times being early morning, at night, and in the middle of the day. Other various studies found the use of the following behaviors and techniques to avoid speeding tickets:

2.10.1. Always drive with situational awareness

Driving with situational awareness means being alert and mindful of your surroundings while driving. This includes being aware of other vehicles on the road, traffic patterns, and any potential hazards. It is important to pay attention to the behavior of other drivers, as sudden braking or erratic driving could be a sign of a hidden patrol vehicle. In addition, it's helpful to scan both sides of the road and keep an eye out for parked patrol cars in driveways or other strategic locations. It's not uncommon for other drivers to flash their headlights to warn of a patrol vehicle, so be aware of this as well. Utilizing situational awareness while driving can help prevent speeding tickets and keep you safe on the road
(Cahn, 2019).

2.10.2. Knowing the preferred speed traps hiding spots.

Police often place speed cameras in hidden positions on the roadway. Thus, this technique consists of knowing all strategic points and locations where the police are likely to place speed cameras or police patrol vehicles (How to Avoid Speeding Tickets, 2015). Vortex (2016) and Heroun (2017) alerted speeders that some strategic spots for speedometers include: Underneath or on top of overpasses, highway onramps to clock cars from behind, or right after the crest at the top of a hill. When the driver approaches the location, the speed must be decelerated below the posted speed limit to avoid a ticket. However, when the police operate a manual radar or laser, the driver, in this case, believes that the officer must still spot his vehicle first. In that brief moment, the driver must make sure to spot them before and begin braking prior to them pulling the trigger. In this context, the driver also believes that every millisecond counts, so the sooner he is prepared, the more time to decelerate before being detected (How to Avoid Speeding Tickets, 2015).

2.10.3. Use the rabbit technique

The "rabbit" technique involves following a fast-moving car ahead of you at a safe distance. If a police officer hits the car with radar or laser, the rabbit will draw their attention and potentially get a ticket, giving the speeder time to slow down and avoid getting caught. The brake lights of a rabbit can also serve as a warning of a hidden patrol vehicle. This technique is often used on lightly-traveled roads where speeders are more vulnerable to being caught (Vortex, 2016).

2.10.4. Use the Smartphone Apps that locate the speed traps.

There are free navigation apps like "Waze, Sygic, etc." these have real-time alert-sharing capabilities. The apps are loaded with features, including alerts for red light cameras, speed cameras, and speed traps; they also notify of new speed limit changes on the route, plus many other useful tools (Heroun, 2017). With them, people can mark in real-time where there are things like traffic, accidents, camera, or even police cars on the side of the road. Everybody using the app can see on a map where other people have marked the position of cops or cameras, which helps them slow down when approaching (Vortex, 2016).

These apps have demonstrated effectiveness at reducing the incidents of speeding tickets, and a number of traffic patrol departments are complaining to their manufacturers to remove the feature (Vortex, 2016). Most of those apps have a large user base, and regardless of their route, the users believe that they will probably receive reports from other users nearby. In addition to locating police, users also use them as GPS navigation tools that can also be used to find areas of interest, petrol stations, and possibly most importantly, imminent traffic dangers (How to Avoid Speeding Tickets, 2015).

2.10.5. Use radar detectors.

Speeders, aware of the prevalent law enforcement method of employing radar guns to issue speeding tickets, have in some instances resorted to using mobile radar detectors. These devices can identify and locate all active police radar lasers on the road. As the driver approaches the radar gun, the detector issues an advanced warning, prompting them to slow down and avoid detection (Vortex, 2016). However, it's crucial to note that the use of such devices is prohibited in Belgium, as is the case in many other European Union countries. Utilizing these tools could lead to significant legal consequences, reinforcing the importance of adhering to mandated speed limits for the safety of all road users.

2.10.6. Install a laser jammer

Across numerous countries, law enforcement agencies utilize laser guns as a standard tool to issue speeding tickets. Some speeders, in their quest to avoid detection, employ devices known as laser jammers. These instruments can interrupt the laser gun's ability to obtain a speed reading from a specific vehicle, providing the driver sufficient time to reduce their speed. Once the driver has slowed to within the speed limit, they deactivate the laser jammer, effectively evading the laser radar (Vortex, 2016). However, it is critical to highlight that the use of such devices is often strictly regulated or outright prohibited under national traffic laws. It's always essential for drivers to comply with legal speed limits, thereby contributing to overall road safety.

3. METHODOLOGY

3.1. Introduction

This study draws on Naturalistic Driving (ND) data sourced from the i-Dreams project, directed by the Transportation Research Institute (IMOB). The i-Dreams project, an initiative funded by the European Union's Horizon 2020 program, was conceived with the aim to define, develop, validate, and implement a 'safety tolerance zone.' Its goal is to protect drivers from nearing the unsafe driving behavior by mitigating risks both during and post-trip (Hancox et al., 2021). This necessitates a comprehensive understanding of drivers' behavior and the underlying causes for their conduct. To this end, a ND study was conducted to gather insights into driving behaviors during everyday trips. The study involved outfitting vehicles with a monitoring system comprising cameras and sensors to record driving behaviors, vehicle speed, acceleration, deceleration, and steering in real-time.

A fundamental aspect of this investigation centered on acceleration and deceleration (A&D) of drivers in the vicinity of speed cameras and an ASSC. The objective was to examine the influence of speed management devices on A&D behaviors in their immediate surroundings. A range of quantitative data was utilized to accomplish this, including vehicle event data (A&D) which enabled a visual representation of speed patterns in the area of interest. Simultaneously, geospatial data including locations of the cameras/ASSC played the crucial role in measuring variations in speed severity from these positions. The data processing and visualization were performed using GIS software and SPSS.

3.2. Study area description

The study area for this research is Limburg, the easternmost province of Flanders, one of the three regions of Belgium. This area is located in the northeastern part of the country, bordering the Netherlands to the north and east, and the Belgian provinces of Antwerp, Flemish Brabant, and Liege to the west and south respectively (Wikipedia, 2021).. Covering an area of approximately 2,422 square kilometers, Limburg is characterized by a largely flat topography combined with a few hilly areas (Karkazis, 2021). It is a significant transportation hub due to its strategic location and well-developed infrastructure that includes extensive road networks (Wiersma et al., 2017), including the E313 and E314 highways, and various local roads that intersect the region (Wikipedia, 2021).

According to the latest information from Wikipedia contributors (2023), Limburg has of a rich combination of urban and rural environments. The urban landscape includes notable cities such as Hasselt, the provincial capital, Genk, and Sint-Truiden, among others. These cities feature a dense network of roads crowded with diverse traffic situations, ideal for a study on driving behaviors. On the other hand, the rural areas of Limburg are characterized by smaller municipalities combined with farmlands, forests, and water bodies. Limburg's road network is dotted with various traffic control devices including speed cameras and Average Speed Section Control (ASSC) systems (De Pauw et al., 2014). This infrastructure is designed to maintain traffic order and safety, making Limburg an ideal environment to study the influence of these enforcement devices on driver behavior.

In terms of climate, Limburg experiences a temperate maritime climate, characterized by mild summers and cool winters (Climate and Average Monthly Weather in Limburg, Belgium, n.d.). Weather patterns may also play a role in driving behavior, a factor to that should be considered in any traffic study. This fusion of urban and rural, the mix of major highways and local roads, and the variety of speed enforcement systems in place makes Limburg an ideal area to conduct a study focused on driver behaviors in the vicinity of speed enforcement devices.

3.3. Participants selection

In this study, all components of the complete i-DREAMS system were combined in a real-world setting and used in vehicles owned by individuals and organizations outside of the i-DREAMS project. To get a realistic reflection of all the target users; the study was conducted on different testing groups focusing on private and professional drivers for three different transport modes: Cars, Trucks, and Buses. The participant selection criteria were primarily based on the factors such as:

a) *Driving experience*: Car drivers' required minimum yearly driving distance was 10,000 km across different road types. And at least 6 months of driving experience for truck drivers and bus drivers.
b) *Age*: Age is a known factor that can influence driving behaviors. Therefore, four age groups were defined to guarantee a spread of the age distribution: 18-25, 26-45, 46-64, 65+. However, these age groups were only applied to cars driver trials and not applicable to bus and truck drivers. The sole criteria for this category of drivers (Truck and Bus) were the minimum age of 21.
c) *Gender*: A minimum of 40% per gender split was mandatory for car drivers. However, this was not applied to bus and truck drivers.
d) *Multi-driver access*: The aim was to have at least 25% of participating vehicles operated by multiple drivers, which is the best way to enlarge the sample size. However, trucks were not subject to this requirement, as it is believed that they are not multi-driver access vehicles. Nevertheless, the second drivers were not counted as the new participants but contributed as an extra source of data.
e) *Environment exposure*: Participants in the field trials should have a mixed driving pattern across urban, rural, and motorway environments, With at least 20% of exposure to each road environment. However, this criterion is required for car drivers and is not applicable to the rest of the study groups.
f) *Vehicle selection criteria*: The vehicles in the trials were selected based on how easy they will be for the installation team to fit the i-DREAMS technology. All vehicles deemed to ease the installation process were considered qualified for the test. However, this criterion only applies to cars and not to other vehicles.

Additional requirements/ obligations for participants:

g) *No change of the vehicle*: The participant should not have plans to change the vehicle during the trial period. This eliminates the possibility that the participant may sell their old car and purchase a new one, causing the installation/Removal of the equipment twice for the same participant.
h) *Smartphone*: Participants should have Android version 6 or higher. As the i-

DREAMS application was not optimized yet for iPhones, those who solely used iPhones were not permitted to participate.

3.4. Recruitment channels

According to i-Dreams report, different ways and channels were used to recruit participants to make the recruitment interactive and guarantee the greatest possible and widespread coverage. Eventually, participants who expressed interest in participating in the study received an initial screening questionnaire. And those deemed eligible were given a detailed questionnaire to complete or a follow-up phone call that allowed a final selection decision. Furthermore, the selection process was followed by the installation process of the i-Dreams set to the selected vehicles. The following were some of the recruitment techniques employed:

- *Own-recruitment database*: Recruitment using a database or lists from previous experiments
- *Personal reference*: Distributing information via Personal contacts of the researchers such as relatives, acquaintances, friends, colleagues, etc.
- *Motorists clubs*: Recruitment from driver and vehicle organizations
- *General media*: Motivating the study's interest through press releases.
- *Social media*: Distribution of information to the broader audience via social media.
- *Vehicle fleets*: Recruitment via contacting fleet operators.

3.5. Data collection procedures

In this study, Fifty (50) automobiles were instrumented with a monitoring system (cameras and sensors) to record all driving behaviors, vehicle speed, acceleration, deceleration, and steering in real time. The system kit was composed of the following tools:

- *The gateway*: a small computer that collects data from all sensors. Its main task was to calculate the safety tolerance zone in real-time and to trigger alerts when potential risks are detected. The gateway has also a built-in auditory system for auditory signals.
- *Mobile eye*: The smart camera that measures the roadway environment and potential elements of the road such as traffic signs, distance to other cars, pedestrians detection etc.
- *Dashcam*: to capture video fragments of a few seconds before and after a dangerous event.
- *Intervention device*: A device that is used to provide visual intervention alerts and information.
- *GPS Antenna*: Used for Geolocation in the i-Dream system.
- *4G Antenna*: Antenna to provide mobile connectivity of the in-vehicle i-Dream system to the i-Dream cloud.
- *Wearable tracker*: Wearable tracker to measure sleepiness by analyzing the heart pulses.

During this study, the above data collection system was designed to seamlessly integrate into the vehicle, starting automatically when the engine was turned on. Upon activation, the system prompted the driver to identify themselves by selecting their name from the

registered records or entering it manually. Once the driver was identified, the home screen displayed an array of monitoring systems available for use. Throughout each trip, the system's tools recorded a variety of data types, including information on speed, steering, Tailgating, acceleration, and deceleration at different levels, etc. At the end of each trip, the system autonomously submitted comprehensive data to the IMOB server, ready for analysis.
For the purposes of this study, only specific data was selected for analysis. This included the locations of speed cameras and Average Speed Section Control, as well as instances of speeding, acceleration, and deceleration at high, low, and medium levels.

Figure 7: Naturalistic driving data flow process

3.6. Data and methods

In order to perform an effective examination of the relationship between the speed cameras, the following data were used:

- Fixed speed camera data: Geospatial data (Shapefile format) of all speed cameras in Limburg province, Belgium.
- Average Speed Section Control data: The linear geospatial data (Shapefile format) of the section of the roadway, controlled by the ASSC system.
- Traffic Data: Car events data (CSV file) included information about vehicle speed and acceleration/deceleration data, collected at multiple points and in diverse trips.
- Administrative data: Administrative boundaries of the Flemish region, and the provinces.
- The dummy-Speed cameras: New shapefiles (point features), created to serve as control group.

The traffic data utilized in this study was obtained from a naturalistic driving test as self-reported data extracted from i-Dream server. Such data was particularly valuable for this

study as it allows for the observation of driver behaviors, specifically acceleration and deceleration patterns. The attribute table of these data has the useful information like: Event location, time (Day, Hour, Minutes and second), Trip ID, Driver ID and the severity of the event, which all were recorded for each vehicle in the real-time (Table 5). This comprehensive dataset allowed for detailed analysis of acceleration and deceleration events in the vicinity of speed cameras.
The geospatial data used in this study was extracted from OpenStreetMap (OSM) via the Flemish Government's official website. OpenStreetMap is an open-source, community-driven mapping project, which provides detailed and up-to-date maps of regions around the world. The OSM data used includes highways and associated elements, as well as administrative data.
The combination of these two complimentary data sets, naturalistic driving test data and OSM data, allows for a thorough investigation of the link between speed camera location and driver behaviors.

Table 4: Additional data information

Data/Layers	Source	Attribute table	Used projection
Car events	EPSG:4326-WGS84	Driver ID, Trip ID, Event type, Time, Severity, Location	EPSG:31370-BD72/Belgian Lambert 72
Speed cameras OSM	EPSG:4326-WGS84	ID, OSM type	EPSG:31370-BD72/Belgian Lambert 72
ASSC	EPSG:3857-WGS84/Pseudo Mercator	ASSC ID, Section Length	EPSG:31370-BD72/Belgian Lambert 72
Roads	EPSG:4326-WGS84	ID, Type, Directions	EPSG:31370-BD72/Belgian Lambert 72
Administrative boundaries	EPSG:31370-BD72/Belgian Lambert 72		EPSG:31370-BD72/Belgian Lambert 72

Table 5: Summary statistics of data used in this study

	Fixed camera site		ASSC Site1		ASSC site2	
Type of Analysis (Events)	Accelera-tion	Decelera-tion	Acceleration	Deceleration	Acceleration	Deceleration
Number of trips	337	276	118	98	120	84
Number of different drivers who passed there	33	28	6	6	12	12
Data collec-tion period	2021/04/21-2022/07/06	2021/04/21-2022/07/06	2021/07/07-2022/07/05	2021/07/07-2022/07/06	2021/07/27-2022/07/06	2021/08/01-2022/07/06

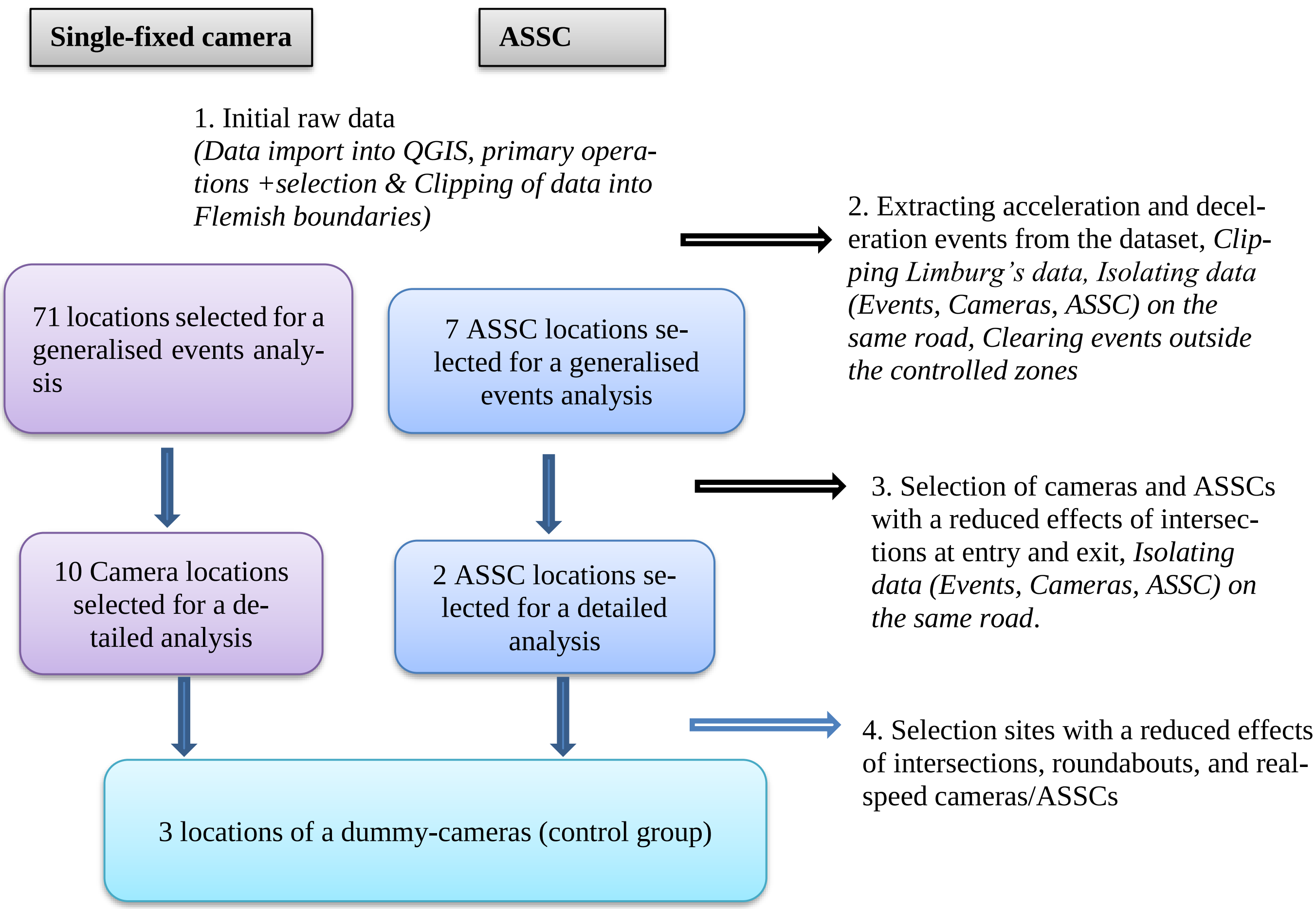
Total number of drivers in the entire Belgium: 50

3.6.1. Data pre-processing and data cleaning

The data cleaning formed a critical part of this project, laying a solid foundation for the data analysis and the subsequent conclusions drawn about the relationship between speed camera positioning and driver behaviors (Acceleration and deceleration). The original data, particularly the vehicle events, were enormous, and some of the events took place outside the region of Flanders. On the other hand, other information was dispersed over several routes without speed camera or ASSCs, and that made it crucial to undergo a data cleaning process. The data cleaning was based on clipping the data to the target study area, isolation of speed cameras and corresponding car events on those specific road sections, choosing locations where the influence of the intersections and crossing vehicles are minimized, excluding road sections outside the controlled zones, etc.

The data cleaning in this study enhanced the accuracy of the analysis by eliminating errors, inconsistencies, and outliers in the raw data (Chapman et al., 2000). It also improved the specificity of the study by focusing the dataset solely on the geographic area of interest in Limburg province-Flanders, and on the specific set of speed cameras. Moreover, data cleaning facilitated the analysis by creating a dataset that was more manageable and efficient to work with (Osborne, 2013).

The raw dataset underwent several modifications to align with the project objectives, ultimately leading to the final dataset utilized in further processing and analysis. The changes to the data are outlined as follows:



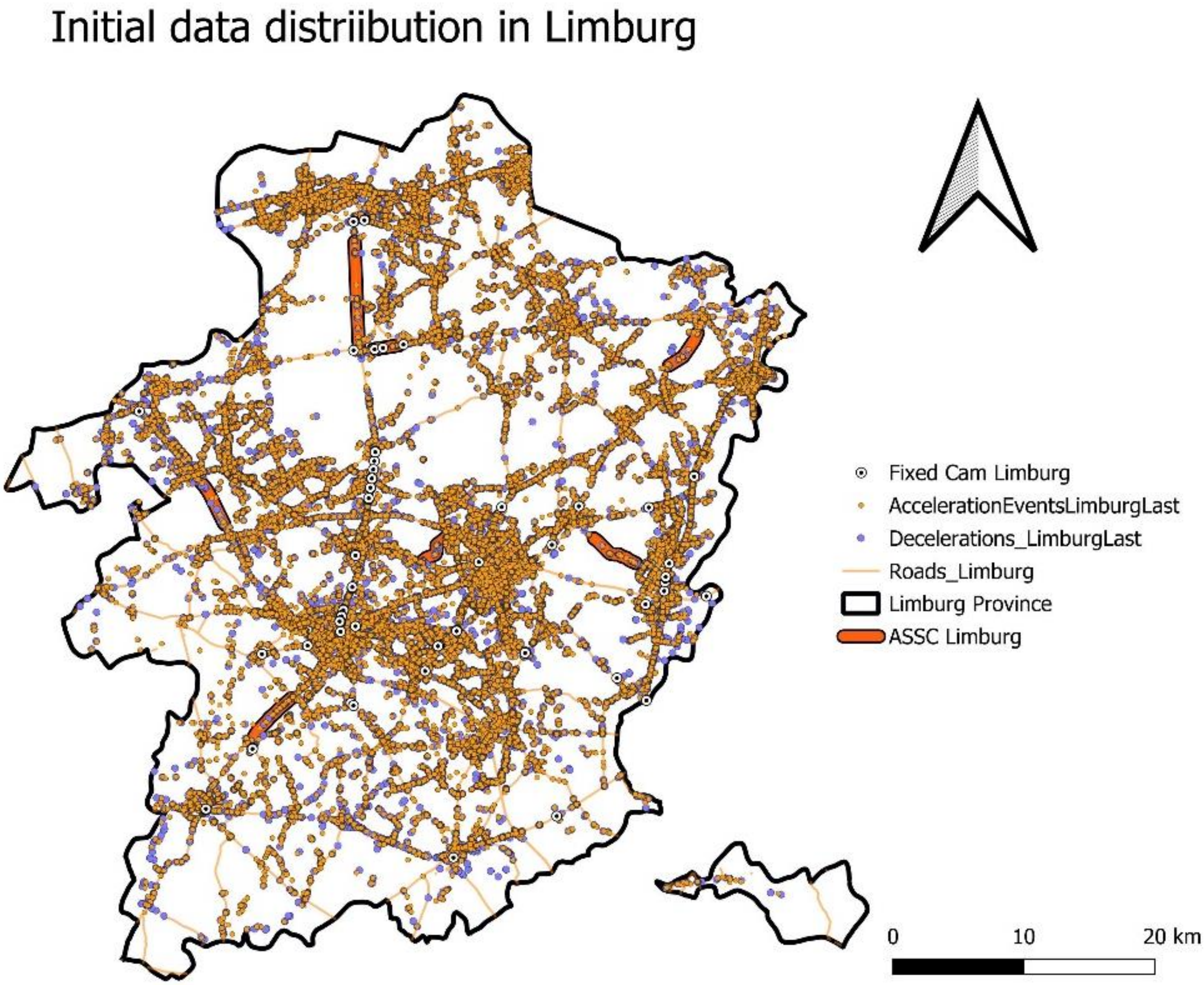


Figure 8: Initial events distribution in the entire Flemish region

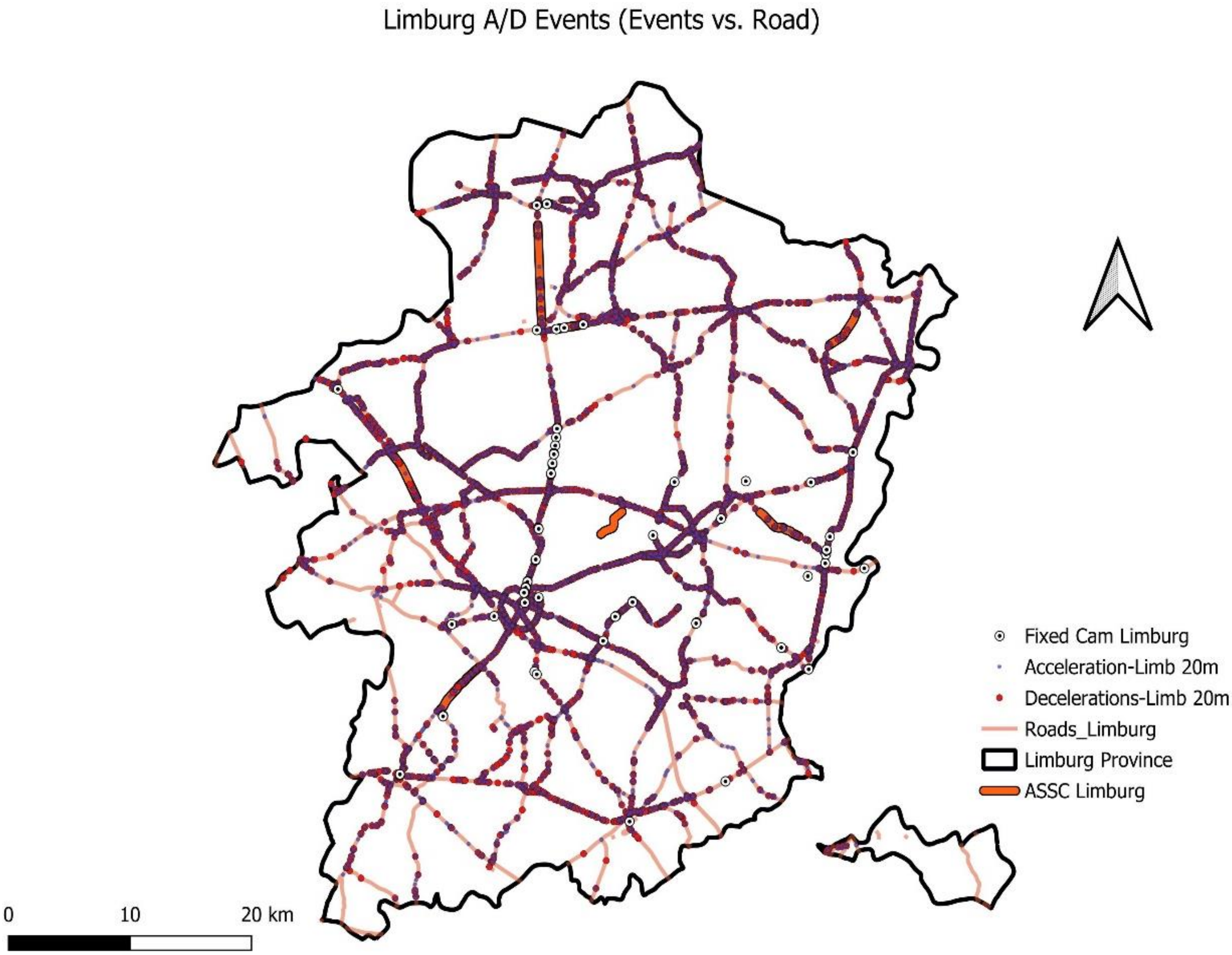


Figure 9: Events distribution after the data cleaning

3.7. Used software and their contribution

1. QGIS (Quantum GIS): Geographic Information Systems played an instrumental role in the conduct of this research project. The spatial nature of the research question necessitated a tool that could handle, manipulate, and visualize geospatial data, which QGIS provided. QGIS is a free and open-source software that allows users to manage, analyze, and visualize geospatial data. It offers a wide range of features, including mapping and geospatial analysis tools, support for different data formats, and the ability to handle large datasets. It also offers advanced geoprocessing capabilities, such as spatial analysis and modeling, which can be used to generate insights and help make data-driven decisions (Bivand et al.,2019). GIS contributed to a range of various processes in this study, the main operations included:

- *Data Management and Integration*: At the outset, GIS was crucial for managing the vast amount of geospatial data that the project entailed. The data from various sources, including the naturalistic driving test data and OpenStreetMap (OSM) data, were integrated in the GIS environment. This integration allowed for a unified view and analysis of the data.

- *Data Projection:* All data layers were transformed into the same projection using GIS, ensuring accurate spatial relationships between different data elements. This uniformity was essential for conducting accurate and reliable spatial analyses.
- *Data Cleaning and Refinement:* GIS played a critical role in refining the data to the study's specific requirements. Given the large volume of data, some of which fell outside the study area, the GIS clipping tool was utilized to "clip" the data to the study area. This operation ensured that all subsequent analyses were based on data strictly from within the specified geographic boundary.
- *Joining Data:* GIS was also used to join the traffic data with the speed camera data based on their spatial relationship. This spatial join operation resulted in a comprehensive dataset that contained both traffic and speed camera information in the same spatial context.
- *Spatial Analysis (Geo-processing tools)*: The research involved a detailed spatial analysis to understand the relationship between speed camera positions and drivers' acceleration and deceleration patterns. GIS facilitated this by providing tools to conduct a range of spatial analyses.

To summarize, GIS served as an indispensable tool in this research project. Its capabilities for data management, spatial analysis, and data manipulation were essential for examining the relationship between speed camera locations and driver behavior. The insights gained from this study were made possible by the unique spatial perspective that GIS brought to the table.

2. SPSS: Statistical Package for the Social Sciences (SPSS) was instrumental in this research project, serving as the primary tool for statistical analysis and interpretation of the collected data. It contributed to a range of processes like:

- *Data Import and Management:* The cleaned and refined GIS data was imported into SPSS for further analysis. SPSS allowed for efficient management of this data, enabling the creation of a structured dataset ready for statistical analysis.
- *Descriptive Statistics:* SPSS was used to generate descriptive statistics, providing a summary and overall picture of the data. These statistics included measures of central tendency and frequency distributions. These offered an initial understanding of drivers' acceleration and deceleration patterns in the vicinity of speed cameras.
- *Correlation Analysis:* The software was instrumental in running correlation analyses to investigate the presence and strength of linear relationships between the speed camera positions and drivers' acceleration/deceleration patterns. The correlation coefficients obtained provided initial insights into the associations between these variables.
- Hypothesis Testing: SPSS's capabilities for hypothesis testing were essential in determining the significance of the findings. T-tests and ANOVA were conducted to evaluate whether the observed differences in driver behavior could have occurred by chance or were statistically significant.
- *Data Visualization:* SPSS also contributed to the visualization of results. It was

used to create charts, plots, and other graphical representations of the data and statistical results. These visualizations helped to better understand and communicate the findings of the study.

In summary, SPSS was a vital tool in this research project. It facilitated rigorous statistical analysis, interpretation, and visualization of the data, enabling a deeper understanding of the relationship between speed camera positions and driver behavior. Through its use, the study was able to present robust and statistically significant findings.

3. Microsoft office: Microsoft Office, specifically Excel and Word, played a significant role in the organization, analysis, and presentation of data in this study. Excel was used for several important tasks including:

- Data Cleaning and Preprocessing: Prior to the statistical analysis in SPSS, the data likely underwent a cleaning process. Excel's various functions such as sorting and filtering were extremely useful.
- Visualizations: After SPSS analysis, Excel has been used to improve the visual representations of the data such as charts, histograms, and scatter plots. These visualizations can made it easier to understand trends and patterns in the data.

Microsoft Word, on the other hand, was likely used for:

- Documentation: Word was used to draft the initial research proposal, document the methodology, and record observations and notes throughout the study.
- Report Writing: Word was used to compile the findings, write the discussion and conclusions, and formalize the study into a cohesive research report.

In summary, while the more specialized tools like GIS and SPSS played key roles in the data collection and analysis stages of the research, Microsoft Office applications like Excel and Word were instrumental in the organization, preliminary analysis, and presentation of the study's findings.

3.8. Data-processing process using GIS

After the pre-data processing was done, the refined data was treated to further analysis. The data requirements for the fixed camera was a little bit different for the ASSC. Below detailed the entire process on both locations:

i. Average Speed Section Control (ASSC)

- *Step 1: Creating the new point feature (Camera):* The first step in the process was to set up the positions of the two cameras that denote the entry and exit of each ASSC section. These were set as new feature points in GIS. The camera positions were crucial as they served as reference points for further analyses.
- *Step 2: Event Selection:* The next step involved selecting all acceleration and deceleration events that occurred within a distance of 1300m from either of the two cameras. This was done by employing the “Select within a distance tool” to select all events within the mentioned range around each camera point. This operation ensured that only events within the specified distance from the ASSC were included in the study.

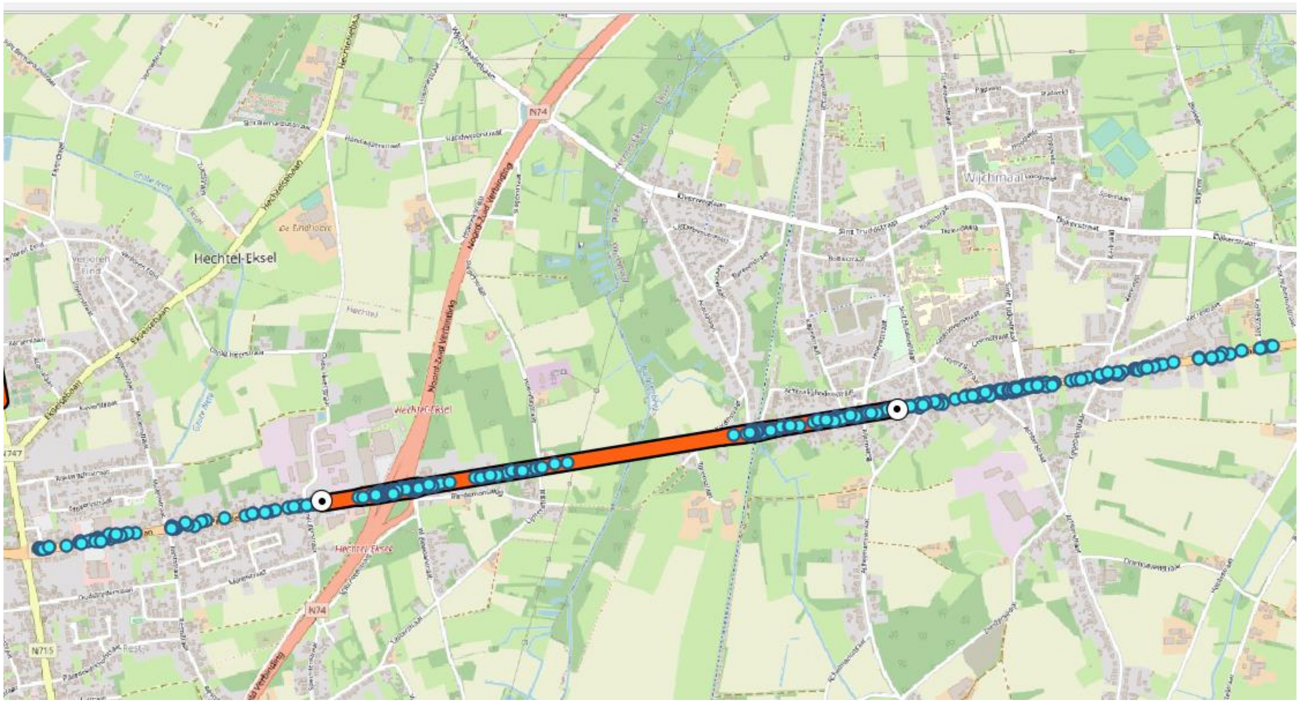
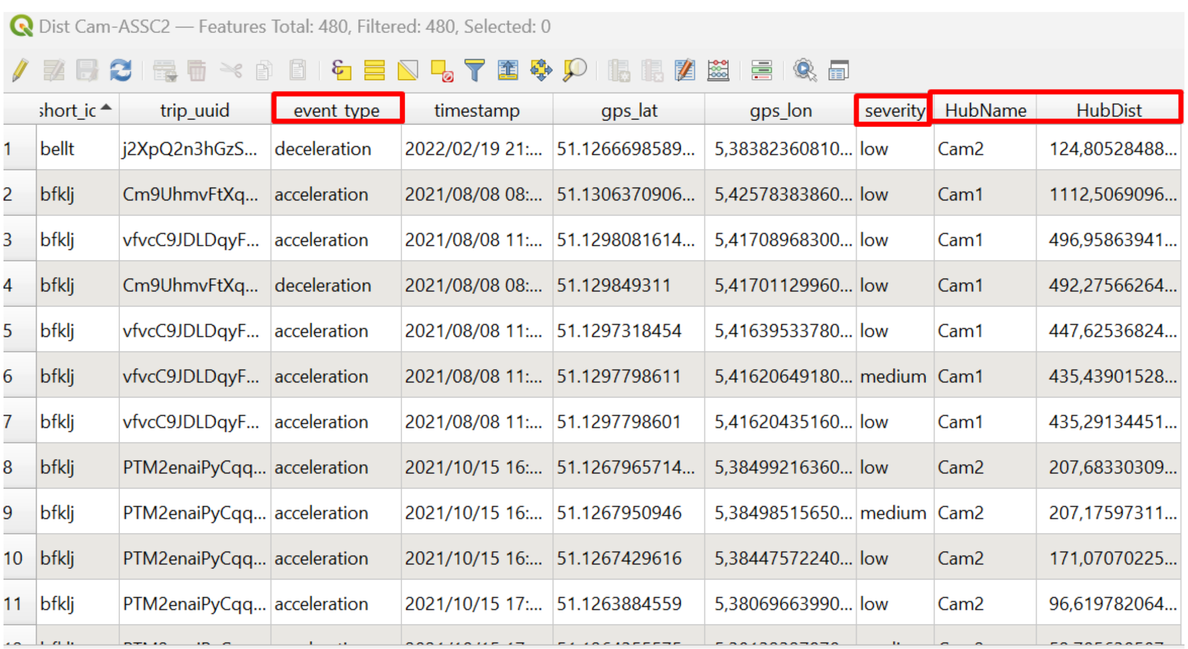


Figure 10: Events view at in the ASSC area

- *Step3: Distance Calculation:* Once the relevant events were selected, the distance from each event to the nearest camera was calculated. This was performed using the 'Distance Matrix' tool in GIS, specifically the 'Distance to the nearest hub-Point to point' operation. This operation computes the distance from each point (in this case, each event) to the nearest point in another layer (in this case, the camera positions). The result is a matrix that gives the distance from each event to the nearest camera.



Dist Cam-ASSC2 — Features Total: 480, Filtered: 480, Selected: 0

	short_ic	trip_uuid	event_type	timestamp	gps_lat	gps_lon	severity	HubName	HubDist
1	bellt	j2XpQ2n3hGzS...	deceleration	2022/02/19 21:...	51.1266698589...	5,38382360810...	low	Cam2	124,80528488...
2	bfklj	Cm9UhmvFtXq...	acceleration	2021/08/08 08:...	51.1306370906...	5,42578383860...	low	Cam1	1112,5069096...
3	bfklj	vfvcC9JDLDqyF...	acceleration	2021/08/08 11:...	51.1298081614...	5,41708968300...	low	Cam1	496,95863941...
4	bfklj	Cm9UhmvFtXq...	deceleration	2021/08/08 08:...	51.129849311	5,41701129960...	low	Cam1	492,27566264...
5	bfklj	vfvcC9JDLDqyF...	acceleration	2021/08/08 11:...	51.1297318454	5,41639533780...	low	Cam1	447,62536824...
6	bfklj	vfvcC9JDLDqyF...	acceleration	2021/08/08 11:...	51.1297798611	5,41620649180...	medium	Cam1	435,43901528...
7	bfklj	vfvcC9JDLDqyF...	acceleration	2021/08/08 11:...	51.1297798601	5,41620435160...	low	Cam1	435,29134451...
8	bfklj	PTM2enaiPyCqq...	acceleration	2021/10/15 16:...	51.1267965714...	5,38499216360...	low	Cam2	207,68330309...
9	bfklj	PTM2enaiPyCqq...	acceleration	2021/10/15 16:...	51.1267950946	5,38498515650...	medium	Cam2	207,17597311...
10	bfklj	PTM2enaiPyCqq...	acceleration	2021/10/15 16:...	51.1267429616	5,38447572240...	low	Cam2	171,07070225...
11	bfklj	PTM2enaiPyCqq...	acceleration	2021/10/15 17:...	51.1263884559	5,38069663990...	low	Cam2	96,619782064...

Figure 11: Attribute table content

- The output of the distance matrix established a clear connection between the position of the camera and the points of the events *("Cam1 & Cam2": which defines the camera position and the "HubDist" which defines the distance from the camera to the event)*. This connection made it possible to associate each event with a specific camera, its severity, as well as the distance from the event to that camera. This added a layer of context to the event data, enabling a more detailed and specific analysis.
- *Step 4: Data Export:* Finally, the processed and linked data was exported from GIS for further analysis in SPSS. The exported data contained information about each event, the associated camera, and the distance of the event to the camera.

ii. Single fixed camera

The methodology for studying fixed cameras was similar to that of the ASSC analysis, with the exception of the first step. Instead of establishing a new point feature, this initial phase involved selecting all acceleration and deceleration events occurring within a radius of 1300 meters from the camera. To accomplish this, the same distance matrix tool used in the ASSC analysis was utilized, ensuring only events within this specified proximity were included. This approach ensured the focus remained strictly on events relevant to the fixed speed camera. Once the relevant events were selected, the distance from each event to the camera was calculated. This was achieved using the 'Distance Matrix' tool in GIS. This tool calculates the distance from each point (in this case, each event) to the point in another layer (in this case, the camera position). The result is a matrix that gives the distance from each event to the camera. Finally, the processed and linked data was imported to excel and SPSS for further process and analysis. The exported data contained information about each event, the associated camera, and the distance of the event to the camera.

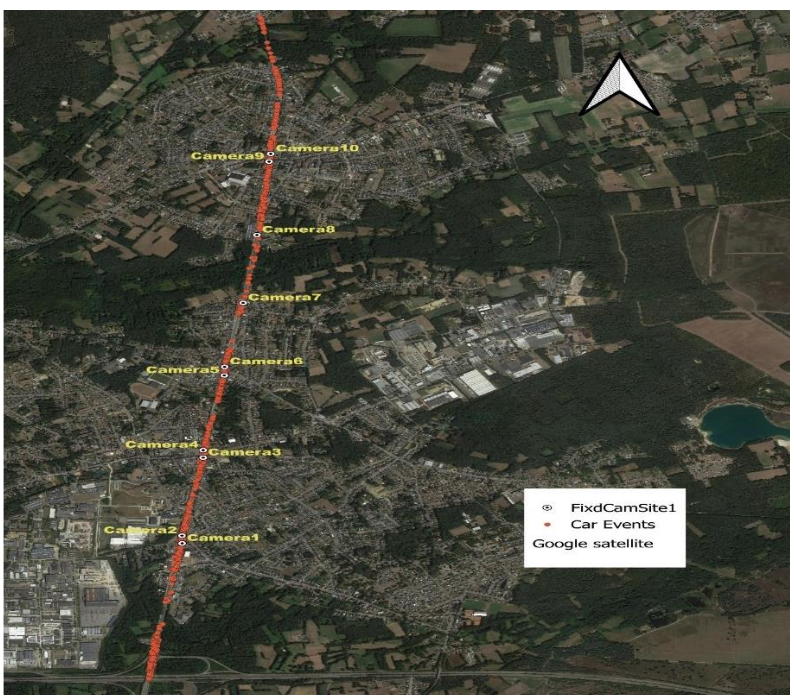


Figure 12: Fixed cameras site

iii. Heatmaps

In the scope of this research, a tool known as a heatmap served as a cornerstone for visually interpreting and analyzing the discrete distributions of both acceleration and deceleration events. A heatmap, in essence, is a graphical representation of data where individual values are represented as colors, creating a spectrum that allows for an intuitive visualization of data patterns. This visual tool facilitated an in-depth comprehension of spatial patterns and concentrations of these events, illustrating their distribution in relation to the layout of the road network and the locations of speed cameras. This usage of a heatmap provided not only a macroscopic overview, but also granular insights into the studied driving behaviors. In this study, specific heatmap settings were set to optimize the representation of the data, ensuring a precise depiction of the event concentrations. These configurations were adjusted as illustrated in Figure 13 to accurately display the density and dispersion of the events, thereby enhancing the visibility of high concentration areas.

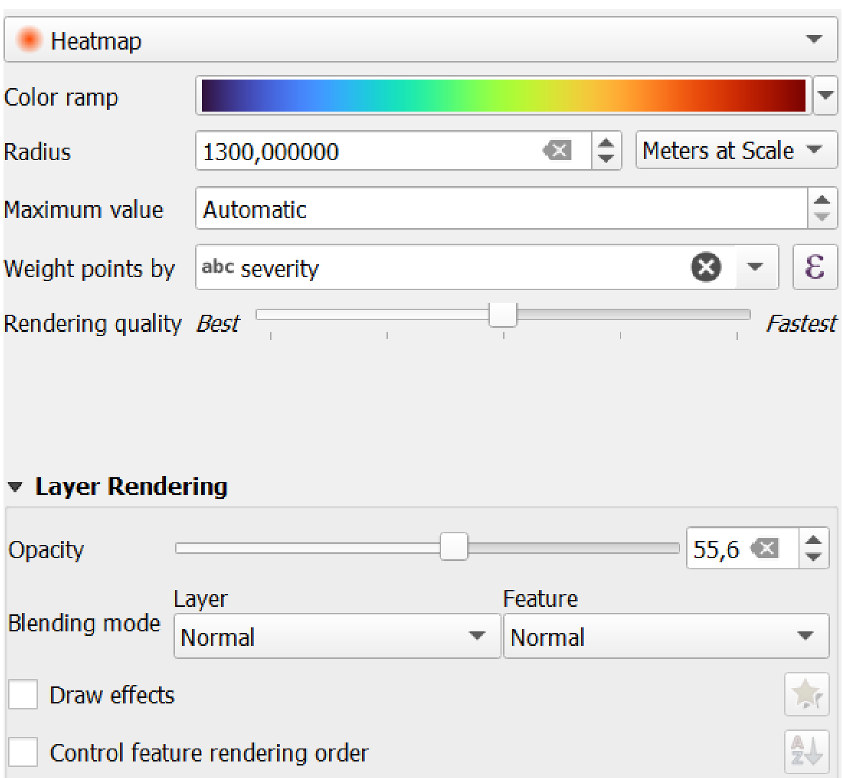


Figure 13: Used settings for Heatmaps

iv. Control group: Fake speed-camera sites

To provide a reference or control group for this study, three additional sites were selected where a decoy or fake speed camera was installed on each road section. Using the same spatial parameter of 1300 meters around these sites, corresponding driving events were selected in a Geographic Information System (GIS). The extracted data was subsequently processed and analyzed using SPSS. The primary objective behind this approach was to evaluate and contrast the drivers' behavior patterns at sites with real speed cameras or ASSC versus those with Virtual cameras. The underlying hypothesis being, any significant differences between these two groups could be attributed to the drivers' awareness of the actual monitoring mechanisms, thereby shedding light on the true impact of these speed control measures on drivers' acceleration and deceleration behaviors.

Figure 14: Sites with a Virtual cameras

3.9. Data processing using Microsoft excel and SPSS

Before the data was imported into SPSS for statistical analysis, it underwent an additional stage of processing using Microsoft Excel. The data, which was exported from the Geographic Information System (GIS) as a dbf file, contained a merged dataset inclusive of both acceleration and deceleration events. Microsoft Excel played a crucial role in this stage. Its robust data manipulation capabilities facilitated the separation of events by their type, isolating similar data into individual groups. This step was essential to minimize potential processing errors and inaccuracies during the subsequent statistical analyses, ensuring that each event type could be examined independently and with greater precision.

Following the completion of the pre-processing stage in Excel, the refined datasets were then imported into SPSS. Here, a series of diverse statistical analyses were performed, each tailored to extract meaningful insights from the data pertaining to the relationship between speed camera positioning and the acceleration/deceleration behavior of drivers.

3.10. Ethics consideration.

In any research study, ethics should be a key consideration. For this study, ethical considerations were taken into account in several ways. Firstly, the study made use of existing data sources that were collected for other purposes. No new data was collected specifically for this study, so there were no issues with obtaining informed consent from participants. The IMOB ensured the confidentiality and privacy of the drivers involved in the naturalistic driving study. Thus, all data used in the study were anonymized to protect the privacy of individuals and to prevent any identification of individuals who participated in the Naturalistic driving study. To summarize, the ethical considerations of the study were taken seriously and appropriate measures were taken to ensure that the research was conducted in an ethical and responsible manner.

4. RESULTS

4.1. Results from GIS outputs.

4.1.1. Distribution of acceleration and deceleration events

The following maps (Figure 15 and 16) provide respectively a comprehensive macro-level view of all acceleration and deceleration events across the entire Limburg Province, with a particular focus on event severity. They effectively illuminates areas of high concentration, shedding light on the spatial patterns of these driving behaviors.

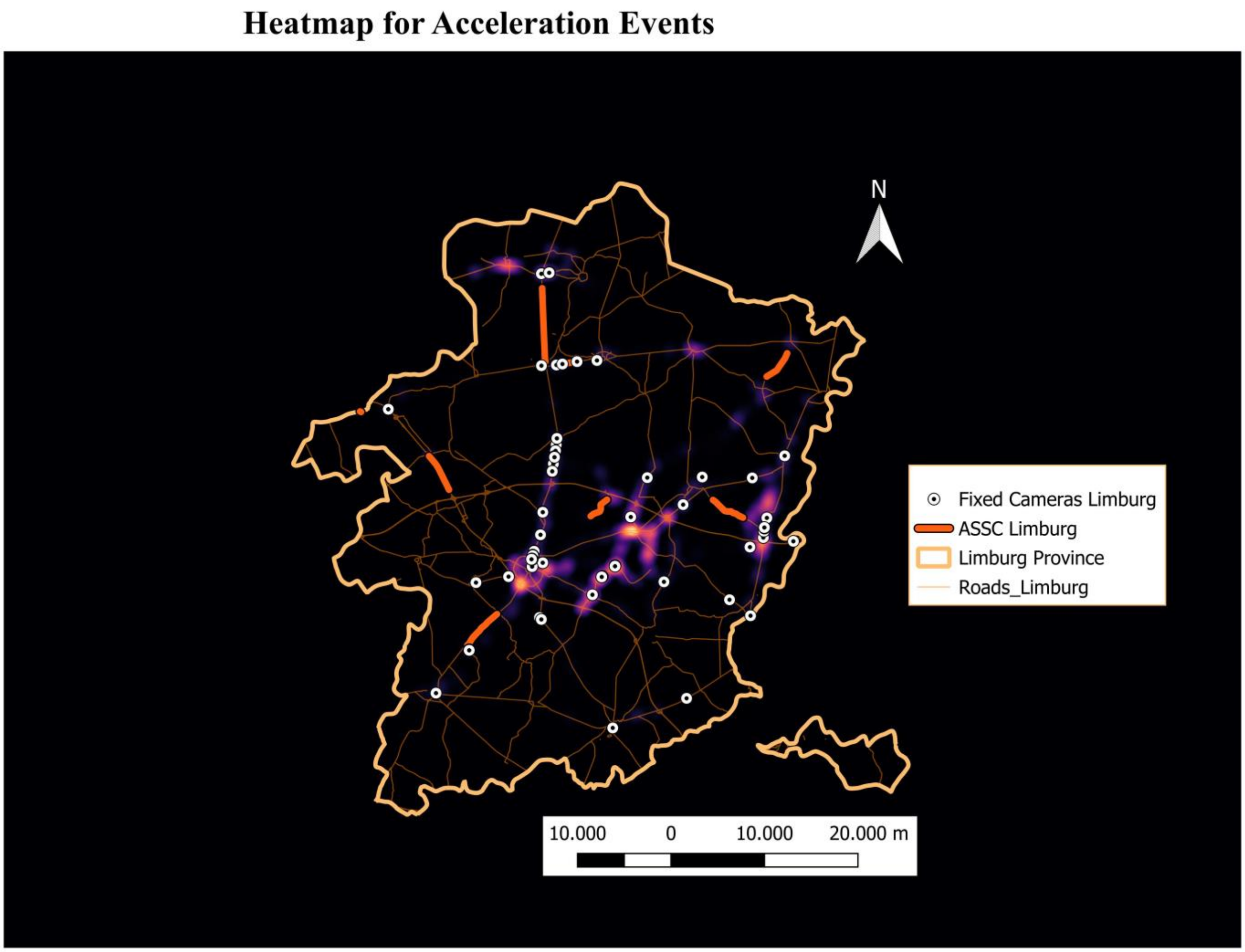


Figure 15: Heatmap of acceleration events (Macro -level view)

Upon examination of these maps, it is apparent that no high-severity acceleration and deceleration events were detected within the vicinity of the Average Speed Safety Cameras (ASSCs). The map also reveals a limited number of such events occurring in proximity to the fixed cameras. However, it's important to note that the level of detail perceivable in the map increases with zooming in.

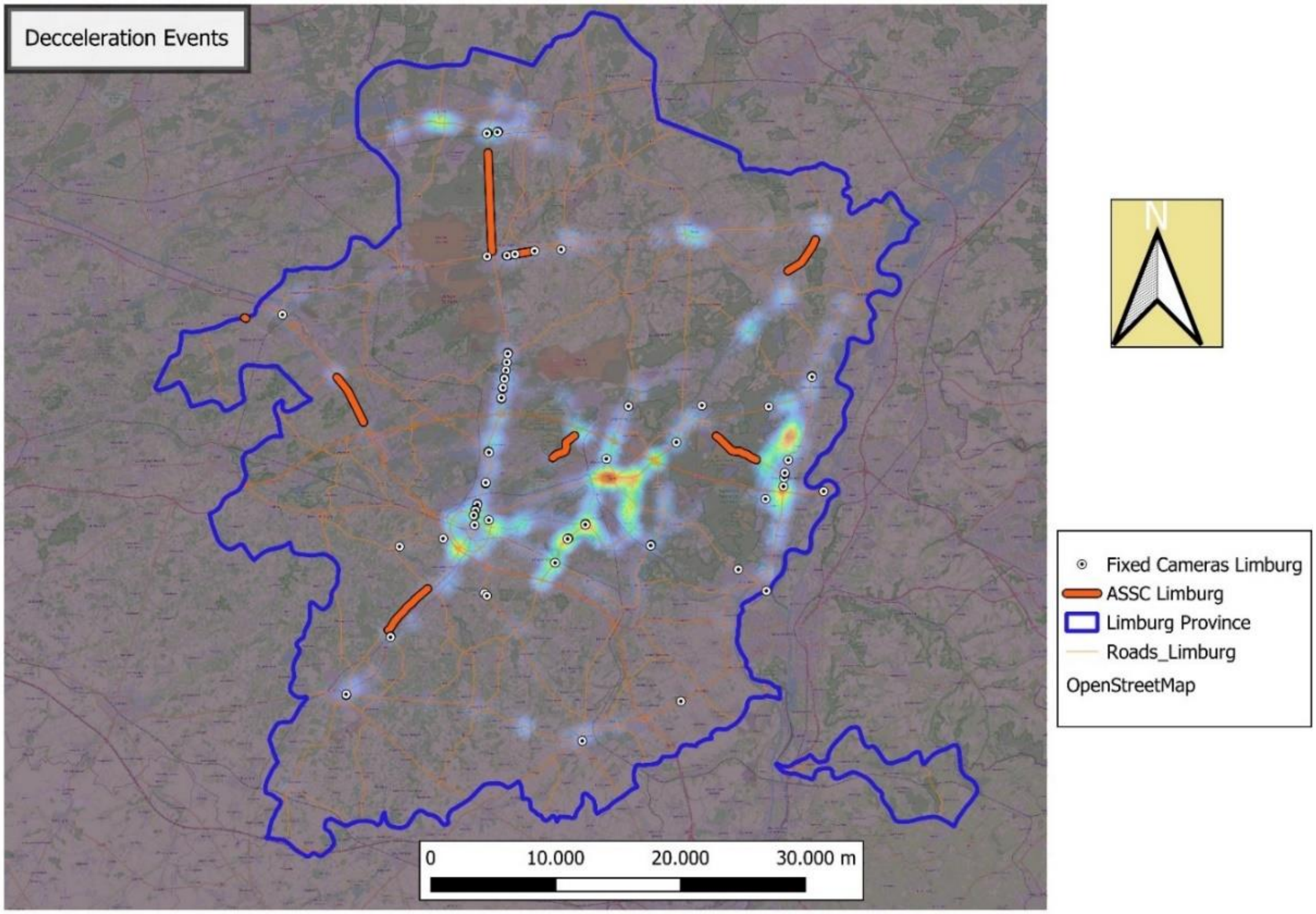


Figure 16: Deceleration events (Macro-Level view)

These views as illustrated in figure 15 and figure 16, can provide valuable insights into more localized patterns and hotspots of acceleration events. However, given these observations, it would be highly beneficial to further examine this situation through a more detailed visualization. As such, the subsequent figures 17 and Figure 18 are designed to provide a more detailed representation of these events and their location vis a vis to the camera locations.

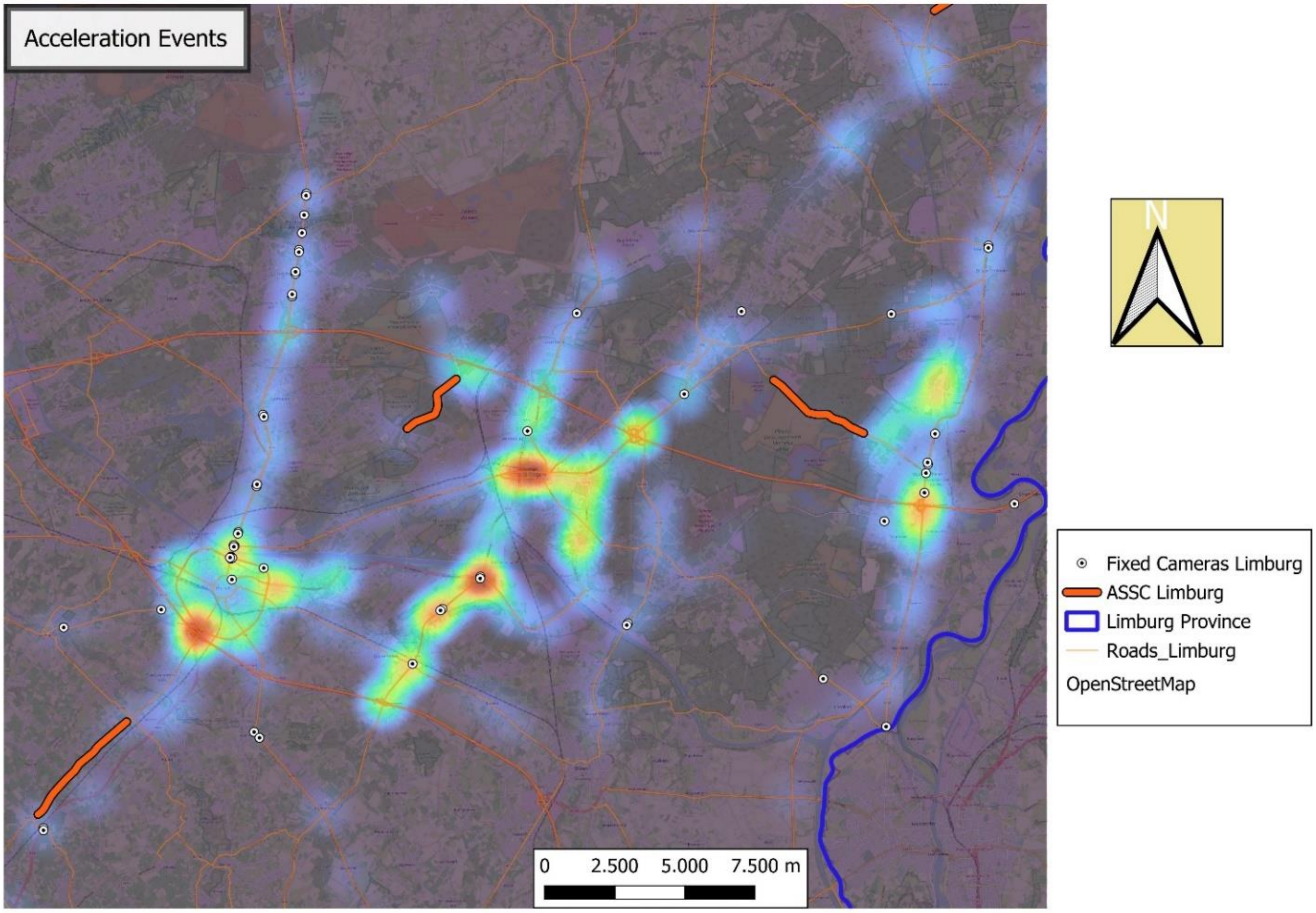


Figure 17: Heatmap of acceleration events (Meso-Level view)

Figure 17 and Figure18, are the zoomed view (Mese-level) of the acceleration and deceleration events respectively. This extract was randomly extracted based on the location of high concentration of data, and on it appear among others, the zone of Hasselt and Diepenbeek. Through these detailed visualizations, several key findings regarding the distribution and severity of events can be discerned:

- It is remarkable that high-severity deceleration events often coincide spatially with high-severity acceleration events. This overlap suggests a possible common factors influencing these two types of speed modification events.
- Upon closer inspection of the areas surrounding fixed cameras, it was observed that locations with high severity of both acceleration and deceleration events occurred in the vicinity of some fixed cameras. This pattern could suggest the further examination of the causing factors.
- From these figures, it also becomes evident that the highest concentration of severe events tends to be located around road intersections. This finding underscores the role of intersections as potential hotspots for drastic speed changes.
- These illustrations reveal that high-severity events often occur outside the zones monitored by speed enforcement devices, including both Average Speed Safety Cameras

(ASSCs) and fixed cameras. This observation could indicate that drivers may be more prone to drastic speed changes in areas not under direct speed enforcement surveillance.

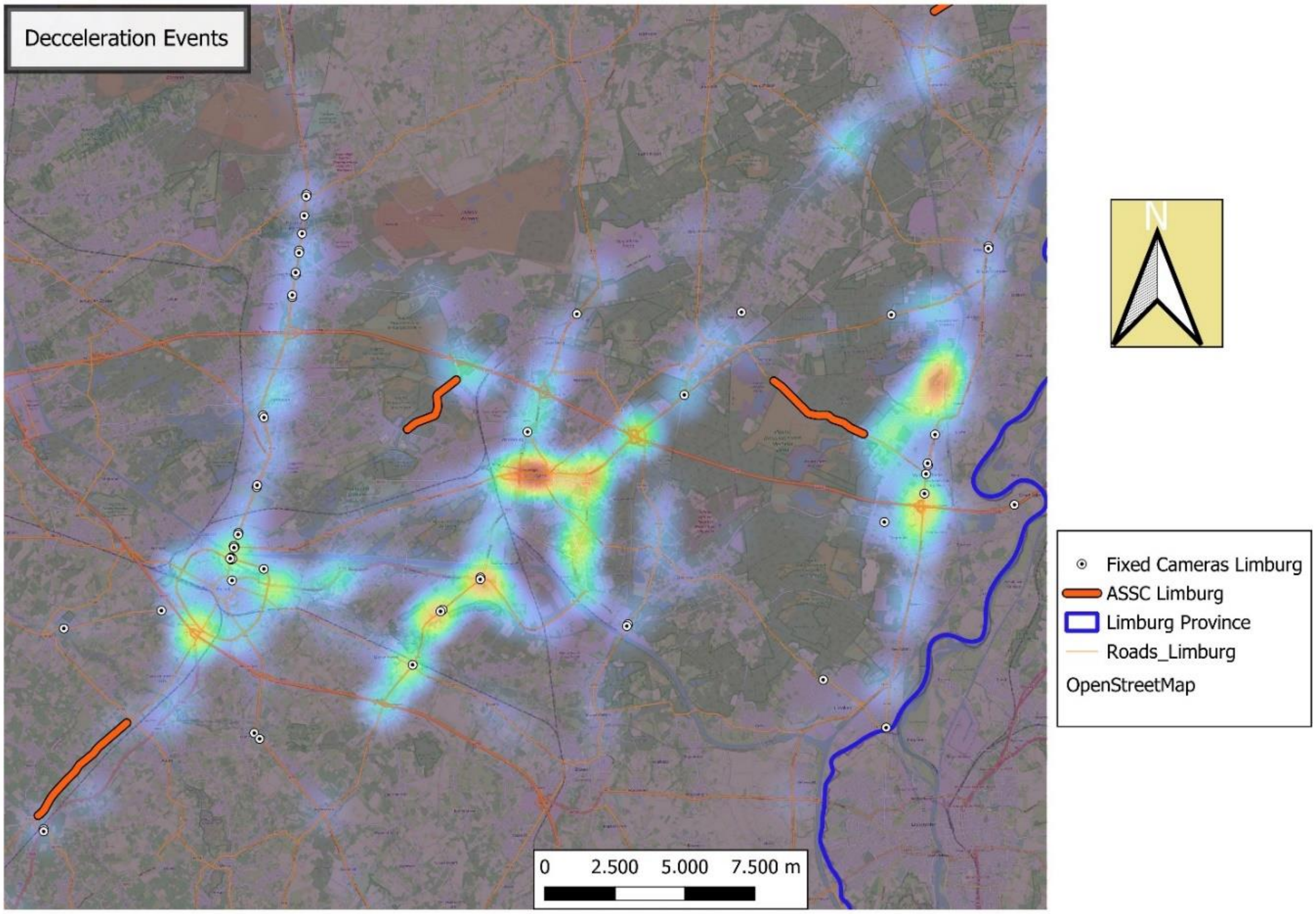


Figure 18: Deceleration events (Meso-level view)

These detailed observations contribute to a more thorough understanding of the spatial patterns of acceleration and deceleration events in relation to speed enforcement systems. However, they do not offer an complete view regarding the patterns of acceleration and deceleration events in direct relation to the precise locations of speed enforcement devices.

Thus, a detailed study using statistics (SPSS) is necessary to evaluate at micro-level, the distribution of events based on the position to the camera. Utilizing statistical methods, we can conduct a rigorous, micro-level examination of the distribution of events relative to the position of the speed enforcement cameras. Such an analysis would enable us to uncover patterns and correlations that may not be evident from the macro and meso-level perspectives, thereby providing a more thorough understanding of the relationship between driver behavior and the position of speed enforcement systems.

4.2. Statistical analysis of results

This chapter provides a detailed examination of both acceleration and deceleration events around Average Speed Safety Cameras (ASSCs) and fixed cameras. This divided analysis allows for a comprehensive exploration of the spatial distribution of these events in relation to the type of speed enforcement systems. By evaluating these events based on their severity, this approach yielded a deep understanding of the relationship between driver behavior and the presence of different speed enforcement devices.

Descriptive statistics were utilized to evaluate the distribution of events. These statistics provided insights into the frequency of occurrence of acceleration and deceleration events of varying severity, thereby offering a comprehensive picture of the event distribution in relation to speed enforcement camera locations.

In addition to the descriptive analysis, the linear correlation (Spearman) analysis was run. This statistical method was used to assess the strength of relationship between the position of the camera (represented by the distance between the camera location and the point of event occurrence), and the severity of car events, which was coded as follows: Low (1), Medium (2), and High (3).

To the site where the significant relationship was found, the correlation analysis was utilized to evaluate whether the observed relationships were statistically significant. These analysis offer a deeper insights into the ways in which these devices might influence the severity and occurrence of acceleration and deceleration events:

4.2.1. Deceleration events in the ASSC-site 1

In the area of "ASSC-site 1", the findings from the frequency distribution analysis presented a notable absence of high-severity deceleration events within a 1300-meter radius from both the entry and exit cameras. This was represented by a 0% occurrence rate, signifying a complete lack of such events in this specified area around the cameras.

Additionally, the analysis revealed a notably low concentration of medium-severity acceleration events, representing 5.6% of the total events. This rare occurrence points to a relatively low intensity of these events in the vicinity of the Average Speed Safety Cameras. However, the predominance of low-severity deceleration events was evident, accounting for a substantial 94.4% of all recorded events. This high percentage highlights the dominance of low-severity deceleration events within the ASSC area.

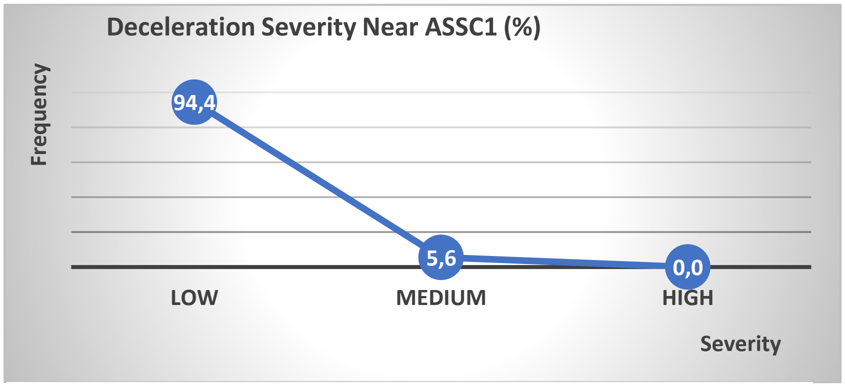


Figure 19: Deceleration events frequency in ASSC zone

Figure 20 provides a detailed representation of the distribution of the aforementioned events, characterized by their severity and distance from the point of occurrence to the camera position (either at the entry or exit of the ASSC section). A careful examination of this figure reveals that a high frequency of low-severity events occurred within the 0-200 meter range and once again within the 600-800 meter range. Conversely, the lowest frequency of low-severity events was observed within the 400-600 meter and 800-1000 meter ranges.

On the other hand, all medium-severity events, which constituted 5.6% of the total events, were found to occur between the 200-400 meter and 600-800 meter ranges from the camera. Moreover, there was a complete absence of medium-severity events within the 0-200 meter range.

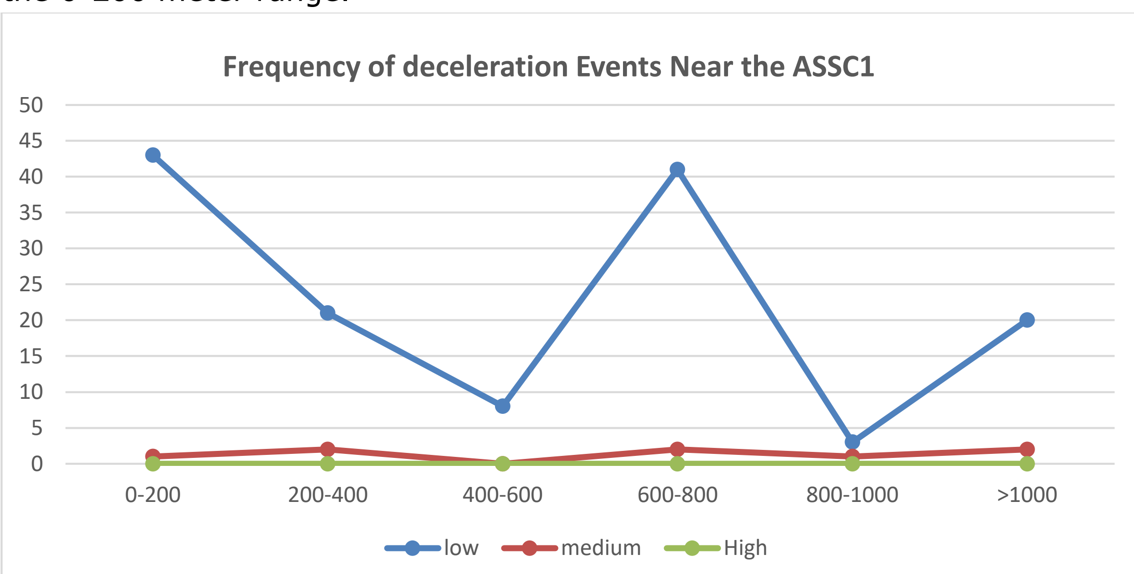


Figure 20: Deceleration events Vs. Distance from the camera

To provide a more precise visualization of the total number of events in relation to their distance from the camera, the following histogram offers a clear illustration. It clearly demonstrates that the majority of these events occurred within the 800 meters from the camera's location.

This visualization offers an insightful depiction of the spatial density of these events, emphasizing the concentration of driver behaviors in close proximity to the camera installations.

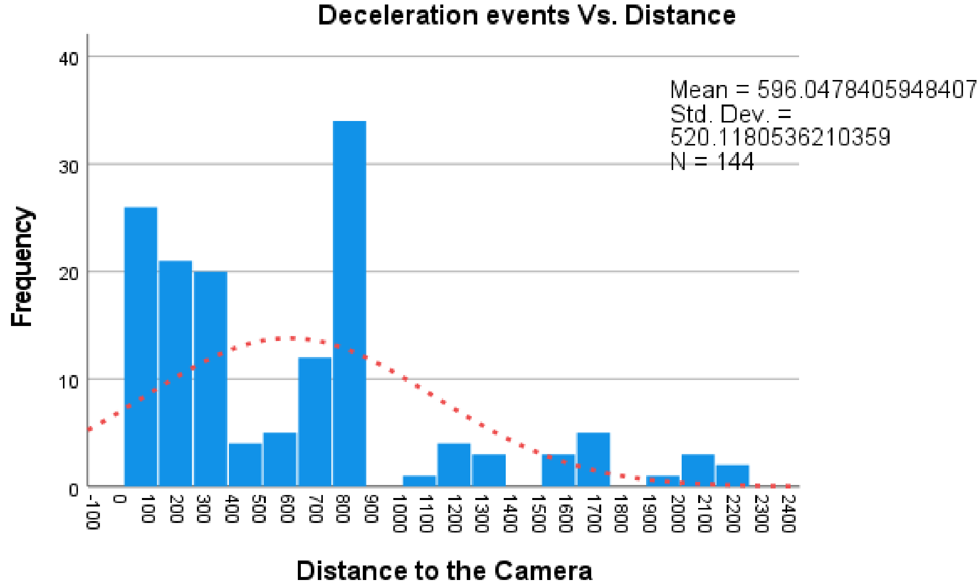


Figure 21: Generalized visualization of Deceleration events in relation to the distance from the camera

Use of the Bivariate correlation (Spearman): The assessment of the relationship strength between the severity of the events and the position of the camera was conducted using two variables: the coded severity and the distance from the camera to the location of the event. This setup aimed to ascertain whether there exists a correlation between the variation in the severity of decelerations and the change in distance from the camera's (ASSC's) position. This analysis intends to determine if the proximity to the camera had any discernible impact on the severity of deceleration events, thereby providing insights into the influence of the camera's presence on driver behaviour.

Spearman's correlation was computed to assess the relationship between [variable 1: Severity] and [variable 2: Distance to camera]. The result indicated a positive but non-significant correlation between the two variables, with rho=0.119 and p = 0.156>0.05.

Table 6: Correlation results for decelerations (ASSC site1)

Spearman's rho		Severity	Distance
Severity	Correlation Coefficient	1	0,119
	Sig. (2-tailed)		0,156
	N	144	144
Distance	Correlation Coefficient	0,119	1
	Sig. (2-tailed)	0,156	
	N	144	144

Since the p-value (0.156) exceeded the threshold for statistical significance (0.05), the study found no statistically significant correlation between the severity of deceleration events and their distance from the camera. This suggests that, within the scope of this study, the positioning of the camera does not significantly influence the severity of such events.

4.2.2. Acceleration events in the ASSC-site 1

In the area of "ASSC-site 1", the findings from the frequency distribution analysis presented a very low high-severity deceleration events within a 1300-meter radius from both the entry and exit cameras. This was represented by a 1% occurrence rate, signifying a rare occurrence of such events in the ASSC area. Regarding the medium concentration, the analysis revealed 17% concentration of medium-severity acceleration events. On the other hand, similar to the deceleration events, the low-severity deceleration events were predominant in the ASSC zone1, accounting for a substantial 82% of all recorded events. This high percentage highlights the dominance of low-severity deceleration events within the ASSC area.

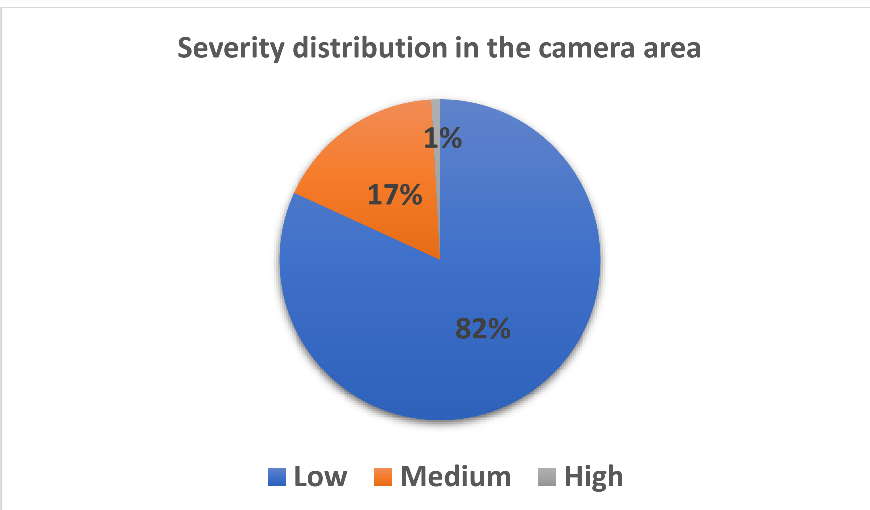


Figure 22: Distribution of acceleration events in the ASSC site 1

Figure 23 provides an in-depth depiction of the distribution of acceleration events, classified according to their severity and relative distance from the camera position (either at the entrance or exit of the ASSC section). A detailed analysis of this figure indicates a dominant frequency of low-severity events within the first 400 meters from the camera. Beyond this point, there is a general decline in the frequency of such events up to the furthest point of measurement.
In the case of medium-severity events, while their overall occurrence is low, a peak in their frequency is evident within the range of 200-400 meters from the camera. As for high-severity acceleration events, their occurrence was noted within the range of 600-1000 meters from the ASSC, demonstrating a different distribution pattern from the low and medium severity events.

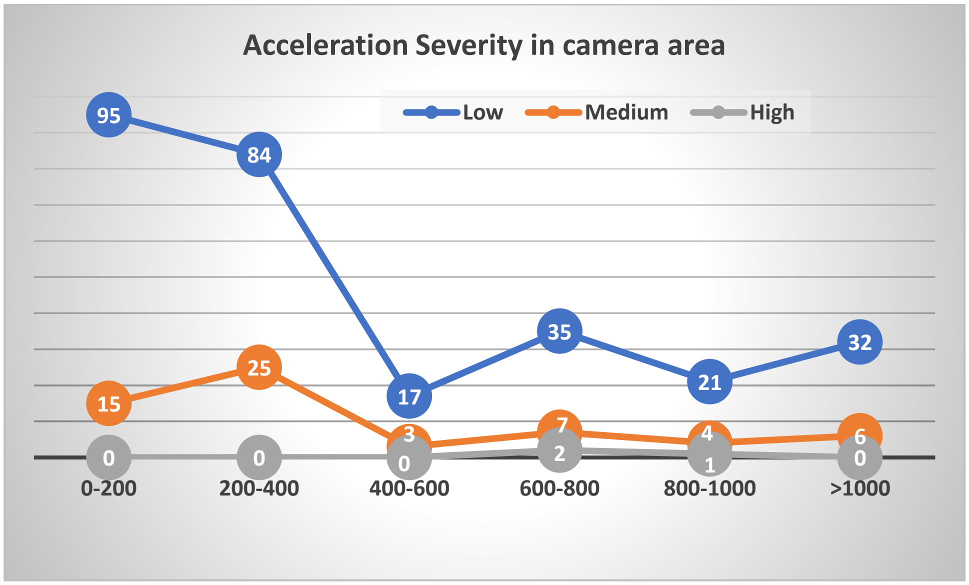


Figure 23: Acceleration events Vs. Distance from the camera

The histogram (Figure 24) offers a detailed visualization of the total number of acceleration events in relation to their distance from the camera, providing a comprehensive view of the distribution pattern. It demonstrates a high concentration of these all acceleration events within the first 200 meters from the camera's position, and a genelised decline of events distribution with the distance. This visualization offers an insightful depiction of the spatial density of these events, emphasizing the concentration of driver behaviors in close proximity to the camera installations.

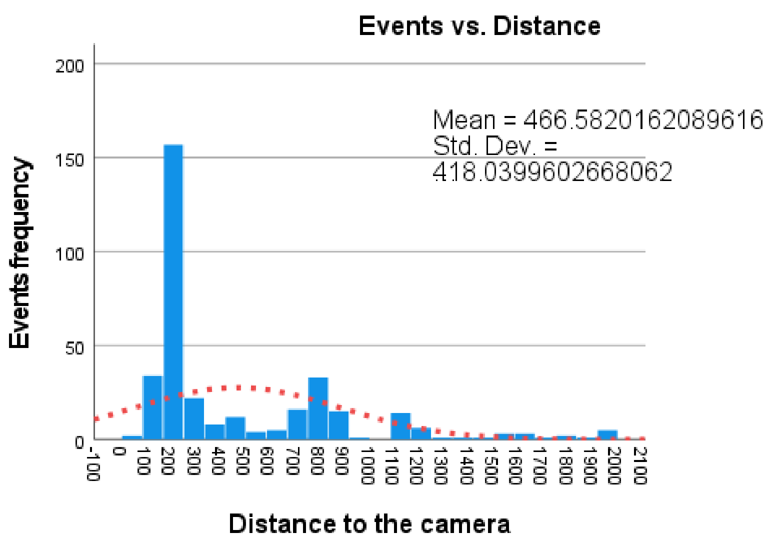


Figure 24: Visualization of acceleration events skewness(ASSC2)

Use of the Bivariate correlation (Spearman): The assessment of the relationship strength between the severity of the events and the position of the camera was conducted using two variables: the coded severity and the distance from the camera to the location of the event. This setup aimed to ascertain whether there exists a correlation between the variation in the severity of accelerations and the change in distance from the camera's (ASSC's) position. This analysis intends to determine if the proximity to the camera had any impacts on the severity of acceleration events, thereby providing insights into the influence of the camera's presence on driver behaviour.

To examine this, Spearman's correlation was computed between [variable 1: Severity] and [variable 2: Distance to camera]. The result indicated a positive but negligible correlation between the two variables, with rho=0.037 and p = 0.491>0.05.

Table 7: Results of Spearman correlation. Acceleration vs. Distance to the ASSC

Spearman's rho		Severity	Distance
Severity	Correlation Coefficient	1	0,037
	Sig. (2-tailed)		0,491
	N	347	347
Distance	Correlation Coefficient	0,037	1
	Sig. (2-tailed)	0,491	
	N	347	347

Since the p-value (0.491) exceeded the threshold for statistical significance (0.05), the study found no statistically significant correlation between the severity of acceleration events and their distance from the camera. This suggests that, within the scope of this study, the positioning of the camera does not significantly influence the severity of such acceleration events.

Table 8: Summarized distribution of events on the ASSC site1

Distance	Severity of decelerations			Total	Severity of accelerations			Total
	low	medium	High		Low	Medium	High	
0-200	43	1	0	44	95	15	0	110
200-400	21	2	0	23	84	25	0	109
400-600	8	0	0	8	17	3	0	20
600-800	41	2	0	43	35	7	2	44
800-1000	3	1	0	4	21	4	1	26
>1000	20	2	0	22	32	6	0	38
	136	8	0	144	284	60	3	347
Correlation results: r=0,119 P= 0.156					Correlation results: r=0,037 p=0.491			

4.2.3. Deceleration events ASSC2

In the area of "ASSC-site 2", the findings from the frequency distribution analysis presented a notable low rate of high-severity deceleration events within a 1300-meter radius from entry and exit cameras. This was represented by a 1% occurrence rate, signifying a rare occurrence of such events in the ASSC area. Regarding the Medium severity rate, the analysis revealed a 15% concentration of medium-severity deceleration events. However, the predominance of low-severity deceleration events was evident, accounting for a substantial 84% of all recorded events. This high percentage highlights the dominance of low-severity deceleration events within the ASSC area.

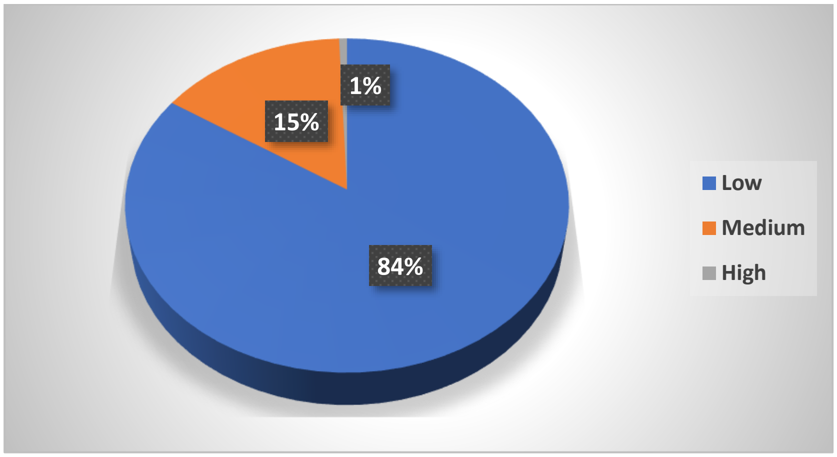


Figure 25: Events distribution with their severity

Figure 26 provides an in-depth representation of the distribution of deceleration events, classified according to their severity and relative distance from the camera position (either at the entrance or exit of the ASSC section). A detailed analysis of this figure indicates a dominant frequency of low-severity events within 200-400 meters from the camera, and sudden decrease from 200m to the camera. The graph also shows from 400m from ASSC, the general decline in the frequency of deceleration events with the increase of the distance from the camera. Regarding the medium-severity events, the results also showed the progressive decline with the increase of the distance from the camera. When it comes to high-severity deceleration events, its occurrence remained relatively low across the entire stretch of the study.

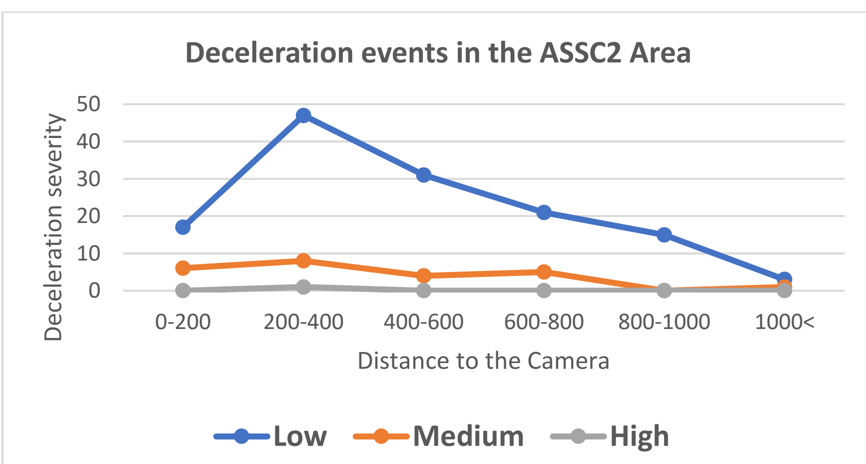


Figure 26: Deceleration events Vs. Distance from the camera

Figure 27, a histogram, presents an accurate visualization of the total count of deceleration events in correlation to their distance from the camera. This diagram facilitates a complete understanding of the distribution pattern of these events. With a bell-shaped distribution, it shows an obvious peak between 300 and 400 meters from the camera. This peak represents the highest frequency of acceleration events. However, as we move further from this peak, both closer to and further away from the camera, there is a decline in the frequency of these events. This symmetric distribution visually shows that the highest concentration of deceleration events tended to occurr within a mid-range distance from the speed enforcement devices.

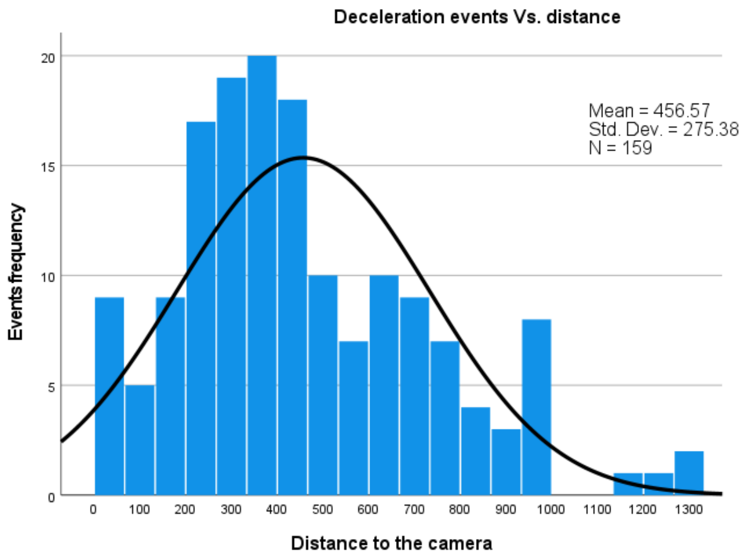


Figure 27: Visualization of Deceleration events skewness(ASSC2)

Use of the Bivariate correlation (Spearman):The assessment of the strength of relationship between the severity of the events and the position of the camera was conducted using two variables: the coded severity and the distance from the camera to the location of the event. This setup aimed to ascertain whether there exists a correlation between the variation in the severity of decelerations and the change in distance from the camera's (ASSC's) position. This analysis intends to determine if the proximity to the camera had any impacts on the severity of deceleration events, thereby providing insights into the influence of the camera's presence on driver behaviour.
To examine this, Spearman's correlation was computed between [variable 1: Severity] and [variable 2: Distance to camera]. The result indicated a Negative but non-significant correlation between the two variables, with rho=-0.145 and p = 0.069>0.05.

Table 9: Correlation results: Deceleration vs. the distance to the Camera (ASSC2)

Spearman's rho		Distance	Severity
Distance	Correlation Coefficient	1	-0,145
	Sig. (2-tailed)		0,069
	N	159	159
Severity	Correlation Coefficient	-0,145	1
	Sig. (2-tailed)	0,069	
	N	159	159

Since the p-value (0.069) exceeded the threshold for statistical significance (0.05), the study found no statistically significant correlation between the severity of Deceleration events and their distance from the camera. This means, within the scope of this study that the positioning of the camera does not influence the severity of such deceleration events in the ASSC vicinity.

4.2.4. Acceleration ASSC2

In the area of "ASSC-site 2", the findings from the frequency distribution analysis found a 9% of high-severity deceleration events within a 1300-meter radius from the camera. Signifying a low occurrence of such events in the ASSC area. Regarding the medium concentration, the analysis revealed 27% concentration of medium-severity acceleration events. On the other hand, the low-severity deceleration events were predominant in the ASSC zone 2, accounting for a substantial 64% of all recorded events. This high percentage highlights the dominance of low-severity deceleration events within the ASSC area.

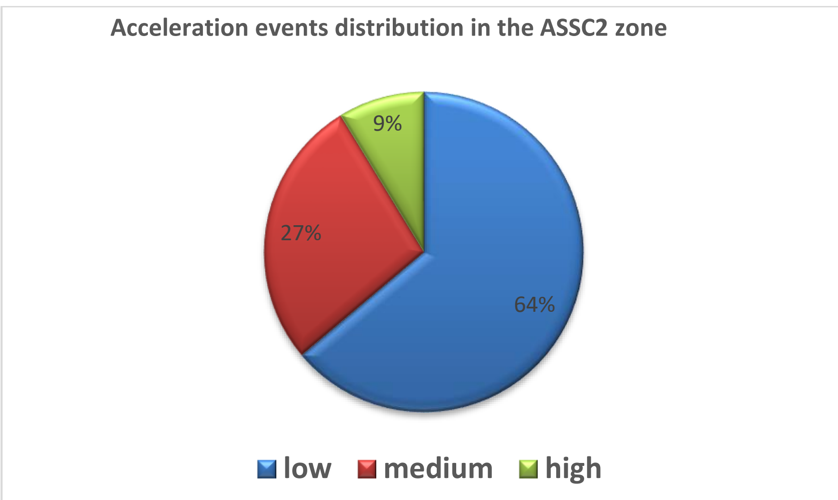


Figure 28: Acceleration Events distribution with their severity

Figure 29 offers a clear representation of the diffusion of acceleration events, categorized based on their severity and their relative proximity to the camera's position. An in-depth examination of this figure reveals a peak frequency for low-severity, medium-severity, and high-severity events between the 200 to 400-meter range from the camera. Beyond this peak zone, a gradual decline in the frequency of all severity categories of events is observed, from 200 to the camera and from 400m to the last point of measurement. This downward trend signifies that, regardless of severity, the frequency of acceleration events diminishes as the distance from the camera increases beyond the 200 to 400-meter range.

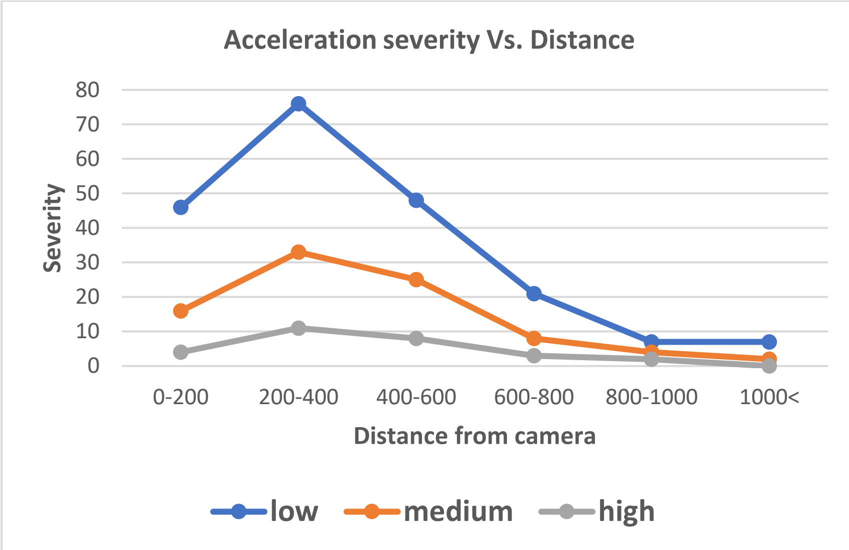


Figure 29: Events distribution, in relation to severity & distance

Regarding the distribution of acceleration events and their distance from the camera, Figure 30 provides a comprehensive and insightful visualization. The histogram demonstrates a high concentration of events in the range from 200-500m, and that declines in the remaining areas.

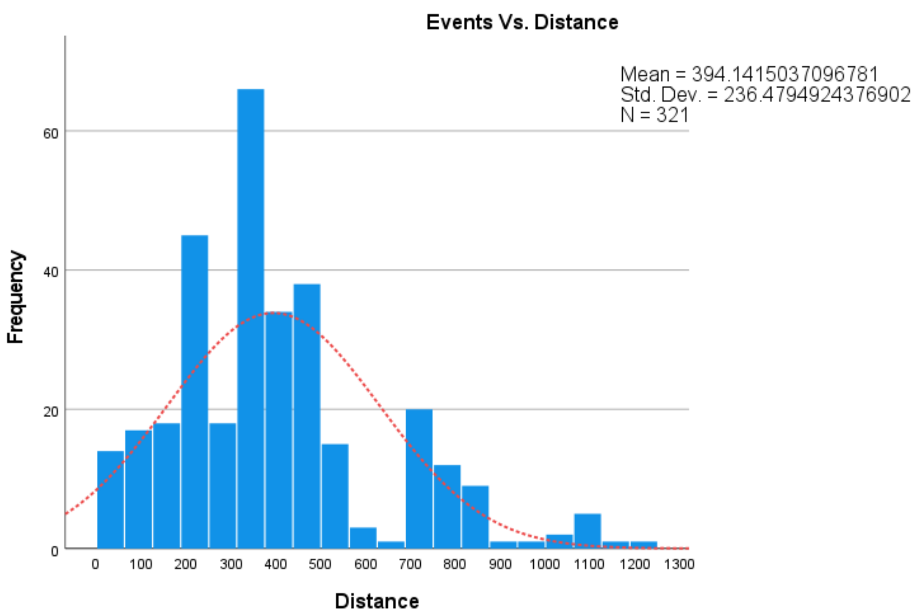


Figure 30: Visualization of events skewness

Use of the Bivariate correlation (Spearman): The assessment of the relationship strength between the severity of the events and the position of the camera was conducted. This analysis intends to determine if the proximity to the camera had any impacts on the severity of acceleration events, thereby providing insights into the influence of the camera's presence on driver behaviour. To examine this, Spearman's correlation was computed between [variable 1: Severity] and [variable 2: Distance to camera]. The result indicated a positive but non-significant correlation between the two variables, with rho=0.023 and p = 0.680>0.05.

Table 10: Correlation results "Acceleration in ASSC2 Zone"

Spearman's rho		Distance	Severity
Distance	Correlation Coefficient	1	0,023
	Sig. (2-tailed)		0,680
	N	321	321
Severity	Correlation Coefficient	0,023	1
	Sig. (2-tailed)	0,680	
	N	321	321

Since the p-value (0.680) exceeded the threshold for statistical significance (0.05), the study found no statistically significant correlation between the severity of acceleration events and their distance from the camera. This means, within the scope of this study that the positioning of the camera does not significantly influence the severity of such acceleration events in the ASSC vicinity.

Table 11: Summarized distribution of events on the ASSC site2

Distance	Severity of decelerations			Total	Severity of accelerations			Total
	low	medium	High		Low	Medium	High	
0-200	17	6	0	23	46	16	4	66
200-400	47	8	1	56	76	33	11	120
400-600	31	4	0	35	48	25	8	81
600-800	21	5	0	26	21	8	3	32
800-1000	15	0	0	15	7	4	2	13
1000<	3	1	0	4	7	2	0	9
Total	134	24	1	159	205	88	28	321
Correlation results: r=-0,145 P= 0.069					Correlation results: r=0,023 p=0.680			

4.2.5. Deceleration events in the fixed camera area

The results from the fixed camera site were run by combining the data from 10 camera locations. The findings from the frequency distribution analysis presented a relatively low rate of high and medium-severity deceleration events within a 1300-meter radius from the camera. This was represented by occurrence rates of 10% (High-severity) and 14% (Medium-severity). This defines a very low occurrence of such events in the fixed camera area. On the other hand, the predominance of low-severity deceleration events was evident, accounting for a substantial 88% of all recorded events. This high percentage highlights the dominance of low-severity deceleration events within the fixed camera area.

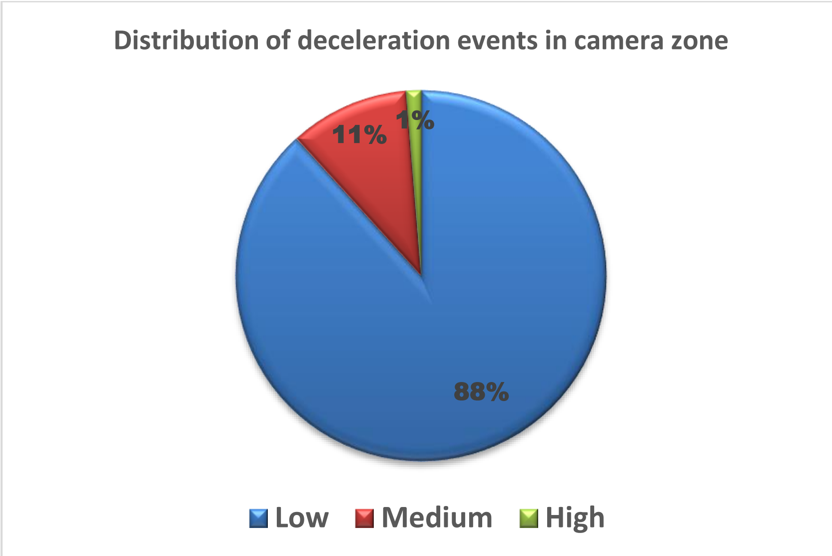
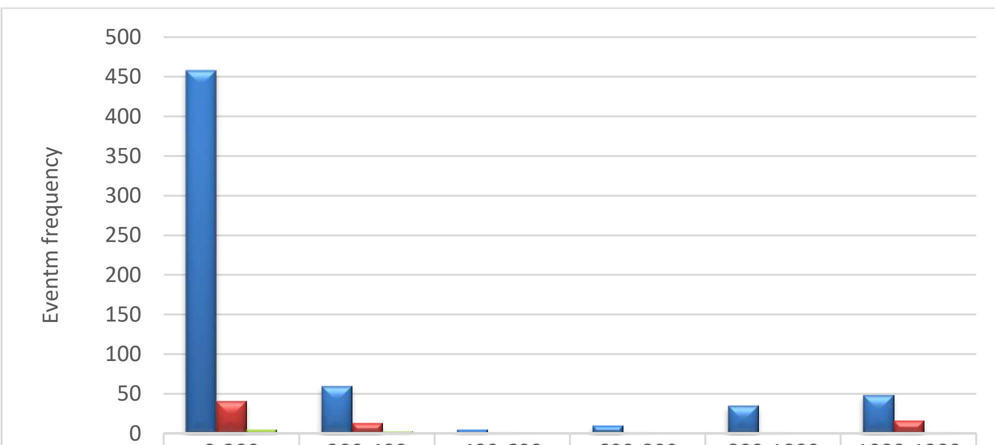


Figure 31: Events severity rates in the fixed camera area

The results of the events distribution, indicated a high concentration of low-severity deceleration events within 200 meters from the camera's location, and a very low concentration of all events severity in the remaining areas.



	0-200	200-400	400-600	600-800	800-1000	1000-1300
Low	458	60	5	10	35	48
Medium	41	13	1	1	1	16
High	5	3	0	0	0	1

Figure 32: Events distribution, in relation to severity & distance

Regarding the overall events distribution based only on their occurrence points, Figure 33 provides a detailed visualization. The histogram demonstrates a right-skewed pattern, suggesting a clear concentration of these events within the close proximity to the camera. This skewness also suggests that the frequency of deceleration events decreased as the distance from the camera increases. But the exception occurred from the distance of 900m to 1300m, where a medium volume of events occurred.

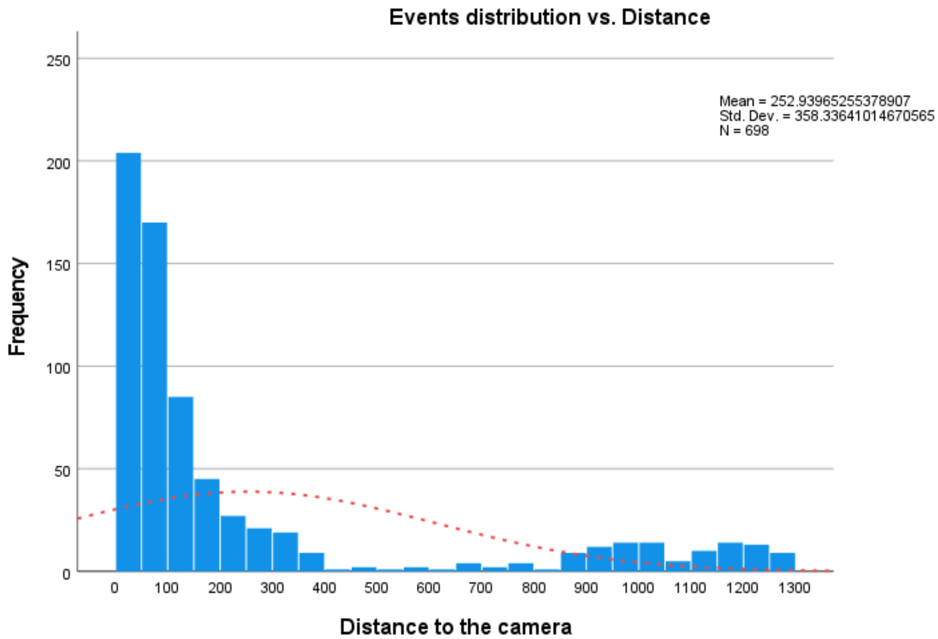


Figure 33: Overall events vs. point of occurrence

Use of the Bivariate correlation (Spearman):The analysis of the relationship strength between the severity of the events and the position of the camera was conducted. This analysis intends to determine if the proximity to the camera had any impacts on the severity of deceleration events, thereby providing insights into the influence of the camera's presence on driver behavior. To examine this, Spearman's correlation was computed between [variable 1: Severity] and [variable 2: Distance to camera]. The result indicated a positive but negligible correlation between the two variables, with rho=0.036 and p = 0.339>0.05.

Table 12: Correlation results: Deceleration vs. the distance to the Fixed camera

	Spearman's rho	Distance	Severity
Distance	Correlation Coefficient	1,000	0,036
	Sig. (2-tailed)		0,339
	N	698	698
Severity	Correlation Coefficient	0,036	1,000
	Sig. (2-tailed)	0,339	
	N	698	698

Since the p-value (0.339) exceeded the threshold for statistical significance (0.05), the study found no statistically significant correlation between the severity of deceleration events and their distance from the camera. This means, within the scope of this study that the positioning of the camera does not significantly influence the severity of deceleration events in the camera vicinity.

4.2.6. Accelerations in the fixed-camera zone

The frequency distribution analysis revealed relatively low occurrence rates for low-, medium-, and high-severity deceleration events within the distance from 200 to 1000 meters. The highest concentration of low-severity acceleration events was observed within a 100-meter radius from the camera. This suggests that the immediate vicinity of the camera is associated with a higher frequency of less severe acceleration events. Furthermore, a secondary peak in event severity was identified between the distances of 1000 to 1300 meters from the camera.

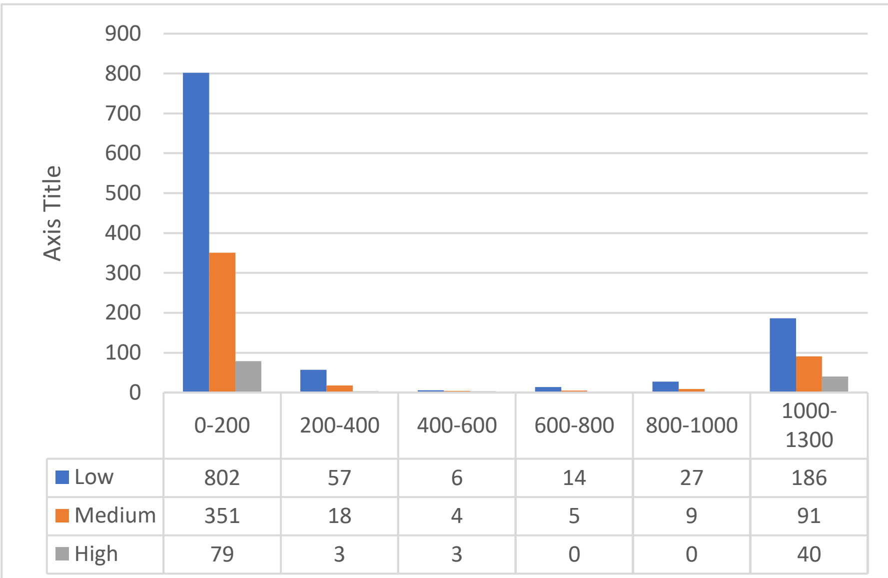


Figure 34: Events visualization based on the distance to camera

Figure 35 offers a detailed visualization of the distribution of acceleration events in relation to their distance from the camera. The histogram displays a distinct right-skewed pattern, signifying a pronounced concentration of these events in the immediate vicinity of the camera. This pattern would point out a general trend: as the distance from the camera increases, the frequency of acceleration events shows a corresponding decrease. However, an exception was observed from the distance of 1000m-1200m from the camera, where the medium rise peak was observed. This trend underscores the potential influence of unidentified cause in that area.

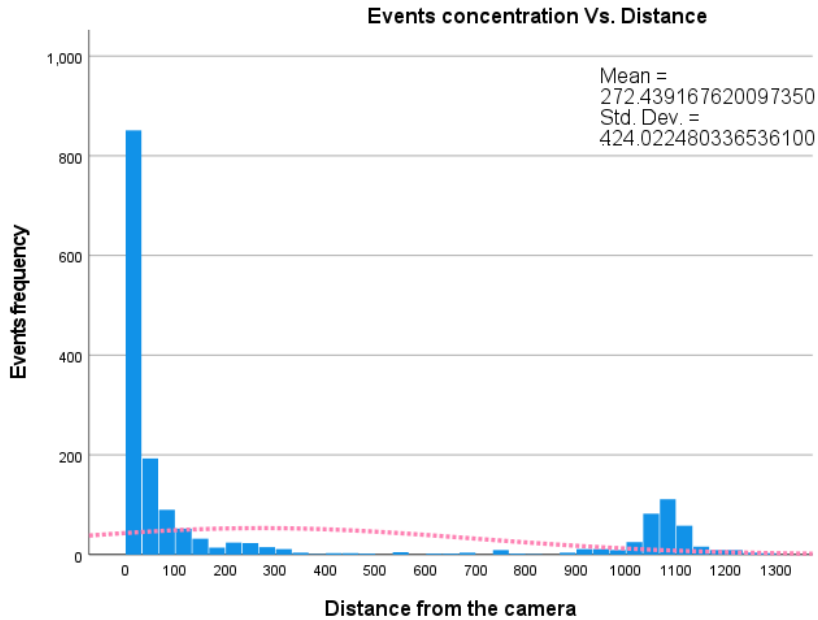


Figure 35: Events distribution vs their point of occurrence

Use of the Bivariate correlation (Spearman):The assessment of the relationship strength between the severity of the events and the position of the camera was conducted. This analysis intends to determine if the proximity to the camera had any impacts on the severity of acceleration events, thereby providing insights into the influence of the camera's presence on driver behavior. To examine this, Spearman's correlation was computed between [variable 1: Severity] and [variable 2: Distance to camera]. The result indicated a little contradicting results : Negative and negligeable correlation, but statistically significant with rho=-0.054 and p = 0.027<0.05.

Table 13: Correlation results: Acceleration vs. the distance to the fixed Camera

Spearman's rho		Distance	Severity
Distance	Correlation Coefficient	1	-.054*
	Sig. (2-tailed)		0,027
	N	1695	1695
Severity	Correlation Coefficient	-.054*	1
	Sig. (2-tailed)	0,027	
	N	1695	1695

*. Correlation is significant at the 0.05 level (2-tailed).

In this case: while the correlation between the distance from the camera and the severity of the acceleration events was found to be statistically significant, the strength of this relationship is negligible, as indicated by the correlation coefficient of r=-0.054. This means that the impact of one variable on another is very small and may not be of practical importance. The negligible correlation suggests that other factors, not accounted for in our analysis, may be influencing the severity of the events. Future research should explore other potential predictors of event severity.

Table 14: Summarized distribution of events in the fixed cameras area

	Severity of decelerations				Severity of accelerations			
Distance	low	medium	High	Total	Low	Medium	High	Total
0-200	458	41	5	504	802	351	79	1232
200-400	60	13	3	76	57	18	3	78
400-600	5	1	0	6	6	4	3	13
600-800	10	1	0	11	14	5	0	19
800-1000	35	1	0	36	27	9	0	36
1000-1300	48	16	1	65	186	91	40	317
Total	616	73	9	698	1092	478	125	1695
Correlation results: r=-0,036 P= 0.339					Correlation results: r=-0.054 p=0.027			

4.2.7. Control group: Virtual camera site

The outcomes derived from an virtual-camera location indicated a low average concentration of both acceleration and deceleration events within the 1300-meter segment surrounding its virtual position. This could be largely attributed to the strategic placement of the virtual cameras at locations minimally impacted by intersections. The different findings are presented in the subsequent paragraphs:

Deceleration events: Within a 1300-meter radius surrounding the virtual cameras, high-severity deceleration events occurred rarely on sites 1 and 3, presenting a rate of 8.3%, while there were entirely absent on site 2. Medium-severity deceleration events showed slightly greater occurrence, constituting 25% on site 1, 23% on site 2, and 8.3% on site 3. However, the most evident observation pertained to the overwhelming presence of low-severity deceleration events. Specifically, they accounted for 67% of the total events on site 1, 77% on site 2, and 83% on site 3. These figures highlight the dominance of low-severity decelerations over high-and medium-severity deceleration events over the whole 1300-meter segment around the Virtual camera. Generally, this indicates the low occurrence rate of high-and medium-severity events on the roadway.

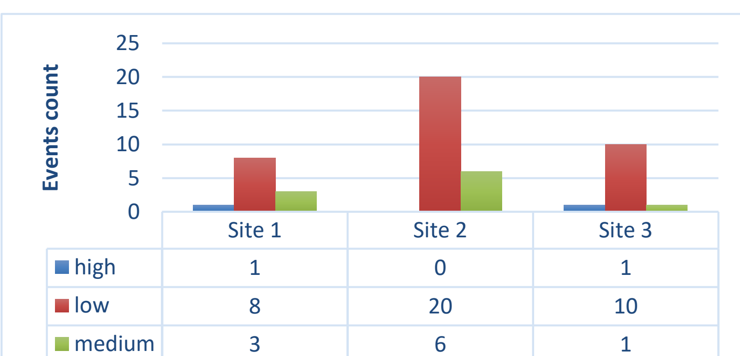
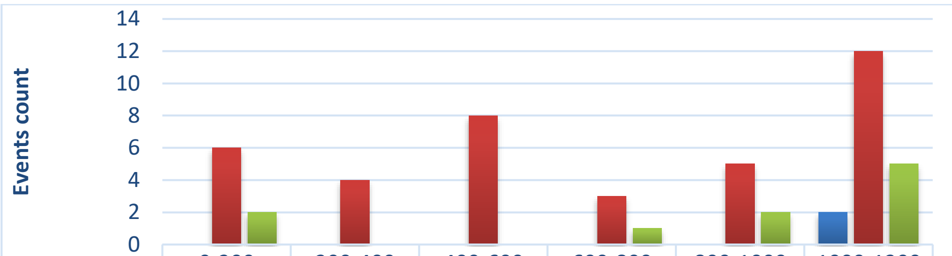


Figure 36: Deceleration events on 3 Virtual camera sites

The figure 37 illustrates the distribution of deceleration events, categorized as low, medium, and high severity, at the Virtual camera sites. In contrast to the distinct patterns observed at some real-camera locations discussed in previous sections, the distribution of events around these Virtual camera sites appears to be less systematic or structured. The distribution seems random, lacking any discernible trends or patterns.



	0-200	200-400	400-600	600-800	800-1000	1000-1300
high	0	0	0	0	0	2
low	6	4	8	3	5	12
medium	2	0	0	1	2	5

Figure 37: Deceleration events based on severity and distance from the Virtual camera

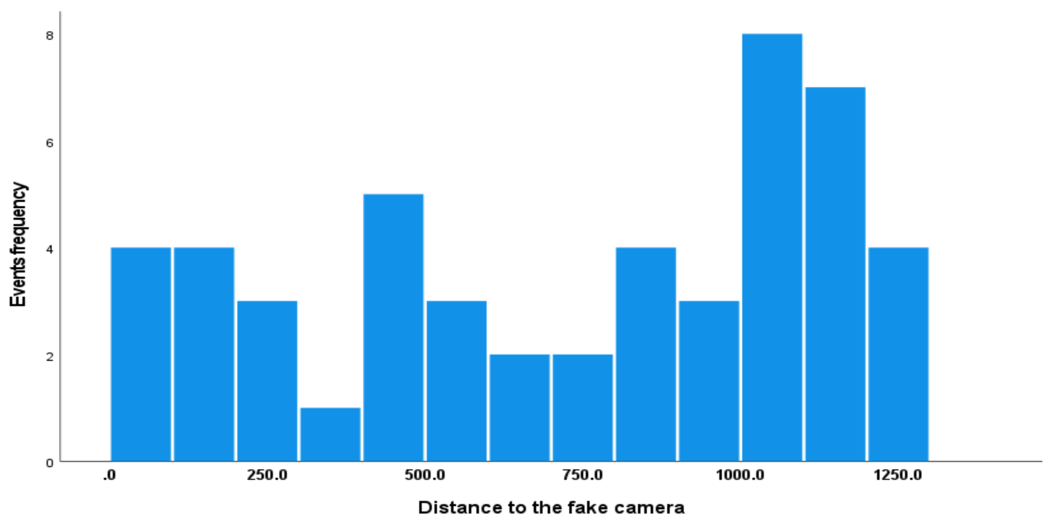


Figure 38: Events distribution based on their distance to the Virtual camera

Acceleration events: Within a 1300-meter radius surrounding the Virtual cameras, high-severity acceleration events occurred were completely absent on sites 1 and 3. The very low occurrence was observed on site 2 presenting a rate of 13%. Medium-severity acceleration events were low too, constituting 10% on site 1, 20% on site 2, and 20% on site 3. However, the low-severity acceleration events were dominant on all sites. Specifically, they accounted for 90% of the total events on site 1, 67% on site 2, and 80% on site 3. These figures highlight the dominance of low-severity accelerations over high-and medium-severity acceleration events over the whole 1300-meter segment around the Virtual camera. Generally, this marks the low occurrence rate of high-and medium-severity events on the roadway.

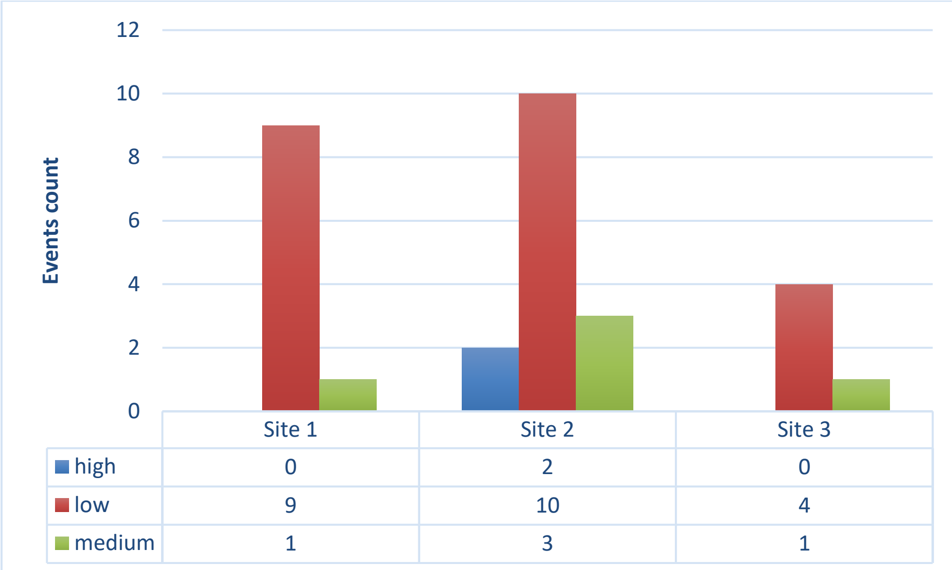


Figure 39: Acceleration events on all sites of Virtual camera

In the analysis of acceleration events across all sites (Figure 40), a remarkable pattern emerges. The occurrences of these events were generally scarce, with low-severity accelerations being the most prevalent category. Interestingly, these low-severity acceleration events exhibited a concentrated distribution within two specific ranges: at a distance of between 1000 to 1300 meters, and again between 200 to 400 meters from the Virtual camera. Other sections however, showed a small number of such events.

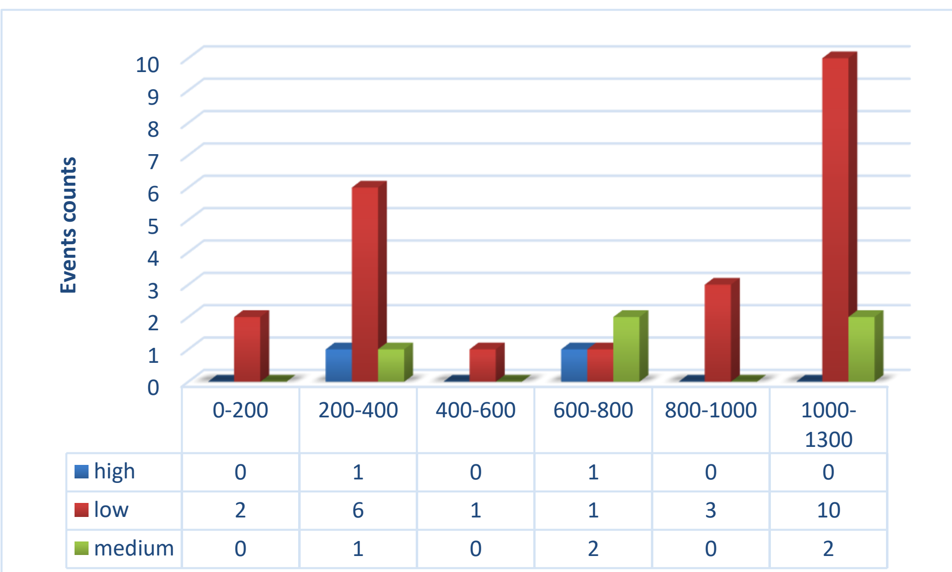


Figure 40: Accelerations distributions based on severity and distance to the virtual camera

Like in previous analysis of deceeration events, the distribution of events around these Virtual camera sites appears to be less structured (See figure 41). The distribution seems random, lacking any discernible trends or patterns. This observation may highlight the normal driving behaviors independent of speed cameras or intersections' influence.

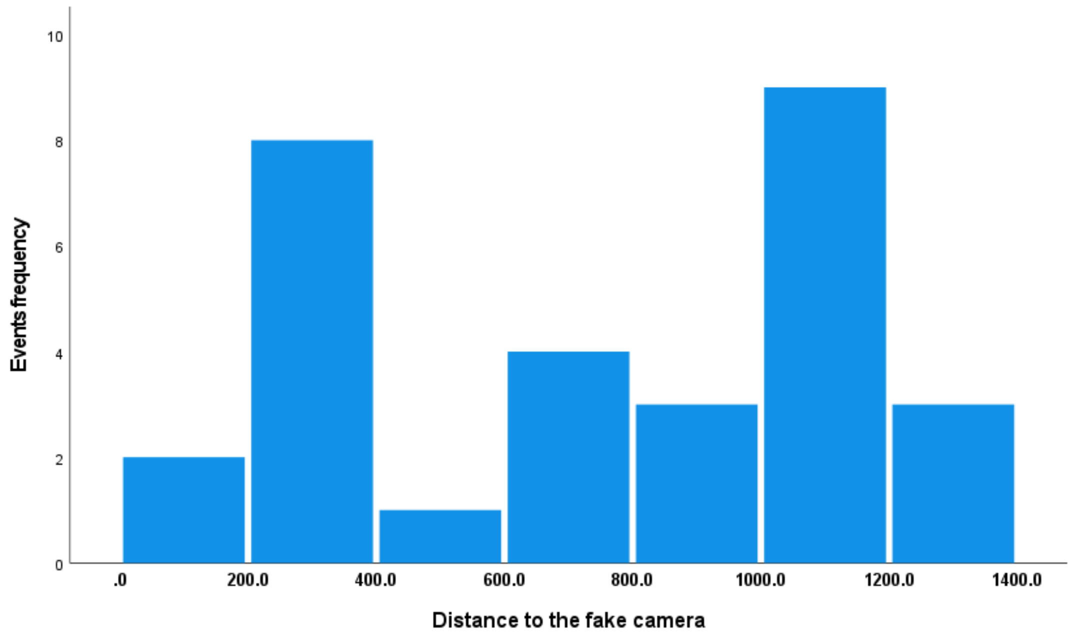


Figure 41: Events distribution based on their distance to the Virtual camera

5. DISCUSSION OF THE RESULTS

5.1. Summary of findings

This study conducted a thorough investigation of relationship between A&D and the ASSC, and fixed speed cameras. The results were achieved through various methods, including GIS, heatmap visualizations, and statistical analyses, thus offering a deep understanding of the spatial distribution of these events and their correlation to speed enforcement devices.
Applying heatmaps provided an effective tool in assessing and visualizing the distribution of acceleration and deceleration events. Upon examination of the heatmaps, a remarkable observation was made. It was found that high concentrations of deceleration events coincided spatially with high concentrations of acceleration events (compare Figure 15 & 16, or 17 & 18,). Additionally, heatmaps revealed that the majority of these high severity events occurred in area of intersections (See figure 17 &18). This overlap suggests a possible relationship between these two types of events, potentially indicating a shared influencing factors. This may reflect the nature of driving behavior at intersections, where deceleration is often required for approaching the intersection, followed by acceleration upon exiting. This could highlight the impact of intersections' influence in the context of this study.
Regarding the event severity, heatmaps provided a compelling perspective. It was noted that no significant high-and medium-severity acceleration or deceleration events were observed in the vicinity of ASSCs. Nevertheless, a little exceptions were observed in a few fixed camera locations. Some of these fixed cameras were found to be located in high-severity acceleration and deceleration hotspots. However, upon deep examination, the study found those fixed cameras to be positioned near intersections (See figure 17 &18). The road intersections are known to be zones where drivers frequently modify their speeds, decelerating when approaching the intersection, and accelerating as they leave.

Validating the findings from the Geographical Information System (GIS), a detailed statistical analysis has further reinforced our understanding of the distribution of high, medium, and low-severity acceleration and deceleration events in proximity to both the ASSC and fixed cameras (refer to Tables 8, 11, and 14). The study revealed a significant concentration of a high volume of events within the first 600 meters from the camera, underscoring a high volume of driver activity in this proximate zone. Additionally, it reveals a prominently lower frequency of high and medium-severity events, alongside a significant concentration of low-severity events within these camera vicinities. However, the results from the virtual camera site, indicated a non-discernible pattern of A&D events in a particular range from the virtual position.

The events were found to be randomly distributed across the entire study section. The subsequent sections details these statistical results:

- On ASSC site1, the high severity decelerations were completely absent (0%) at the entire ASSC and within the range of 1300m from it. Whereas the high-severity accelerations found to be 0.86%. Secondly, the medium-severity decelerations and accelerations were 5% and 17% successively. Whereas the Low severity decelerations and accelerations were quite high, 95% and 82% successively. The result the relationship analysis Between the camera position and the severity of event was conducted using Spearman's correlation. The results indicated a positive but non-significant correlation between the two variables for both types of events, with correlation coefficient (rho)=0.119 and p-value = 0.156>0.05, for deceleration events; and rho= 0.037, p=0.491 for accelerations.
- On ASSC site 2: the high severity decelerations were rare(0.7%) at the entire ASSC and within the range of 1300m from it. Whereas the high-severity accelerations found to be 9%. Secondly, the medium-severity decelerations and accelerations were 15% and 27% successively. Whereas the Low severity decelerations and accelerations were quite high, 84.3% and 64% successively. The result of the relationship analysis was conducted using Spearman's correlation. The results indicated a negative but non-significant correlation between the two variables for deceleration events, with rho=-0.145 and p-value = 0.069>0.05. For acceleration events, the results indicated a positive but negligeable correlation between the two variables of acceleration events, rho= 0.023, p-value=0.680.
- On the fixed cameras site, the high severity decelerations and accelerations were rare(1.3% and 7.4% successively) in the range of 1300m from the camera position. Whereas, the medium-severity decelerations and accelerations were 10.5% and 28.2% successively. On the other hand, the Low severity decelerations and accelerations were quite high, 88.2% and 64.4% successively. The result of the relationship analysis between the camera position and the severity of event was conducted using Spearman's correlation. The analysis found no relationship between the two variables for deceleration events, where rho=0.036 and p = 0.339>0.05. For acceleration events, the correlation was found to be statistically significant (p-value=0.027), but the strength of this relationship was negligible, as indicated by the correlation coefficient of rho=-0.054. This means that the impact of one variable on another is very small and may not be of practical importance.

- Data from the study at three virtual camera sites provided significant insights into driver behavior within a 1300 meter radius of the fake speed cameras. High-severity deceleration events were rare, appearing at a rate of 8.3% on two sites and not at all on the third. Medium-severity deceleration events also occurred less frequently, but the vast majority of deceleration events were of low-severity, accounting for 67%, 77% and 83% across the three sites. Similarly, high-severity acceleration events were almost completely absent from the study sites, with the only significant occurrences observed on one site at a rate of 13%. Medium-severity acceleration events were also sparse, occurring at a rate of 10%-20% across the three sites. In contrast, low-severity acceleration events dominated, making up 67%-90% of all acceleration events.

Table 15: Differences and similarities in findings between Virtual camera sites and real camera site/ASSC

Similarities	Differences
▫ Low occurrence rate of high and medium severity A&D on the study section ▫ High concentration of low-severity A&D events on the study section ▫ Inconsistency in the distribution patterns of A&D events.	▫ Low volume of total A&D events was observed at Virtual camera site contrary to the real camera/ASSC sites ▫ There is a high concentration of total A&D occurrences within 600m of the fixed camera or ASSC. ▫ Events distribution seemed to be independent to the distance from the virtual camera site.

5.2. Interpretation of Results

The empirical results derived from this study provide an insightful evaluation of the hypotheses and research questions initially set. This study focused on assessing the influence of fixed speed cameras and ASSCs on the acceleration and deceleration severity in their vicinity. Beginning with the null hypothesis (H0) stating that the presence of speed cameras or ASSCs results in increased frequency of A&D rates in its vicinity. This hypothesis predicted that the spatial position of speed cameras could significantly impact driving behaviors (A&D), resulting in a phenomenon known as the "Kangaroo Jump" or "V-Profile" in the camera's immediate vicinity (Pauw et al., 2014). The null hypothesis was found confirmed after observing that the high volume of overall events on the study section (1300m from the camera) were concentrated in the range of 600m from the camera or ASSC position. That suggests that drivers frequently tend to change their behaviours in the distance of 600m from the position of the camera or ASSC. This result leads to the rejection of the alternative hypothesis (H1), which proposes that these enforcement tools do not influence the frequency of A&D events in the fixed camera/ ASSC areas.

However, the study results shows that the high volume of all observed A&D events, is occupied by the low-severity A&D events. The analysis of results from both statistical and GIS components, provide a deep understanding of the patterns of high, medium, and low-severity A&D events in the vicinity of the ASSC and fixed cameras. In it, the study found a dominance of low-severity deceleration events within a 1300-meter radius around these camera locations, while high and medium-severity events were relatively scarce.

This lack of high- and medium-severity A&D near the cameras suggests that drivers might not significantly alter their speeding behaviour upon approaching these enforcement devices. This indicates that drivers may already be adhering to what they deem as safe and appropriate speeds, suggesting other contributing factors irrespective of the camera's presence. Alternatively, the lack of high-severity events near the cameras may imply that drivers are using in-vehicle real-time intervention systems, and are hence aware of the camera positions, which make them change their speed accordingly in advance, avoiding abrupt accelerations or decelerations in the camera's immediate proximity. This could be an intentional effort to avoid penalties (Elsagheer Mohamed et al., 2021). Regarding the high concentration of low-severity A&D events in the vicinity of the camera, this observation might suggest that while the presence of speed enforcement systems could influence driving behavior within a certain proximity, it has less of an impact in causing medium and high-severity acceleration or deceleration events. Such a pattern possibly reflects drivers' tendencies to moderately decelerate when approaching a known camera location and slowly accelerate once they have passed it.

This low acceleration and decelerations found in controlled sections, would also be explained by the change in gears. According to Bokare & Maurya, (2017), the vehicle normally reaches the maximum acceleration in first gear. And this phenomenon fades while changing gears in the fourth and fifth gears. The reason for this is that the difference in speed while shifting from third to fourth or fourth to fifth gear is insignificant. As a result, the rate of change (Severity) in acceleration is insignificant. This is the same to the deceleration, the deceleration also wouldn't be severe when minor changes are made to speed.

The speed at which deceleration is highly severe is shown to be vehicle type dependent. The speed at which the driver achieves maximum deceleration varies depending on vehicle type and approach speed. This suggests that at greater approach speeds, drivers attain their maximum deceleration rate rapidly to stop at the earliest (Bokare & Maurya, 2017). This means in the context of our study, that the deceleration rates were low, because the drivers' attempt was to moderately reduce the speed rather than stopping in the camera areas. This can also explain concentrations of high severity of events that was observed near intersections. There, all sort of vehicles highly decelerate for a short stop for red light or yielding, and severely accelerate when the light is green. This make the intersection the area of high concentration.

Regarding the insignificant statistic relationship between A&D and the camera position, as revealed by the correlation analysis, the study does not imply that no relationship exists between these variables. it suggests the complex nature of these events, shaped by a multipart interchange of various factors. Those factor could for instance be but not limited to: Traffic density, in-vehicle real-time interventions, vehicle capacity, road conditions, weather, time of day, and driver characteristics.

5.3. Role of Other Factors on Event Severity

- *In-vehicle real-time interventions*: The effect of real-time intervention systems installed in all participated vehicles, must be considered. In-vehicle technologies, particularly real-time interventions, can play a significant role in reducing the incidence and severity of acceleration and deceleration (A/D) events near speed enforcement devices (Vlassenroot et al., 2007). For, all the vehicles that entered the test were all fitted with the informative and warning systems, that may be the cause of scarce high and medium severity deceleration and acceleration events in the camera zone. The drivers might have been warned of the speed limit before they arrived in the vicinity of the camera (Connelly et al., 2002. This could have contributed to the observed scarcity of high and medium-severity A&D events in the camera vicinity.
- *Smart phone apps*: The proliferation of smartphone apps and navigation systems that alert drivers to the locations of speed cameras can significantly impact driver behavior, especially concerning the severity of A&D (Heroun, 2017). These apps and systems essentially turn speed cameras and other enforcement devices into known quantities rather than unexpected hazards (Vortex, 2016). When drivers are aware of an upcoming speed camera, they are more likely to adjust their speed in advance, reducing the need for abrupt decelerations or accelerations in the controlled zones.

5.4. Limitations of the Study

- *Data Limitations*: The data used in the analysis are limited by their accuracy and comprehensiveness. Any errors, missing data, or biases in the data collection process may have influenced the results. For instance, potential inaccuracies in the GPS data for the exact location of speed enforcement systems or events could have affected the derived conclusions. Furthermore, the study focused only on a specific area and might not represent all geographical regions, driver demographics, or traffic situations.
- *Methodological Limitations*: The study employed a specific radius around the speed enforcement systems to assess changes in driver behavior. However, this range may not reflect the actual distance at which drivers start to react to the presence of these devices. Additionally, the study assumed that all drivers were aware of the camera locations, which might not always be the case. The severity of speed modification events was also categorized into low, medium, and high, which could oversimplify the continuum of speed changes and potentially mask trends within each category.
- *Analytical Limitations*: The statistical analysis assumed a linear correlation between event severity and distance from the camera. However, the relationship could be more complex, potentially involving non-linear or interactive effects. It also assumed that other factors, such as driver characteristics, vehicle type, road conditions, and traffic volume, remained constant, which was not necessarily the case. Further, the statistical analysis has its own limitations, such as the assumptions made about the distribution of the data and the potential for Type I and Type II errors.
- *Influence of External Factors*: Factors not controlled or measured in this study could have significant effects on driver behavior. These include in-vehicle technologies like real-time

feedback systems, the use of speed trap locator apps, the presence of other traffic enforcement measures, intersections, local driving cultures, or individual driver traits.

- *Temporal Factors:* The study did not consider the potential effect of different times of day, days of the week, or seasons, weather, all of which could impact driving behavior.
- *Generalizability:* The findings of this study may not be generalizable to other regions, cultures, or traffic systems due to differences in driving habits, traffic laws, road infrastructure, and speed enforcement practices.
- Geographic limitations: The study is limited to a specific geographic area (Limburg-Belgium), which may not be representative of other regions. The results may not be generalizable to other areas with different road conditions or traffic patterns.
- Lack of qualitative data: The study did not collect qualitative data on drivers' perceptions of speed cameras/ASSC, which could provide additional insights into their behavior.

Considering these limitations is essential when interpreting the results and planning future research. Further studies could address these issues by employing a more robust data collection process, incorporating a wider range of influencing factors, and testing the effects of varying distances from speed enforcement systems on driver behavior.

5.5. Recommendations for Future Research

- The findings of this study, along with its limitations, open up several promising avenues for future research. These could include:
- *Broader Geographical Scope*: To enhance the generalizability of the findings, future studies could examine a wider range of geographical locations. This would allow researchers to explore regional variations in driver behavior near speed enforcement devices, and potentially identify local factors influencing these behaviours.
- *In-depth Examination of Driver Characteristics*: It would be worthwhile to investigate how individual characteristics influence speed modification behavior around speed enforcement devices. This could be combined with an analysis of the impact of different vehicle types.
- *Effect of In-Vehicle Technologies and Apps*: The influence of in-vehicle technologies and speed camera locator apps on driver behavior warrants further research. These tools could be altering the traditional dynamics of speed enforcement and require more extensive investigation.
- *Temporal Analysis*: Analysing driver behavior at different times of the day, days of the week, or seasons could yield further insights into how these temporal factors influence speed modification behavior.
- *Non-linear Relationships:* Future research could also explore potential non-linear relationship between A&D and the ASSC and fixed camera. This would require more sophisticated analytical techniques but could yield a more deepened understanding of driver behavior.
- *Mixed Method Approach*: Incorporating qualitative research methods, such as interviews or focus groups with drivers, could provide valuable insights into the motivations and perceptions behind the observed behaviours.
- *Impact of Other Traffic Enforcement Measures*: Investigating the impact of other types

of traffic enforcement measures on speed modification behaviours, such as police patrols or traffic calming measures, would provide a more comprehensive picture of effective speed management strategies.

- *Longitudinal Study:* A longitudinal study that tracks changes in driver behavior over time, particularly following the introduction or removal of speed cameras, could provide valuable insights into their long-term impact.

By pursuing these directions, future research can deepen our understanding of driver behavior around speed enforcement devices and contribute to more effective traffic safety strategies.

5.6. Alternative methods to study the driving behavior in the vicinity of speed cameras or ASSC

i. *Driving Simulators*: These are advanced systems that replicate real-life driving scenarios within a controlled environment. They are instrumental in studying human behavior under diverse driving conditions without posing actual risks to the participants. Participants can interact with simulated traffic situations, roadside infrastructure, including speed cameras or ASSC systems. Researchers can collect data on a range of parameters like reaction times, speed adjustments, and braking behaviours. They can provide insights into the understanding of how the presence of speed control systems influences driving behaviours.
-Advantages: Driving simulators offer a safe environment to study driver behavior under varied and controlled conditions, including risky scenarios that would be unethical or unsafe to conduct in real life. They also allow for repeatability of experiments.
-Disadvantages: They may not entirely replicate real-life driving conditions, and the driver's awareness that they are in a simulation can influence their behavior (simulation bias). High-quality driving simulators can also be costly.

ii. *Connected Vehicles Data*: Modern vehicles are often equipped with telematics and vehicle-to-everything (V2X) communication systems. These connected systems can transmit real-time data about the vehicle's operation, including speed, acceleration, deceleration, and even steering angle. Such high-resolution data can provide valuable insights into driving behavior, especially in the vicinity of speed control systems.
-Advantages: Connected vehicle data offers real-time, high-resolution data and a comprehensive view of vehicle operations, enabling a detailed analysis of driver behavior. It also allows for large-scale studies without extra equipment.
-Disadvantages: Privacy concerns might arise as the data can be personally identifiable. Additionally, it may not fully represent all vehicles on the road as not all vehicles have connected capabilities.

iii. *Vehicle Black Boxes (Event Data Recorders):* These devices continuously record a variety of data elements related to the vehicle's operation. They can provide valuable insights into the vehicle's speed, throttle position, and brake usage in the moments leading up to a sudden deceleration or acceleration event. This data can be used to analyze driving behaviour in relation to speed control systems.

-*Advantages:* They provide precise, objective data about vehicle operations leading up to specific events, which can aid in understanding driver behavior during incidents.

-*Disadvantages:* They are limited in that they only capture a small amount of data before a crash event. Privacy concerns may also arise.

iv. *Smartphone Applications:* Modern smartphones, with their built-in GPS and accelerometer capabilities, can collect valuable data on speed, acceleration, and deceleration. There are various smartphone apps available for such purposes. These apps, with the appropriate user permissions, can serve as cost-effective tools for studying driving behavior.

-*Advantages:* Smartphone applications provide a cost-effective and easily deployable method for collecting driving data. They leverage the capabilities of modern smartphones, which most people already possess.

-*Disadvantages:* They are dependent on the quality of the smartphone sensors, which may vary widely. Data quality may also be affected by the placement of the smartphone in the vehicle. Privacy and distracted driving concerns may also be significant.

6. CONCLUSION

The findings from this study provide an informative and comprehensive overview of the relationship between acceleration and deceleration events and their spatial connection with speed enforcement devices such as fixed cameras and Average Speed Safety Cameras (ASSCs). The use of Geographical Information System (GIS) techniques, and statistical analysis provided a new perspective into the patterns and spatial distribution of acceleration and deceleration events, revealing the potential influence of these enforcement devices on driving behaviors. The null hypothesis, which suggested that the presence of speed cameras or Average Speed Section Control influences the high frequency of acceleration and deceleration events in its vicinity, was confirmed by our results. The study revealed a noticeable concentration of a high volume of A&D events within 600 meters of these enforcement devices, suggesting that they do influence driver behavior within a certain range.
However, it is important to note that most of these events were of low severity, indicating that drivers might not significantly change their speeding behavior when approaching these devices. This could be attributed to drivers already adhering to safe speeds, the use of in-vehicle real-time intervention systems. It also sheds light on the complex nature of driver behavior, that might potentially be influenced by other factors such as traffic density, road conditions, weather, time of day, and driver characteristics. Further, the study highlighted that high-severity events often occurred outside speed enforcement zones, particularly around intersections, indicating these as potential hotspots for drastic speed changes. These findings call for a broader perspective on traffic safety interventions, beyond reliance on speed enforcement devices. However, the study acknowledges certain limitations, such as its reliance on secondary data and specific geographical focus, which may impact the broad applicability of the findings. Additionally, the severity of speed modification events was also categorized into low, medium, and high, which could oversimplify the continuum of speed changes and potentially mask trends within each category.

In light of these findings, it is recommended that further research be conducted to investigate the role of other potential influencing factors on driver behavior. Additionally, exploring the impact of different types of speed enforcement tools on driver behavior, beyond fixed speed cameras and ASSCs, could also provide further insights into the ways we can improve road safety. In conclusion, this study represents an important step towards a more comprehensive understanding of the ways in which speed enforcement tools affect driving behavior. The results suggest a complex interplay between a variety of factors, reinforcing the need for further research to understand and improve road safety effectively.

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