ALMA MATER STUDIORUM - UNIVERSITÀ DI BOLOGNA

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DICAM

(Department of Civil, Chemical, Environmental and Material Engineering)

MASTER THESIS

in

Road Safety Engineering

ROAD SAFETY INVESTIGATION OF THE INTERACTION BETWEEN DRIVER AND THE CYCLIST

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Road Safety

Video analysis

Surrogate measures (PET & TTC)

Time to reaction on signals

Frame by frame analysis

Abstract

With growing global concern to reduce CO_2 emissions, the transportation modal shift from car to bicycle is an encouraging alternative, which is getting more popular in Europe and North America, thanks to very low impact on the environment.On the other hand, the infrastructure for cyclist should be improved, since cyclists are vulnerable road users and with increase in number of cyclists, the concern for their safety also gets increased.

In this thesis, the analysis of accidents in which cyclists have been involved and understanding the reason for these accidents have been discussed, then the requirements to design and implement a safe bicycle network is introduced.

The study focuses on the drivers' behaviour in terms of interaction with cyclists when there is a presence of a cyclist crossing. Therefore the road safety investigation on cyclist infrastructure was made with observing drivers'interaction with cyclists.

Then the time-based surrogacy measures used to investigate the safety level of the cyclist, in particular PET (Post Encroachment Time) and TTC (Time to Collision) between driver and bicyclist were determined keeping in mind the right-angle collision.

Furthermore we tried to find the reaction time of the drivers especially on signals and also with the presence of cyclist on the crossing to understand the time which is needed for the driver to stop the car. All of this data could be later useful for the reconstruction of the accidents. Understanding the instants at which driver applies the brakes was made possible by installing a V-Box device inside our test vehicle which also used to determine measures such as speed, distance and other relevant variables.

Finally by using mobile eye tracker the driver visual behaviour when arriving the crossing point where observed and results showed that at a number of situations driver's gaze was distracted and only cyclist became an important focus only when he was at a considerable length from the crossing.

Contents

1. Introduction

1.1 MOTIVATION Sustainable transportation mode

Cycling is probably the most sustainable urban transport mode, accessible not only for short trips but for medium-distance trips too long to cover by walking. Cycling causes no damage to environment, promotes health through physical activity and saves public infrastructure costs. In small words, cycling is economically, environmentally and socially sustainable. It has been noticed that cyclist hold a large share of all traffic-related accidents and can be considered as a vulnerable group among the other groups having their share on the roads. However, it has been claimed that number of benefits (for instance health and economic) can be achieved through cycling and it outweigh the risk being posed to the cyclist. Increased cycling is of great importance for the cities strive to enhance sustainability and to make the bicycle competitive to other means of transportation. The cycle infrastructure must be efficient regarding travel time and distance, as well as being safe.

A good insight into the problem provides an opportunity to improve the road safety of this cheap, convenient and environmentally friendly mode of transport.

1.2 PROBLEM STATEMENT Cyclist Safety-Vulnerable User

In almost all European countries, including Italy, there has been an increase over the last decade considerable use of the bicycle, as it is used to go to work, and to move around in free time, for sports, etc. Therefore, appropriate spaces are necessary for it, but unfortunately the quality of these places is not always adequate, meaning that the design of the slopes and road crossings take place without any planning of cycling and mobility. Also have an incorrect dimensioning and a bad maintenance. Furthermore, the increase in cyclists in our cities has led to an increase in accidents, therefore the bicycle is currently the means of transport it has recorded in the last decade the greatest number of accidents (compared to a significant decrease of the other users of the road) and therefore the cyclist, are among the weak road users, and are the one that needs the most attention to safety. The causes of this high accident rate are many and cannot be traced back only to the irresponsible action of the cyclist or to the poor quality of the road spaces dedicated to the circulation of bicycles, but also depend on a lacking and dated national regulation, and to non-homogeneous and confusing regional rules and / or directives. Therefore, the rules and construction techniques do not fully meet the safety expectations of all the individual types of users, leading the streets to be a place of probable and daily conflicts.

The problem of road safety in urban areas is therefore of great relevance the growing trend road accidents can no longer be treated with solo dependence on limits of circulation and speed.

1.3 OBJECTIVE Cyclist Road Safety Investigation

The objective of this work was to find the interaction between vehicular flow and mobility of the cycle by focusing on vehicle-cycle interaction on particular locations (bicycle-pedestrian crossing) in our case and looking for the correlation between location of intersections and behaviour of drivers inside the car. Firstly, the most important tools to achieve our task were to determine surrogacy measures (including Time to collision (TTC) and Post encroachment time (PET) which explains in terms of values the interaction between cyclist and driver and also the threat of collision one location might have for the cyclist. Among other tasks carried out in this thesis were to understand the driver's reaction time (Tr) both to apply brakes when signal becomes red and also to accelerate the vehicle when it gets green to understand how well different drivers would behave in case an unfavourable event might occur on our locations of interest. Lastly, we determined attention/disattention of our drivers by frame by frame analysis in order to fully understand what the major elements of attention are or disattention at both locations.

1.4. Benefits of cycling as a transportation mode through an EU report

Before going to the literature review we would like to mention an EU report enlightening not only the role of cycling in the transport sector but also touching its positive effect on Industrial, health, employment and social policy. It also makes an effort to convince investors to invest in cycling and aid governments in EU to make a more cyclist-friendly policy (federation). It explains how a cyclist-friendly policy, if implemented, can move the burden of spending a big amount of budget on transport sector to other sectors and unleash the full potential of active mobility. Components of the active mobility agenda can be seen in the following figure

Figure 1-1 Benefits of cycle usage

Source: (Neun)

1.4.1. Environment and climate

The calculations in above report under ECF study "Cycle more often too cool down the planet" considered reduced amount of CO2 emissions and thus a saving of worth 2 Billion euros. Some of the other uses were reduction in air and noise pollution along with environmental asset development as cycling infrastructure need less space than infrastructure for cars causing reduced building cost and more resource savings. Along with that it will also lead to less pollution of groundwater.

1.4.2. Energy and Resources

In the above-mentioned report, a fuel saving of 32% of car traffic was replaced by cycling. Another noticeable point in the above report is the use of E-bikes as they require less input by the user and hence more distance can be travelled (3 times more) than normal bikes. Moving on to the manufacturing of the bikes, it was noticed that building bikes require considerably fewer resources than cars so much so that building a bike requires only 2% of the resources of the resources needed to manufacture a car. From a civil engineering point of view it is also economical as only less amount of material such as concrete and asphalt is needed reducing the amount of money to be spent on infrastructure building.

1.4.3. Health benefits

To consider the health benefits a report from World Health Organization was considered where cycled kilometres /year = 264 km (reference: Austria) was kept consideration showing number of death prevention by this level of cycling was 27,860. Also 40% decrease in morbidity was also noticed in this report.

Moving forward to the benefits of cycling on brain health some of the other studies mentioned in this report were

- A Dutch study showed increase in white matter (due to cycling) and better connection of brain network both in healthy and patients with schizophrenia.
- A meta-study showed that regular physical exercise like cycling increased concentrations of peripheral brain-derived neurotrophic factor (BDNF), a protein

supporting healthy brain function and helping to avoid diseases like Parkinson's or Alzheimer's.

A healthy brain is important for a healthy body, considering both are important. Active mobility and cycling can be recognised as an excellent way of improving both.

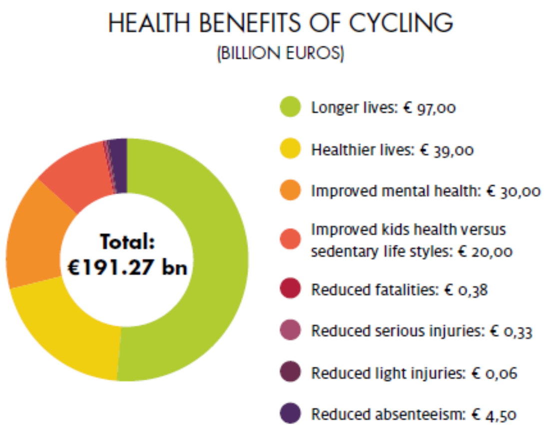

Figure 1-2 Health benefits of cycling in terms of amount of spending

Source: (Neun)

1.4.4. Road Safety Benefits

From this report, it was noticed that every death on Europe's roads there are an estimated four permanently disabling injuries such as damage to the brain or spinal cord, eight serious injuries and 50 minor injuries.

		Cost per unit	Total cost
Car crash fatalities avoided:	268	1,417,267 €	379,364,254 €
Serious injuries avoided:	3,212	103,342 €	331,943,722 €
Light injuries avoided:	13,384	4.606 €	61,646,691 €
			772,954,667 €

Figure 1-3 Fatality and injury statistics

Source: (Neun)

1.4.5. Micro-economic benefits

The direct benefit through this policy as mentioned in report was fruitful for manufacturers and repairers of bicycle hence direct benefit to bicycle production sector. Another sector which got benefit from this was bicycle tourism based on 2.3 billion cycle tourism per year in Europe. Another point to be noticed was that since there would be a smaller number of automobiles on the road due to increase in bicycling, material damage could be avoided from car accidents as there would be lesser number of cars on the roads.

1.4.6. Social benefits

Improving social and gender equality was also noticed in this report, as bicycle is easily affordable even by most disadvantaged population groups improving their social equality was noticed as they can participate more now in their social life less reluctantly. With regards to gender equality as it can still be noticed that kids and older adults could move more easily with less dependence on women who have to still take care of them providing more free time to these responsible women and furthered their emancipation. Lastly with regards to social affairs an improvement in social safety was noticeable as more people will be outside making it difficult for criminals to commit crime on roads who had an ease of doing their activities as less amount of people were there to notice their activities.

1.5. Growing number of cyclists & reasons

The Transportation Research International Documentation (TRID) index showing an increment from an average of 197 cycling-related publication per year in 1991-1995 to 610 per year in 2011-2016 demonstrating a 3-fold growth as can be seen in the (Figure 1-4).

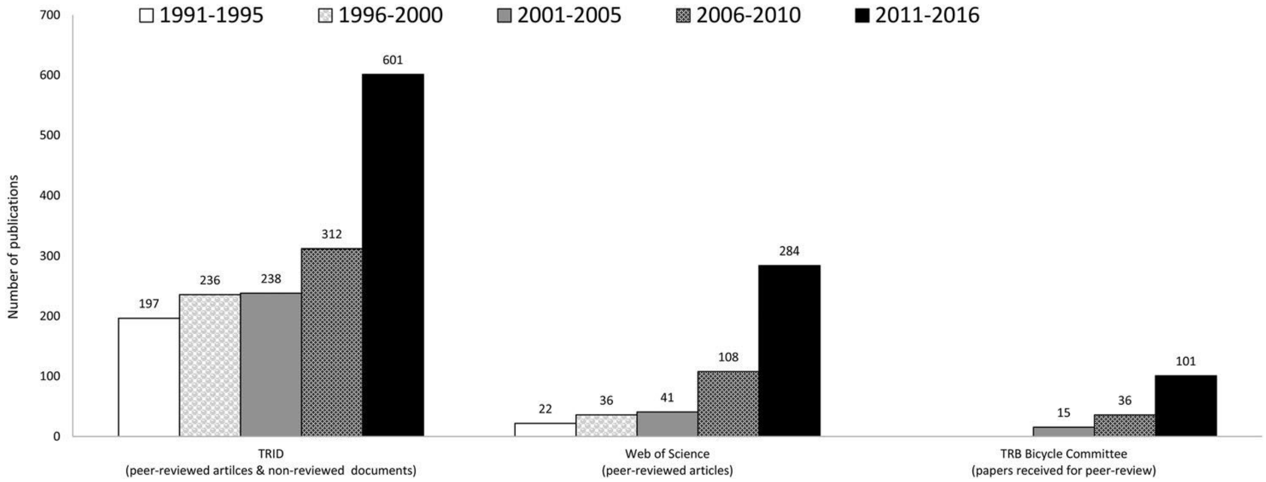

Figure 1-4 Average annual number of publications about cycling by five-year periods, 1991–2016.

Source: https//www.bikeleague.org/content/what-can-rise-cycling-tell-us-about-its-future

In addition to booming academic research on cycling, there has been a proliferation of professional and academic conferences on cycling; increasingly influential, widespread and interconnected local, state, national and international cycling organisations; Internet sites devoted to sharing knowledge about best practices; various other information-sharing forums, including social media. The growing worldwide network of researchers, planners, advocates, and cyclists has inspired, enabled and actively promoted cycling.

1.5.1. Cargo delivery

The increasing demand for delivery of goods increases the problem of congestion, air and noise pollution and decreases the quality of living in the inner cities of Europe. Urban areas of the future are likely to look very different from today's with conflicts over urban space putting increasing pressure on logistics companies to do things differently.

Global transport body the International Transport Forum (ITF) is predicting that passenger mobility will increase upwards of 300% by 2050. With up to 18% of road traffic represented by goods transport, this statistic suggests that delivery fleets will be competing with passenger transport for access to road infrastructure and parking. If current low emission zones, restricted access areas and congestion charges are anything to go by movement with vans and lorries in city centres will only get harder and more expensive. Combine this with the ease and increase in on-line ordering by both organisations and individuals and the resulting exponential rise in the volume of packages, parcels and packets requiring delivery on a day to day basis, viable and practical alternative delivery options are required.

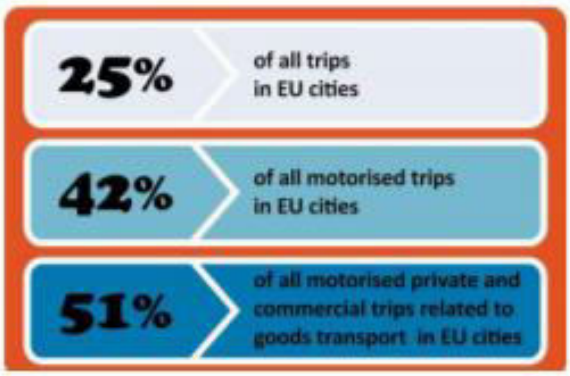

Figure 1-5 Potential to deliver cargo through cycles

Source: Cycle Logistics D7.1 A set of updated IEE common performance indicators including their baseline assumptions for extrapolation

1.5.2. Bike sharing

Bike sharing is growing at a high-speed rate and is now available in over 70 countries. Mostly Asian operators have been expanding fast. On the downside, authorities are alarmed by the excessive growth and severe acts of vandalism to the public property as well. Overall, the bike sharing market is expected to grow continuously by 20% in the years ahead.

In Italian cities especially Milan, Rome and Bologna there have been an increase in trend of bike sharing as many people feel comfortable in using app to unlock bikes and after their use park them on the street. Other benefits of bike sharing are that its cheaper than taxis and car sharing, it is more flexible than public transport and can be combined with other means of transport

Figure 1-6 Typical easy to use shared bike

Source: http//www.manchestersfinest.com/shopping-in-manchester/our-guide-to-manchesters-new-mobike/

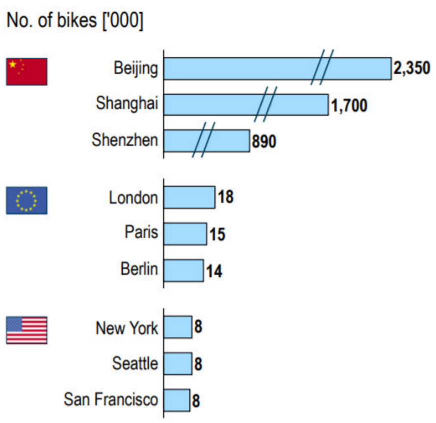

Figure 1-7 Largest bike sharing cities by region

Source: Press research; Roland Berger

1.5.3. For earning extra-income

Many of the students and other low earners who are not satisfied by their income utilise bicycles to earn extra income and could be very vulnerable to accidents since they spend much time on roads..

Figure 1-8 Bicycle food delivery guy

Source: https//elpais.com/ccaa/2018/07/19/catalunya/1532009601_014775.html

1.6. CYCLISTS SAFETY

1.6.1. Cyclist accidents

Cyclists, while relatively small in proportion with respect to motorized vehicles, have a high level of vulnerability, creating a significant need to better understand the characteristics specific to this user group. A good insight into the problem provides an opportunity to improve the road safety of this cheap, convenient and environmentally friendly mode of transport. In 2013, more than 2.000 cyclists were killed in road traffic accidents in 27 EU countries, constituting almost 8% of all road accident fatalities for that year. Although a considerable decrease by 32% in the total number of bicycle fatalities in noted within the decade 2004–2013, it is still smaller than the respective reduction of the overall road fatalities by 45%. (Petros Evgenikos)

1.6.2. Types of bicycle accidents

The typical conflict situations for cyclists as show in above figure are as follows

- Incident 1. Right crossing

It is the most widespread accident. A car exits a side road or a parking lot or a step

car on the right. There are two different cases, where

- the cyclist is in front of the car and the driver hits the front wheel.

- the car enters the road in front of the cyclist and the front wheel slams against it, without being able to brake.

- Incident 2. Sudden opening of the door

A parked car suddenly opens the door to the cyclist while he is passing. If the front wheel have crossed the visualization point and the reflections are not visible, the impact is unavoidable.

- Incident 3. Red light

The cyclist stops at an intersection with a red light (or a STOP) immediately to the right of a car, waiting for the same light. By introducing the green, the motorist, not seeing the cyclist start crossing the intersection to go straight, turn right and hits the front wheel of the bicycle. This type of incident is very frequent with buses and trucks as they have the guide top left and have a dead angle that prevents you from watching cyclists (even pedestrians, motorcycles) from the right-side rear-view mirror.

- Incident 4. Sudden turn to the right

A car passes and turns right in front of and / or against the cyclist.

- Incident 5. Cross on the left

A car comes from the opposite direction of the cyclist, suddenly turned on his left and, not seeing the front wheel, he hits it.

- Incident 6. Posterior impact

The cyclist, skidding slightly to the left to avoid a parked car or an obstacle suddenly, he risks being hit by a car coming up behind him.

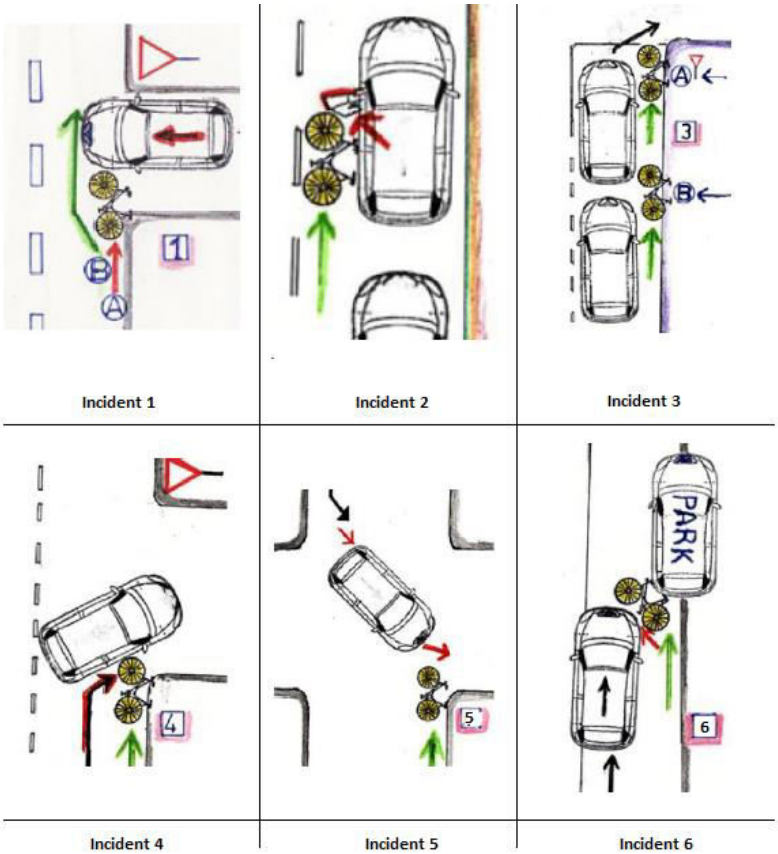

Figure 1-9 Typical risk situations for cyclists

Source: (Maternini)

1.6.3. Overall road safety for cyclists

Comparing the data for amount of fatalities on roads it was found that in the year 2013 , 2017 cyclists were killed in road traffic accidents in 27 different EU countries where as in US only 743 cyclists died accounting for 2 % of all traffic fatalities. ((NCSA))

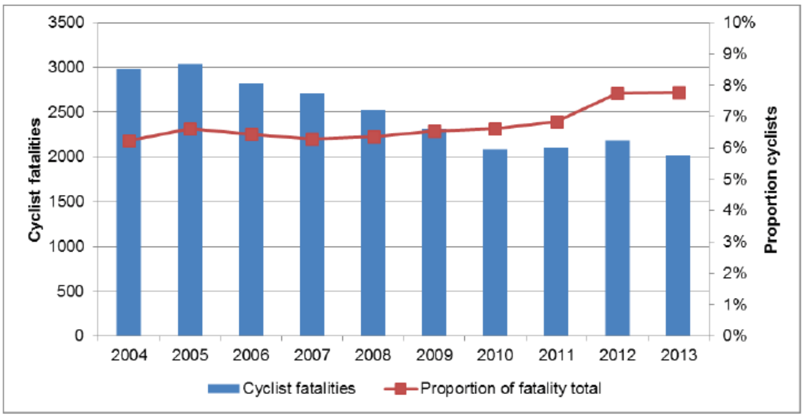

Figure 1-10 Number and proportion of cyclist fatalities in the EU, 2004–2013.

Source: CARE database

Looking at the above figure It could be noticed that although the number of cyclist fatalities has decreased by 32% over this period, the overall number of road accident fatalities has fallen faster (reduction by 45%) and the share of bicycle fatalities of all road fatalities in the EU increased from about 6% to almost 8%, especially from 2010 to 2012.

1.6.4. Time of the year for accidents

From the Figure 1-12 it was analysed the peak for EU countries occurred in August (13% of cyclist fatalities) and the fewest fatalities occurred in January and February (4% of cyclist fatalities). Also the number of cyclists on the road could be associated more to the bicycle accidents than indication of risk of injury per cyclist.

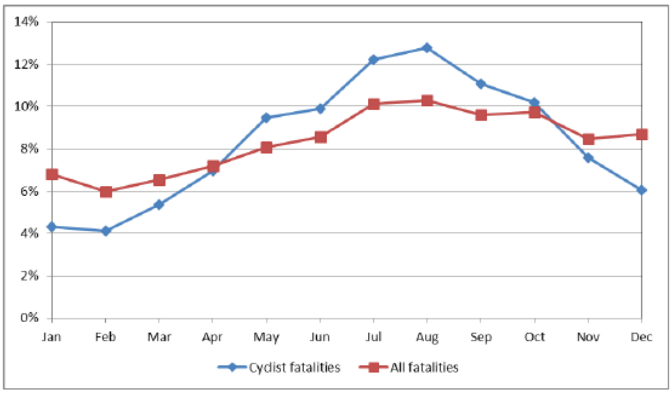

Figure 1-11 Proportion of cyclist fatalities and total road fatalities per month in the EU, 2013.

Source: CARE database, data available in May 2015.

1.6.5. Accident causation analysis

As shown in the figure 1.133, the most frequently noticed cause for both drivers and riders involving in the accident was ‘the premature action’ which describes a critical event with an action started too early before any signal was given or required conditions established. In combination with prolonged distance and prolonged action/movement – movements taken too far and manoeuvres that last for too long (for example, not returning to correct lane).

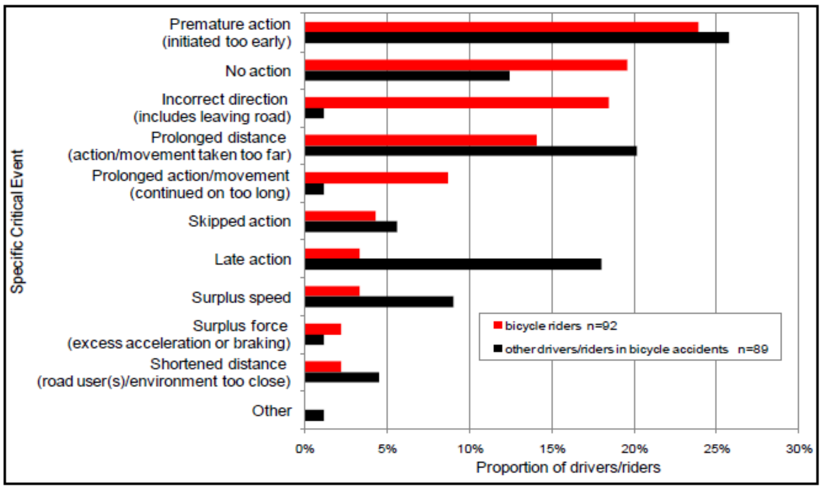

Figure 1-12 Distribution of specific critical events – bicycle riders and other drivers/riders in bicycle accidents.

Source: SafetyNet Accident Causation Database 2005 to 2008 / EC; N=181. Date of query 2010.

Links between causes	Frequency
Faultydiagnosis – Information failure (driver/environment or driver/vehicle)	13
Observation missed – Faulty diagnosis	6
Observation missed – Inadequate plan	6
Observation missed – Temporary obstruction to view	5
Observation missed – Distraction	4
Observation missed – Permanent obstruction to view	4
Faulty diagnosis – Communication failure	4
Inadequate plan – Insufficient knowledge	4
Observation missed – Inattention	3
Information failure (driver/environment or driver/vehicle) – Inadequate information design	3
Others	22
Total	**74**

Figure 1-13 Ten most frequent links between causes – bicycle riders.

Source: SafetyNet Accident Causation Database 2005 to 2008/EC. Date of query 2010.

The above figure mentions the frequent links between causes for injury accidents involving bicycle riders. For this group 74 such links were there in total. Importance of causes could be noticed from their number of appearance (frequency).

1.6.6. Road Safety

Risk posed to bicycle users on roads considering a cyclist-only crash shows that there was just a small amount of energy transfer between both the cyclists due to small masses and low speeds but if it was the case of cycle vs car the results are incompatible as a car have a huge mass in comparison to a bicycle. For one car casualty there are 150 bicycle casualties in car-bicycle crashes. Therefore, vulnerable road users such as cyclists run an even higher risk of getting injured in a crash with a 'disproportionally strong crash opponent'. Measures to ensure bicycle safety on roads

- **Through helmets**

One of the protective devices available for cyclists is the bicycle helmet. It is widely accepted that a properly designed helmet provides protection for the most vulnerable part of the body, the head, against being severely injured in a crash (SWOV). SWOV has calculated the maximum effect of a bicycle helmet to be approximately a 45% reduction of the risk of head and brain injury when a good helmet is worn correctly. However, if one needs to use 'controlled trials' as the only way of finding proper scientific evidence, some doubts remain. Whereas the helmet generally is compulsory for participants in sporting events, wearing a helmet for bicycle touring or bicycle rides in general is still optional in most countries. This introduces another heavily debated issue how conclusive are studies that evaluate the safety effects of introducing helmet legislation?

Some cyclists are opposed to the helmet as it conflicts with their feeling of freedom that goes with riding a bicycle, or because it is unsightly, uncomfortable, or unnecessary over short distances. Others are strongly in favour of it as it provides good head protection. One of the often-heard arguments is the negative impact of compulsory helmet use on the use of bicycles, and this is supported by an unmistakable decline in the use of bicycles after the introduction of compulsory helmet use in provinces in Australia and Canada. Presently, the conclusion must be that deciding on helmet legislation is a political decision, given that such a decision will have positive and negative effects on cycling and cyclist safety.

- **Through noticeable jackets**

A review study from The Cochrane Library (Kwan) studied randomised controlled trials (RCT) to assess the effects of increasing pedestrian and cyclist visibility. The study found 42 studies comparing the visibility with and without visibility aids. These studies showed that fluorescent materials improved drivers' detection during the day, while lamps, flashing lights and retroreflective materials improved the detection at night. This randomised controlled study delivered strong evidence that cyclists are protected against multiparty accidents when wearing a bright-coloured jacket.

1.7. Infrastructure and Bicycles

Starting with the question “why is cycling infrastructure needed?”. A simple answer to this question could be because of ignoring the bicycle users in planning cities when there has always been an approach to have a distinct path for pedestrians to move. Since bicycle users are faster than pedestrians there is in no way; they can be compared to the speed of other moving vehicles which have more intensity and speed than bicycles. If we want to facilitate the use of cycling as an environmental friendly transport mode used by masses, adaptation in infrastructure will be needed. Two approaches are needed to be understood when designing cycling infrastructure

-Taking cyclists seriously.

- Integrating cycling infrastructure.

To make sure that above both approaches are completely respected we are of the philosophy namely “The network/segregation philosophy” which is a strongly technical engineering approach making sure that cycling infrastructure is considered as an additional network in its own right, consisting of separated, dedicated infrastructure having its own technical design norms. But the above-mentioned philosophy is quite expensive when it comes to practical implementation so we might have to be flexible on some places for instance an area with less traffic or where speed of cars is of less intensity (areas with a speed limit 30km/h) so that bicycles can integrate with the cars.

Cyclists’ needs

It is important to keep in mind that bicycles are in general used for short distances of less than 5km as could be seen in the table below which is from the research conducted in Flemish region in Belgium.

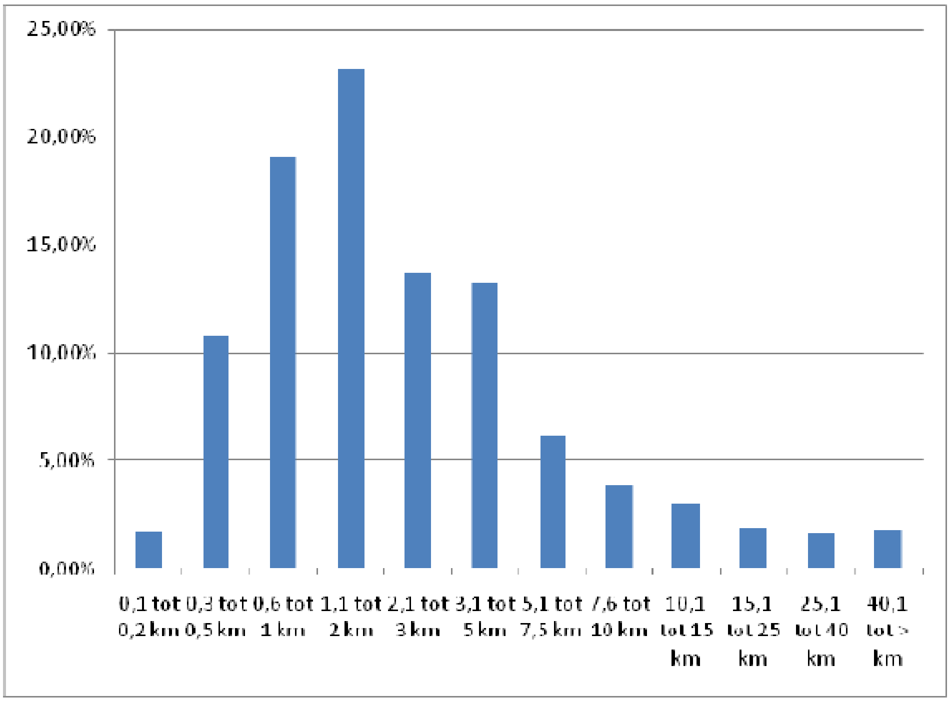

Figure 1-14 Share of bicycle trips per distance

Source: OVG Flanders 2001 (Travel behaviour survey)

Now the question which arises is what makes cyclists want to get on their bikes, and some of these essential needs could be

- Safety
- Direct route
- Good connections to public transports
- Attractive pathways
- Comfortable journeys

1.7.1. Main requirements of a cycling network

For a cycle network, three out of five main requirements (see above) are very essential safety, directness and cohesion. The other two are important on the level of specific design of routes and road sections.

The most important among these three important requirements is cohesion meaning good connections without it there would be only a bunch of single routes. Cohesion is the extent to which cyclists can reach their destination through the route of their choice.

To make a network cohesive, a clear understanding of major origins and destinations is important. By drawing in lines of desire between those, we can get an idea of potential travel flows. Using computer models to calculate travelling patterns is only feasible for CHAMPION CITIES with sufficiently large numbers of cyclists to provide meaningful data.

Apart from the internal cohesion of a cycle network, the cohesion with other networks also plays a role. Especially the intermodal connection for the cycle network to public transport points is very relevant as cycle trips are an import means of transport to and from public transport.

The network directness concerns the distance or time you need to cycle between points of departure and destination. In terms of policy, the bicycle should have more direct routes than the car in the built-up area. This way cycling is quicker than taking the car. Directness in the distance can be determined by calculating the detour factor which is the relationship between shortest distance over the network and distance as the crow flies. The lower the detour factor the higher the directness of the network.

Moving on to the third important factor “safety” which is not just a factor of physical design. Much work could be done to ensure safety on the network level. Below are given some guidelines to ensure network safety

- Avoid conflicts with crossing traffic.
- Separate different types of road users.
- Reduce speed at points of conflict.
- Ensure recognizable road categories.

1.7.2. Characteristics of a bicycle network

However, what exactly is a cycle network? Here is a working definition a cycle network is an interconnected set of safe and direct cycling routes covering a given area or city. It is worth stressing once again that a network consists of routes, not tracks or lanes. The quality of a route or a network does not depend on one particular type of infrastructure, such as segregated tracks. A quality cycling route is an uninterrupted itinerary fitting as closely as possible the criteria outlined above safe, direct, cohesive, comfortable and attractive. The physical shape may vary from route to route and even within one route. A route may start in a residential 30 km/h area mixed with light traffic, move onto a cycle lane where traffic is slightly heavier, run through a dedicated cycling tunnel under a ring road, continue as a segregated track along a main road, cut through a park as a short-cut and through a pedestrianized shopping area reach to the railway station. The quality of the network as such depends on its structure how well does it fit together; how easily does it make urban destinations accessible; how well does it avoid or manage risky situations?

Keeping under consideration the physical characteristics of the activity of bicycling we need to have the following things in our mind when designing a bicycle network

- **Stability**

Bicycles are unstable vehicles. Crosswinds, lorry slipstreams, bumps and holes in road surface and involuntary low speeds determine the stability of the bicycle network. A speed of at least 12km/h is required to maintain balance otherwise the bicycle will start wobbling, which could be due to pulling away from a stationary position, slowing down in the narrow bends and riding uphill.

- **Zigzagging**

When riding, cyclists continuously have to maintain their balance. That is why they always move slightly from side to side, even when riding fast. This is called zigzagging. Apart from the speed, zigzagging also depends on age, experience, physical capacity, disruptions in the road surface and cross winds. At normal cycling speeds in normal conditions, the zigzagging movement is about 0.20 m. In situations where cyclists are forced to travel at less than 12 km/h, more free space is required. This is the case at traffic lights, for example, where cyclists have to pull away from stationary position and when cycling uphill. In that kind of situation, zigzagging may require a track width of up to 0.80 m.

- **Fear distances from obstacles**

Designers also have to take the fear of obstacles into account cyclists will want to keep their distance from kerbs, edges and walls. The Dutch Design Manual indicates the following obstacle distances for green verges and low kerbstones, the obstacle distance is 0.25 m; for higher kerbstones 0.50 m, for closed walls 0.625 m.

- **Section of free space**

Now we can calculate the pavement width required for one cyclist take the width required by the bicycle and its rider (0.75 m) and add to that the zigzagging margin and fear distances from obstacles (these margins may overlap). The most common situation is that of a cyclist riding along a high kerb on one side an absolute minimum pavement width of 0.9 m is required.

Whenever possible, we should provide room for side-by-side riding this makes cycling amore enjoyable social activity, allows adults to drive next to children and allows faster cyclists to overtake slower ones. This means we should go for a recommended minimum width of 1.5. For comfortable driving in tunnels, provide minimum 0.75 m headroom.

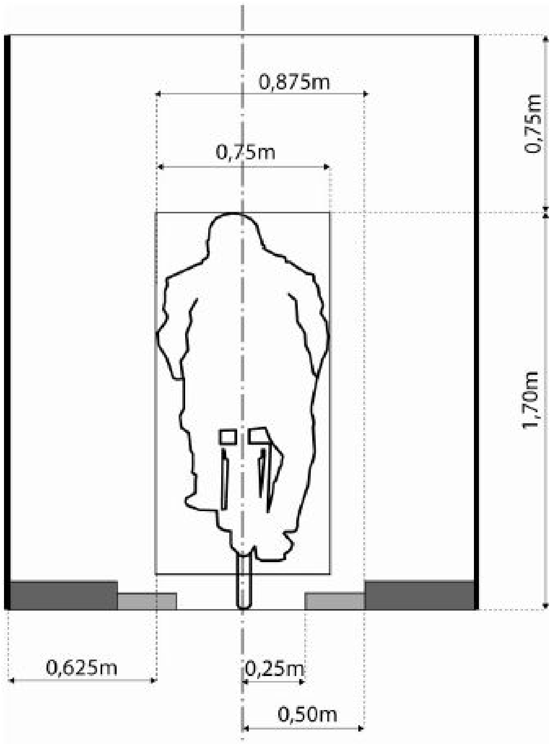

Figure 1-15 Section of free space

Source: adapted from CROW – 2006 Design Manual for Bicycle Traffic. CROW-record 25

1.7.3. Road signs

Indication signs are intended to provide users with the necessary information for the correct and safe circulation, as well as for the identification of itineraries, locations, services and road installations. As for the recommended cycling routes, it is necessary to integrate the road signs standard with compound signals that recall this preferential and recommended condition.

- **Horizontal signs for cycle paths**

The cycle lanes on a reserved lane from the roadway are separated from the lane of vehicles driven by two continuous horizontal signal strips side by side, a white one of 12 cm of width, and a yellow one of 30 cm of width, space between them is 12 cm (Figure 1-16). The yellow strip must be placed on the side of the cycle path (Regulations for the implementation and implementation of the New Highway Code, DPR 16.12.1992 n 495); the symbol of the bicycle, in white, will be repeated repeatedly along the development of the track.

With a correct application of the road markings, a proliferation becomes superfluous repetitive of vertical signals at each intersection with side roads. Horizontal signage it clarifies by itself the presence and the continuity of a cycle route.

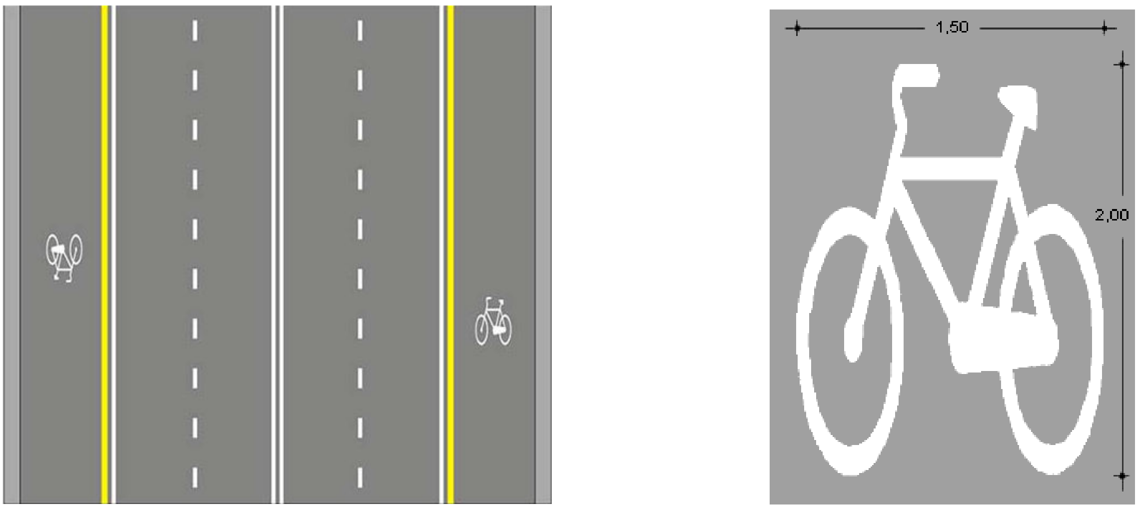

Figure 1-16 Horizontal signals for cycle paths

Source: (Maternini)

- **Vertical signage for cycle paths**

The Italian Highway Code provides three prescriptive signals to indicate the existence of a structure specifically designed for cycling the "cycle path" sign, to be used at the beginning of a track, lane or itinerary reserved for the circulation of bicycles; the signal "cycle lane adjacent to the sidewalk", which identifies a track or lane always reserved for bicycles but parallel and contiguous to a path reserved for pedestrians; the signal "Pedestrian and cycle path", which identifies a path intended for a promiscuous use of pedestrians and bicycles (Figure 1-17).These signals indicate that the road, or part of it, is reserved for the single category of users expected, that is cyclists and in the last case, cyclists and pedestrians, while it is forbidden to others categories.

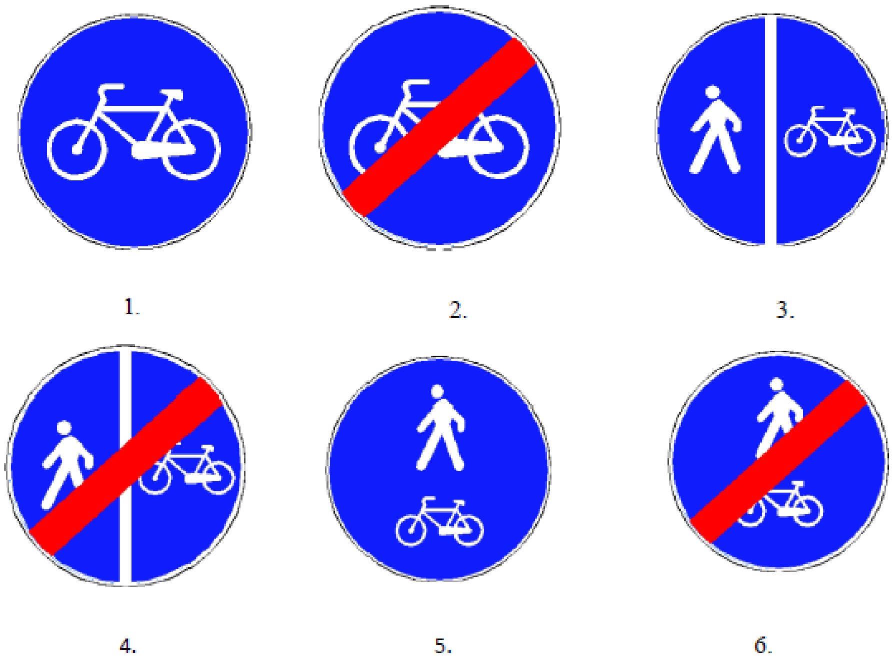

Figure 1-17 Vertical signals obligatory for cycle paths

Source: (Maternini)

The signals in the above figure could be explained as

- Figure 1. Cycle lane indicates the beginning, or continuation, a track, a lane, a path, reserved only for bicycles.
- Figure 2. End of cycle track indicates the end of a track, a path, reserved only for the bicycles.
- Figure 3. Cycle lane adjacent to the sidewalk indicates the beginning or continuation of a track or lane, reserved for bicycles, contiguous and parallel to a sidewalk or in

any case of one path reserved for pedestrians. The symbols can be inverted to indicate the real layout of the track and sidewalk

- Figure 4. Pedestrian and cycle path indicate the beginning or continuation of a route, a itinerary, or an avenue, reserved promiscuously to pedestrians and bicycles.
- Figure 5. End of the cycle lane next to the sidewalk indicates the end of a cycle path next to the sidewalk
- Figure 6. End of the pedestrian and cycle path indicates the end of a location, route or itinerary, reserved promiscuously to pedestrians and velocipedes.

1.7.4. Bicycle Track pavement

The paving of a cycle path is the element that absolutely characterizes the track, through its discreet recognition, comfort, environmental inclusion.

The design definition of a cycle path paving cannot be separated from one careful study of the context in which the track develops, of the prevalent type of user expected, construction and maintenance costs. In some cases, not competent designers are good administrators and can't fulfil make the design a good reality. A knowledge of the construction techniques of the roads (a cycle path is still a road), and in particular the basic elements of hydraulic protection of road foundations, it is a necessary and sufficient prerequisite for building economic cycle paths which can last a good amount of time.With this essential prerequisite, the cycle plan must have adequate capacity carrier that can be obtained with crushed stone materials with controlled granulometry and adequately compacted, even without the use of hydraulic binders or hydrocarbons. Similarly effective are the preparations of the foundations and even of the same cycle surfaces with land stabilized with lime or lime / cement in relation to the type of land present in place. Cycle loads and occasional loads of light motorized vehicles to maintenance services, they do not generate solicitations of such magnitude as to require important superstructures. On the other hand, it is essential to avoid water stagnation or to leave surface portions uncovered not compacted and yielding which, among other things, are prejudicial to the stability of the cyclist. More the tangential surface actions are significant and therefore the type is very important for them and also the durability of coating surfaces is of equal importance.

The cyclist prefers a compact surface with good adherence, regular and without roughness of a closed bituminous conglomerate, hot microtapes or stone pavement or in perfectly laid and maintained concrete slabs (limited drainage, stability of the single element and control of the dimensions of the rolling plan), and this is the case of paving solutions for bicycle lanes in reserved lane on carriageway or on sidewalk and generally solutions in urban and sub - urban circulation.The same levels of comfort and lower running costs, especially for long runs tracts of slopes in green areas, parks, rural areas, can be obtained through treatments surfaces of cold dedusting by bitumen emulsions.

Among these solutions, very interesting for speed of execution and cost-effectiveness of the process, there are single layer treatments with double shot blasting (grades of 6/10 mm + 2/4 mm grit), double-layer to double-layer treatments and "sandwich" treatments (Figure 1-18).

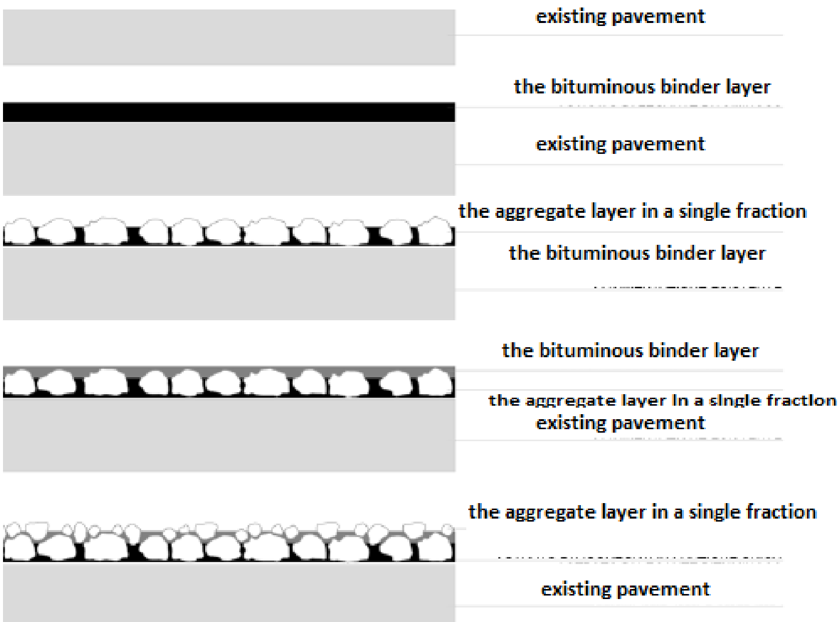

Figure 1-18 Surface treatment of cold dedusting (Double - Layer)

Source: (Maternini)

The dosage of grit and bituminous emulsion per unit area varies according to the type of treatment to be carried out and of the granulometric classes of the stone aggregates used.

At the Source: of potentially very positive outcomes, the treatment project is still very much delicate and passes from a careful evaluation of the shape and lengthening of individual grains and by a good organization of the installation works. The spreading temperature and reopening times traffic are decisive for the final result with processes that take place at temperature environment and therefore completely eco - compatible.

For areas of environmental and landscape protection, when we do not want to derogate from the maximum comfort in the cycle path, the evolution of the technologies of the bituminous conglomerates allows for some years to be able to conceive and realize road surfaces colored in the mixture that, for the design of the cycle paths in the regime of "traffic calming ", can also highlight specific destinations of the urban roadway (tracks cycle paths in their own or on a reserved lane, intersection areas, etc.). Such conglomerates, from structural and functional point of view, they are identical to traditional bituminous mixtures being packaged asphalted bituminous binders or with polymeric resins transparent with any colors that are obtained with the addition of specific pigments introduced in production plant (Figure 1-19).

Figure 1-19 Laying of transparent bituminous conglomerates

Source: (Maternini)

The colouring in paste guarantees the maintenance of the essential characteristics of adherence between the tire and the flooring, which can be less when the colours road surfaces are made with inadequate paints or paints on bituminous surfaces traditional. More effective is the colouring, always in paste or with specific paintings, of streets and bicycle tracks in concrete blocks, generally self-locking, that identify in a way explicitly the partition the way for each user (Figure 1-20).

Figure 1-20 Cycle tracks in coloured bituminous conglomerate and self-locking blocks

Source: (Maternini)

The approach is different if the colour of the track bottom is made in correspondence of the cycle crossing using paints. In this case, it falls into all effects in field of horizontal road signs and therefore this practice is prohibited. Emerge in fact the contrast with the provisions of art. 137 paragraph 5 of the Execution Regulation of the Italian Highway Code, which lists the colours that can be used for signalling horizontal and specifies its use. Technically, less than an objective sense of recall given by the chromatic contrast, the cycle or cycle-pedestrian crossing made on backgrounds coloured (red, blue, green) is not visible better than normal white stripes on a black background, with the latter combination that has the optimal ratio contrast and which is more effective in night time or during one meteoric precipitation. Therefore, the best perception by users is obtained creating a cycle or cycle path crossing with white stripes on a black background.

2. Literature Review

2.1. Role of driver's behaviour in road safety investigation

2.1.1 Driving behaviour

Driving may be described as a control task in an unstable environment created by the driver's motion concerning a defined track and stationary and moving objects. The task includes requirements for route choice and following, coordination of manoeuvre in support of navigational objectives, and ongoing adjustments of steering and speed.

One way to observe the behaviour of driver is analyse the eye movement . The theme of visual perception is one of the strengths of scientific psychology; not by chance precisely in this field psychology has made its most significant scientific progress, thanks also to the collaboration with other disciplines, such as neurophysiology or computer science.

2.1.2 Visual perception

The term perceives means "learning with the mind" and derives from the Latin "percìpere", which means "gather"; our brain, collects, records, organises, reworks and memorises the data of sensory perceptions. When you see an image, the brain registers the forms, colours and movements that have captured, processed and classified the information received and, therefore, defines the displayed object allowing to become aware of his identity, its shape, its colour, its position in space, its movements etc. In short, the brain allows us to see and know the perceived object. Visual perception is, therefore, an essentially mental activity; however, the brain does not it intervenes only to define an image but also to connect a visual perception to others sensory impressions (tactile, gustatory, olfactory, auditory) so that we can know one object from the sum of these perceptions.

Moreover, the activity of the mind allows to associate an image with other information present in memory in this way, thanks to the memory and the association of ideas, an image can be easily cataloged (recognized and compressed). From this set of components finally comes the "judgment" that, linking a given perception to feelings, feelings or memories, determines a psychological and emotional reaction for which an image can get consensus and interest or to arouse repulsion and rejection, can evoke feelings and memories, can be judged beautiful or ugly, pleasant or unpleasant and so on. Visual perception, therefore, is based on a set of mental operations (memorization, cognition, learning) that allow us to perceive, catalogue and process information and that determine their attitude and their reactions to him.

2.1.3 The visual perception of space

Perception of space means the perception of geometric and spatial characteristics of individual objects (their size, volume, orientation, etc.) and all those characteristics that make it possible to locate objects that are variously arranged in space, beyond at the distance between the object and the observing subject (absolute distance) and between the various objects themselves (relative distance). Depth cues provide information only on the distances between one medium and another (the relative distance), not on the distance between the vehicle and the observing person (the absolute distance). The perception of spatial contrast is the ability to recognise the objects that constitute its visual scene. Constancy is a perceptive compensation, i.e. a visual phenomenon in which the object it remains relatively constant when it is perceived by the observer regarding his property, despite the fluctuations of its physical characteristics.

2.1.4 The visual perception of movement

The movement of an object not only indicates some properties dynamics such as direction and speed, but also some spatial properties such as position and the distance. The perception of movement is not always due to a real shift of the image on the retina, but to a mental interpretation of what the eye sees. Which set of conditions is enough in the physical environment to be able to perceive one movement. You can see a movement if a dot moves on a stationary background at speed of 0.2 radians of visual angle per second (rad / s). For example, when a pawn moves by night, in a dark place, wearing bright shoes. Many objects in the world that surround us move, and road traffic is an example explicit, or transform, while our behavior is characterized by movements of the body, head and eyes. Because of this it is good to talk about a flow of stimulations always changing at an optical level. The optical flow is the set of rays of light that comes from the environment to the eyes and comes focused on the retina, while the individual moves in the environment. It refers exposure to the type of repetitive movement that adapts when, for example, you drive or ride a bike. The optical flow can provide information that specifies one possible imminent collision with a moving object approaching. The flow component optical is the consequence of locomotion, it represents a perspective transformation keep it going. The optical flow that hits the retina during locomotion takes precedence over all other information since the outside world is perceived as a stationary entity e the observer as a moving unit.

During locomotion, the components of the visual environment are interpreted as structures rigid in the relative movement since "people perceive the environment as an entity rigid. " It should be remembered that visual information about locomotion by the cyclist or pedestrian does not it is a single isolated entity, it interacts with the signals that come from other sense organs present in the joints, muscles, inner ear, etc., which report on the bodily movements. The apparent movement refers to any illusory movement that takes place when no real movement or object is corresponding to the perception of movement. It includes various phenomena, such as the stroboscopic movement, which is at the basis of a perception of movement in the cinema or on TV. In the if in A the lights (or) light up later with constant time, it is perceived a movement that goes from t_1 to t_n. In B, if the lights t_1 and t_2 are switched on and off at precise time intervals, there is a perception of movement from the moment t_1 to the moment t_2. This is called the "phi" phenomenon, which has effects more convincing than the real movement indicated in A.

<u>A</u> t_1 o → t_2 o → t_3 o → t_4 o → t_5 o → t_n o   <u>B</u> t_1 o → .... → t_2 o

Figure 2- 1 Perception of movement

Source: (Maternini)

The perspective of movement is the set of variations of the perspective projections produced from the observer's movement. When a rider looks in the direction he is moving, the field of view expands from one focal point located on the horizon; in the length of the arrows indicates the different flow velocity of the various parts of the visual field. These perspective contractions of expansion, sliding and contraction of the field become very visible when you are there moves at high speed in cars or trains as shown in Figure 2-1.

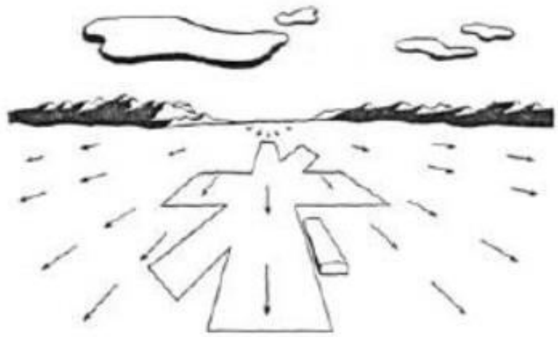

Figure 2- 2 Flow velocity of the visual field parts

Source: (Maternini)

2.1.5 Visual perception of colours

Colour is not a physical property of objects, but a subjective experience. The colour is an incredibly engaging appearance in the world around us; although many visual functions they could be carried out by simple detection of light / dark reports, others behaviours strongly depend on the properly chromatic aspects of what we see. Colour has direct effects on people's perception, mood and behavior. The constancy of colour is above all a rational phenomenon given that the things we see do not know they are isolated and suspended in nothingness, but they are normally surrounded by other things, at least stand out against a background. The colours are differentiated based on 3 different perceptive qualities the colour, the clarity and the saturation. To draw colors in eurpean languages only 11 terms is being used; white, black, red, orange, yellow, green, blue, brown, pink, purple and gray. Table 2-1 shows the sequence percentual- norm of colors - base in normal adults (male and female).

Basic -Colours	% noticing in adults
Blue	20.2
Red	17.6
Green	16.4
Yellow	12.6
Orange	10.0
Viola	7.3
Brown	6.9
Black	6.0
White	2.0
Gray	1.0

Table 2- 1 Basic Colours- Noticing in adults by percentage

Source: (Maternini)

Not all people have a correct perception of colors, like those that come used in road signs, including traffic lights. Total or partial insensitivity to red or green is relatively frequent (about 8% of the total population), in males (6 - 7%) more than in females (1%). The colour-blind they perceive two fundamental colors yellow and blue, and this leads them to confuse the red, the blue - green and grey. the colors of the road signs are established by the Highway Codes.

2.1.6 The colour contrast

Figure 2.2 shows a research conducted by the Institute of Psychology of the University of Bologna, on the readability of a biochromatic signal, using the letters XYZ and the background color. The following readability order has been obtained Black on yellow; Yellow on black; Green on white; White on blue; Black on white; White on black; Orange on black; White on Green; Green on orange.

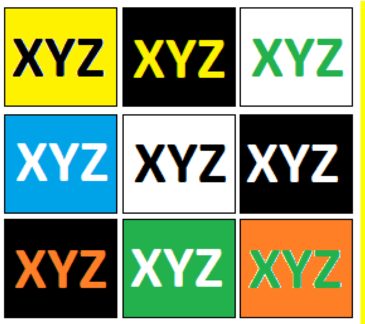

Figure 2- 3 Order of readability of a biochromatic signal

Source: (Maternini)

2.1.7 visual field in the dynamic scene

Perception is a process of sensory organization and unification of events sensitive, closely linked to experience what perceives us does not correspond necessarily to the physical reality of objects. In fact, there may be discrepancies between the real data and perceived data as, for example, the distance, shape or size of the eye human perceives does not always correspond with distance, form or objective size. "The physical world is not the world of physics". The visual system has the function of constructing a model of the visual scene it takes into account environmental lighting, its effects on various types of surfaces and distribution of spatial shadows. The visual scene is seen in an instant by an ideal observer who photographs it, but who in reality explores it by focusing its vision mainly on only some details of the same, on which he then reconstructs the scene in a unified way. The visual field and therefore the visual scene are different for a pedestrian, a cyclist or a driver of a vehicle. In 2.29 the visual field of a pedestrian or a cyclist, of a motorist travelling at 30 km / h and a motorist who travels at 50 km / h.

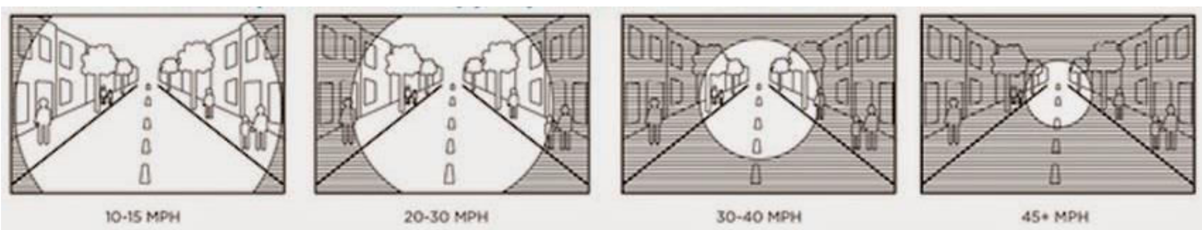

Figure 2- 4 Field of vision of a motorist (speed 10- 45+ km / h) of a pedestrian / cyclist

Source: http//www.copenhagenize.com/2015/01/is-copenhagen-finally-up-to-speed-on.html

Peripheral vision orients our foveal vision on one object rather than another to allow identification. If, for example, a cyclist, traveling by day, passes from an external road to a tunnel unenlightened can see that the adaptation to darkness in the transition from an exposure in bright light in the dark it implies a certain time in which the cones and the first are involved subsequently, with a longer time, the rods. In cyclists belonging to different age groups, i.e. the youngest and the oldest, adaptation to the obscurity it is a lot slower for the latter.

2.1.8 Road environment and visibility of the elements

The fact that a road has been well designed does not necessarily imply that all users will feel the limits that the course of the road imposes to their behavior or even warn them. Insecurity, sometimes, is attributable to the system (man, vehicle, Street). The surfaces of the environment, both natural and artificial, usually have a grain of weaving, both for their colour that is not uniform, and because they are not perfectly smooth, they are grainy, wavy, pitted or otherwise irregular. Some road surfaces are visibly made up of many parts put together so that their texture is more evident. The texture gradient is the modification of the appearance of visual objects, depending on their distance, important in the perception of this. The texture gradient constitutes a depth indication for example, the paving stones of a road gradually appear smaller hand that the observed point is farther. A study conducted in France, on over a thousand drivers, ascertained that speed used seems to be strictly dependent on the characteristics of the first roadway of the intersection, i.e. the layout and the lining of the road pavement.

Visibility intervenes in the more general framework of the setting process and treatment information that is a fundamental aspect for choosing the behavior to be held. Visibility is different at night, during the day, with fog and mist or with rain and snow. This requires those who manage the streets to implement tools that promote a level of coherent visibility in relation to the road, as indicated in the Highway Code, and to his displacement, and possibly in all the different situations found. Those interested in the traffic safety problem must be able to use any a means that can help people to make a correct assessment of what they must face.

2.2. Main features of a human eye

The eye has the function of capturing the light signals and transforming them into nervous signals. The illuminated objects reflect the luminous radiations that strike them; the reflected radiations they reach the receptors in our eyes, which send electrical impulses to the brain. The eye works like a camera. The entire orbital cavity is enveloped by a very resistant white fabric, the sclera it is the so-called "white of the eye" which, in the front part and central, to let the light pass, it becomes transparent, curves into glass with time and shape the cornea.
The light passes through a hole, the pupil, which be the diaphragm of the camera expand or shrink by muscle fibers arranged circularly "donut" around to it, so as to regulate the amount of light that enters. When, for example, we enter one dark room coming from an enlightened environment, the pupil expands. These fibers, together with connective tissue that unites them, form the iris, the part that gives color to the eyes. More internally there is a real lens, the crystalline lens. The crystalline is curved or gets flatten to focus on the retina the image, turned upside down like in a camera.

The space between the crystalline lens and the retina is occupied by a gelatinous liquid, which maintains the shape of the eye ball. In people with hypermetropia the eye ball is shorter than normal and the image is focused behind the retina (Fig 2-4). In the short-sighted people, instead, the globe is longer and the image is focused in front of the retina. The retina, which records the image as a photographic film and transmits it to the brain, is a membrane consisting of two types of light receptors or photoreceptors the cones and the rods.

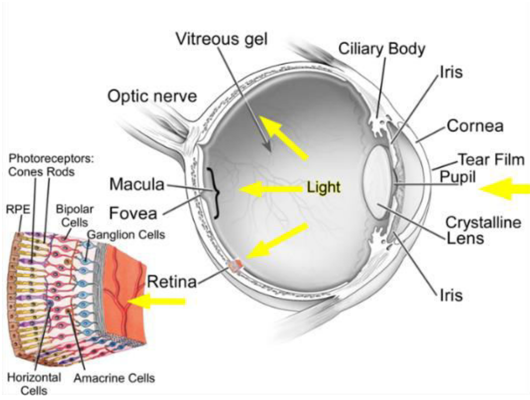

Figure 2- 5 Structure of the eye

Source: http//www.optics.arizona.edu/sites/optics.arizona.edu/files/alexander_lyubarsky_ms_report.pdf

The light follows the following path before reaching the retina

Light → Cornea → Pupil → lens → Retina

The rods, sensitive to light of low intensity, are about 120 million. They are distributed fairly evenly over the entire retina, except in the area, called the fovea centralis, where the concentration of the cones is maximum. The cones, sensitive to intense light, are also responsible of color vision. In a smaller number of rods, about 6 million, the cones are not in fact all equal. Some of them are sensitive to red light, others to green light, others to that one blue variously stimulated, they allow us to perceive colors. Color blindness, a disease genetics which involves the inability to distinguish certain colors, is generally due to the lack of red or green receptors. The light that arrives on the photoreceptor "impresses" them because it determines the rapid and complex reactions of the photosensitive pigments (i.e. sensitive to light) contained in them.

In rods, for example, there is a red pigment, the rhodopsin, which is formed starting from vitamin A. When light hits the rhodopsin molecules, they change generating nerve impulses which, through the optic nerve, reaching the brain. Unlike the photographic film, the pigment of the eye does not end. In fact, in the eye there is a complex chemical system that continuously returns the pigment to the original structure if it would not be like that we could not see anymore. During the time necessary for the reconstitution of the pigment the eye is not sensitive to light it is what happens when we are dazzled. It is usual to make the mechanism of optical perception clear and understandable by comparing it to that of analogue photography. In fact, the camera was built following the functions of the eye. Visual rays penetrate through the lens of the photographic lens, which performs the same function as the lens, making the visual and intersecting rays cross projecting the image upside down on the back of the machine, the latter consists of a photosensitive surface on which, thanks to the chemical reactions, the inverted and negative image is recorded (in which, in other words, the relationships are reversed between light and dark). Subsequently, during printing, the image is projected onto a sheet of sensitive paper, rectified and recomposed (becoming a positive image), similar to what happens in our brain. The view is able to focus on an object, or to fix the gaze on an object placed at a certain distance and distinguishing it with greater clarity from the surrounding environment, the perception of which will remain more confusing and less defined, i.e. blurred. This is firstly due to the possibility of modifying, thanks to the action of a muscle, the curvature of the crystalline lens through which the visual rays penetrate inside the eye; this effect is similar to that of focusing a photographic lens when it comes adjusted according to the distance of the object to be shot. Secondly, the ability to distinguishing an object with greater clarity is due to the greater sensitivity of the central retina, called fovea the images that affect the fovea will therefore result more defined as those that will affect the peripheral areas of the retina. Therefore, it will result clearer the vision of the objects on which the gaze is projected directly, because their rays visuals will be in line with the hole of the pupil and the fovea; on the contrary, the images that they are displayed sideways, i.e. with the corner of the eye, they will remain blurred and less clear. Like other organs of the human body, the eyes also present themselves in pairs and collaborate in the realization of visual perceptions giving a sense of spatial depth to images two-dimensional that are formed on the curved surface of the retina. In fact, the eye globes have a certain possibility of movement so they can converge to capture the visual rays coming from an object (the convergence will be greater, the less is the distance from the object observed); in each of the eyes a slight image is then kept at a distance from the same object and our brain can convert this inequality of the two images in the perception of relief, or spatial depth. This vision, called stereoscopic, can be reproduced with a device (stereoscope) which allows the simultaneous viewing of two slightly different, related photographic images to the perception of the right and left eye, causing an illusion of spatial depth (Fig 2-6)

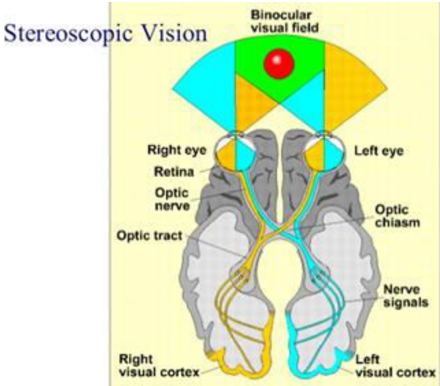

Figure 2- 6 Stereoscopics or binocular vision

Source: https//airfreshener.club/quotes/capuchin-monkey-life-span.html

2.3. Eye Movements

There are at least three important reasons to understand eye movements in scene viewing. First, eye movements are critical for the efficient and timely acquisition of visual information during complex visual-cognitive tasks, and the manner in which eye movements are controlled to service information acquisition is a critical question. More generally, the interaction between vision, cognition, and eye movement control can be seen as a scientifically tractable testing ground for theories of the interaction between input, central, and output systems . The vast majority of our current knowledge of eye movement control in complex visual-cognitive tasks derives from studies of reading, but a complete theory will require generalization to other ecologically valid tasks like scene viewing. Second, how we acquire, represent, and store information about the visual environment is a critical question in the study of perception and cognition. Visualization is a dynamic process in which representations are built up over time from multiple eye fixations. The study of eye movement patterns during scene viewing contributes to an understanding of how information in the visual environment is dynamically acquired and represented. Finally, eye movement data provide an unobtrusive, online measure of visual and cognitive information processing.

2.3.1 Review of eye movements during visualization of scenes

Eye movement behavior during scene viewing can be divided in two relatively discrete temporal phases namely

- Fixations which are periods of time in which target point in still at a particular location demonstrating that eyes are at a still position
- Saccades which are periods of time when the eyes are performing some kind of movements a rat to reorient the point of regard from one spatial position to another.

In case of fixations it is possible to determine the useful information but in case of saccades relatively less useful information could be determined as we need to utilize visual masking and central suppression for that task.

2.3.2 Fixation of Eye Movements

It is widely accepted that deficiencies in visual attention are responsible for a large proportion of road traffic accidents (Taylor). An understanding of the visual search strategies of drivers is thus extremely important, and much research has been conducted in this area- Although there are clear problems with the assumption that records of eye movements fully describe the distribution of visual attention, these provide the best Source: of data available from naturalistic studies. At their simplest, drivers 5 fixation patterns on straight roads can be described as concentrating on a point near to the focus of expansion (the point in the visual field in front of the driver where objects appear stationary) with occasional excursions to of road furniture and road edge (M. &. Helander).This reliance on the focus of expansion in the scene is assumed to be because it provides precise directional information to the driver and is the location near to which future traffic hazards are likely to be first visible.

Increasing the complexity of the visual scene (by adding vehicles, road furniture, or irrelevant signing) increases the number of eye movements made and decreases the mean fixation durations on individual objects. Erikson (Erikson).This seems to be a natural response to having more objects available in the visual field to look at; it is not evident decreases in fixation durations mean that objects are processed less completely or that redundant fixation tin-re is simply reduced. Cohen (Cohen)found that subjects viewing slides in the laboratory adopt longer fixation durations than those actually driving a vehicle in the same situations. He suggests that this is largely a consequence of the lack of time pressure in the laboratory and argues that on the road subjects adopt more task—relevant strategies and pick up more information per unit time. It may thus be that long fixation durations in situations with low visual complexity tell us little about the information that is being extracted from the scene and more about the low subjective workload imposed in such situations.

2.3.3 Patterns of eye movements

The eye movement patterns become slightly more complex when the driver is required to negotiate a curve- Drivers generally adjust their fixation locations to maximize their sight distance and provide inform-nation about the future curvature of the road (M. &. Helander).In many cases this means focusing on the tangent point by the driver's line of sight ahead to the inside of the curve (M. &. Land), though information about lane position from closer to the vehicle's current position also seems to be necessary for accurate curve following (M. &. Land). Once again it should be noted that although extended fixations on the tangent point are frequently observed, these may be optional strategies adopted in workload situations, a possibility which is supported by large individual differences in the number of off—road features which drivers choose to fixate (M. &. Land).

The above patterns of eye movements may be to some degree simply determined by the nature of the visual scene rather than representing some complex learned ways of information acquisition. As the above-mentioned work sounded interesting it was one of main reasons for the performance of our work on field to have an actual traffic experience and understand the nature of the drivers (especially young ones in our case but with a reasonable level of experience in driving).

2.3.4 Benefits of recording eye movements

Eye movement recording and analysis provide important techniques for understanding the nature of the drivers performing the driving task and are important for developing driver training strategies and accident countermeasures. Moreover, it is difficult to generalize from existing research to the kinds of dangerous situations which actually cause road accidents. The study reported here records the eye movements of relatively large groups of both novice and experienced drivers while watching videos of dangerous situations. Records of visual behavior can thus be aggregated over groups of drivers watching identical situations. The largest overall difference between the groups was that novices had generally longer fixation durations than experienced drivers. It is argued that this reflects the additional time required by novices to process information in the visual scene. To fully understand the subtlety of such

data, and to draw realistic conclusions about the cognitive process underlying observable behavior, it is necessary to develop a detailed understanding of the moment by moment 'syntax' of driving situations as commonly known as ‘frame by frame’ in our case.
An advice provided by six American driver education publications revived by Zwahlen (1993); raises a number of practical and theoretical questions, for example

(i) is there good experimental evidence to support the general patterns of differences between novice and experienced drivers which they describe'?
(ii) are differences between drivers consistent across all types of road environment, or do they depend on the precise characteristics of the ongoing situation?
(iii) are these differences present only in the earliest stages of learning to drive, or may they also be related to differences in accident liability later in one's driving career?
(iv) how can we define a ' 'point of interest" or ' 'areas of risk" in everyday driving situations?

Eye Tracking consists of a technique that records dilatation and contraction of the pupils, realizing an effective ocular tracing that defines the entire path performed by the eye during viewing.
It is born for clinical purposes, with the aim of understanding how the mechanisms of vision work human identify what you are looking at any time or with what level of attention, through the registration of the dilatation and contraction of the pupils. When you look in fact, the eyes move at least 3 or 4 times per second, following an order apparently random. Each move takes about a tenth of a second, while the stops, or fixations, they last from 2 to 4 tenths of a second.
The instrument that records eye movements is called the Mobile eye tracker The Infrared device is hidden inside a monitor to not disturb in any way who observes the image. The infrared rays emitted are reflected by the lens of the eye and recorded by a sensor. An integrated test model must include the realization of laboratory simulations to define comparable results in controlled contexts and to vary them possibly with reality tracking, that are methods provided in a natural context. The latter represents the Eye-tracking realized in the reality of everyday life, based on one very small camera inserted on a cap, or on special glasses.

The eye-tracking therefore allows to detect the path of visual attention for how long the user focuses a particular object on which frame of the screen passes most of time, which part confuses it or is difficult to understand, where the user expects to find certain information and insecurities and hesitations in behavior that cannot be detected they could be detected by other methods.
The driver wore glasses attached with two cameras, where one camera was to record the view forward and had the field of view rotated with driver's head since it was fixed to the glasses. The other camera whereas was to measure the foveal direction by determining pupil's position with respect to head co-ordinates.

2.4. Reaction time of the driver

Reaction delay is a common characteristic of humans in operation and control, such as driving a car. The operational coefficients and delay characteristic of humans can vary rapidly due to changes in factors such as task demands, motivation, workload, and fatigue(Boer). However, estimation of these variations is almost impossible in the classic paradigms. Therefore, an assumption of a fixed reaction delay in a certain regime still cannot be completely circumvented. Driver reaction time was defined as the summation of perception time and foot movement time by earlier car-following research.
In psychological studies the estimation of Driver Reaction Time from Car-Following Data Application in Evaluation of General Motor–Type Model Xiaoliang Ma and Ingmar Andréasson studies, the driver reaction process is further represented in four states perception, recognition, decision, and physical response. In microscopic traffic simulation, the driver and vehicle are normally modeled as an integrated unit and the delay within the mechanical system of the vehicle is often neglected. Although research on car-following models historically has focused on exploration of different modeling frameworks and variables that affect this behavior, it has been recognized that the reaction delay τn of each driver n is an indispensable factor for the identification of car-following models. It affects the traffic dynamics not only in a microscopic way but also macroscopically (Aycin). Many studies have estimated the reaction time based on indoor experiments and driving simulators. For example, in the study by Johansson and Rummer (Johansson) , more than 300 subjects were instructed to press a pedal as soon as they heard a sound. The estimated reaction time varied from 0.4 to 2.7 s, with a mean value of 1.0 s. A recent study using both a real driving

environment and a simulator (T. Magister) indicates that the reaction time of drivers to an anticipated danger in a real environment has a mean value of 0.42 s and a standard deviation of 0.14 s, whereas the mean value of the reaction time distribution to an unanticipated danger by extreme braking is about 1.1 s, and that in a simulator is about 0.9 s. In real traffic, the driver reactions to expected and unexpected stimuli are also different; Fambro et al. (Fambro) reported that the mean reaction times for unexpected and expected stimuli are 1.3 and 0.7 s, respectively. To estimate driver reaction delays from real data, several approaches have been proposed. Ozaki (Ozaki) developed a graphic method to identify the individual driver reaction time based on speed difference and acceleration profiles.Ranjitkar et al. (Ranjitkar) applied the graphic method in stability analysis of car-following behaviors and, on the basis of car-following data collected on a test track, they estimated that the average driver reaction time for individual drivers ranged from 1.27 to 1.55 s. Ahmed (Ahmed) computed the reaction time jointly with other parameters of the car-following model, and the estimated mean value of reaction times was 1.34 s. The reaction time distribution, assumed lognormal, was estimated from empirical data using the maximum-likelihood method under assumptions of a predetermined GM-type model form.

2.4.1 Reaction time for the traffic lights

The reaction time is important for the setting time on the traffic light. There are certain restrictions on red-light timing setting in the traffic intersections in every country. In Germany it is 60 seconds and Britain is 45 seconds. In China, there are certain basic principles on red-light timing setting that mainly depend on the road traffic flow index and signal cycle phase to co-ordinate the distribution of red-light timing on the road of different natures. But in most cases psychological effects of this anticipation is ignored. It is ignored what will happen when red-light turns into green, what will the driver’s reaction be? The report of the Department of transportation of China showed that 50%-80% of the urban traffic accidents occurred at intersection and out of which 30% occurred in the signal lights transition from red to green or green to red. The accident occurrence relies heavily on driver’s red-light running proneness. Another reason for behaviour of driver during the anticipation of red light to turn green could be ‘dilemma zone’. Foreign scholars believe that the formation of dilemma zone is influenced by the driver's expectations (the previous experience of red-light timing to the intersection). The researchers also find that the red-light timing too long can make the driver anxious and lead to change of driving behavior, increasing the traffic accident rate (Allos).

2.5. Surrogacy Measures

Conflict studies use to classify various locations with different safety level to identify the infrastructure liability. (F.Gharaybeh) (Al-Maita) (I.Hamarneh) There is general concern that high rates of traffic conflicts may indicate lower levels of safety for a given infrastructure, given that conflicts generally result from a lack of communication or visibility between the different users of the road (R.Risser) (J.Archer).The problem of road safety is composed of two basic pals, one is given by the frequency of conflicts, the other is the severity of conflicts that occur.

Among the surrogate measures related to the severity of the conflicts we find the Time To Collision (ITC). (C.Hyden) (J.Hayward).Some researchers have indicated that TTC is the surrogate for the security measure, while others refuse that lower TTC indicates greater severity of accidents. Firstly, because the speed is not included in the measure. (H.Kruysse) (G.Tiwari). It means that the lower the TTC certainly indicates a higher probability of collision, but it cannot be directly linked to the severity of the collision. Some research indicates the deceleration rate (DR) as a main indicator of gravity instead of TTC. (N.Ferguson). Other surrogate measures of the present conflicts are listed in Figure 2-6 (M.Ghaffari) (B.Allen)

For the left or right-tum conflicts events (intrusive crossover vehicle in front of traffic with the right of way), some studies report a ranking the measures mentioned above in "overall desirability" as follows (P.Songchitruksa).

1. GT.
2. PET.
3. DR.
4. ET.
5. IAPT.
6. PSD.

Surrogate Conflict Measure	Description
Gap Time (GT)	Time lapse between completion of encroachment by turning vehicle and the arrival time of crossing vehicle if they continue with same speed and path.
Encroachment Time (ET)	Time duration during which the turning vehicle infringes upon the right-of-way of through vehicle.
Deceleration Rate (DR)	Rate at which crossing vehicle must decelerate to avoid collision.
Proportion of Stopping Distance (PSD)	Ratio of distance available to maneuver to the distance remaining to the projected location of collision.
Post-Encroachment Time (PET)	Time lapse between end of encroachment of turning vehicle and the time that the through vehicle actually arrives at the potential point of collision.
Initially Attempted Post-Encroachment Time (IAPT)	Time lapse between commencement of encroachment by turning vehicle plus the expected time for the through vehicle to reach the point of collision and the completion time of encroachment by turning vehicle.
Time to Collision (TTC)	Expected time for two vehicles to collide if they remain at their present speed and on the same path.

Figure 2- 7 Surrogate safety conflict measures.

Source: (M.Ghaffari) (B.Allen)

This ranking takes account of the crash report history, relations between other measurements, the consistency over time, brake relation to the application, ease of measurement. and the application to other types of conflict. TTC is similar to GT and would be classified accordingly. The measures in Figure 2-7 are calculated for each event in conflict (as appropriate for the measurement, for example, GT does not apply to rear conflicting events). The extent of these surrogate measures must be validated from time to time depending on the type of conflict. (P.Songchitruksa)

In the data analysis we can divide two large areas, measurement and evaluation. As for the evaluation of the safety surrogate measures has been done on several occasions in the past, also using microsimulation models of conflict. Among all situations, the traffic conflict has attracted the most research attention. A major issue, and probably the most critical. is the validity of the traffic conflicts as a measure of security alternative. Security researchers have typically evaluated the validity of traffic conflicts evaluating a relationship between the crash frequencies and conflict. In some cases, the relationship was confirmed; in other cases, the estimated coefficients lacked stability, therefore they cannot be used outside of locations analyzed. The results inconsistent and the lack of confirmation of the incident-conflict relationship can be attributed to problematic assumptions of fixed and significant measurement errors crash-conflict proportionality. (F.Mannering)

Difficulty of measuring and evaluating the insecurity of a traffic system bring different implications the results of the safety evaluation are less convincing or even unreliable when the security measure may be questioned. The identification of dangerous areas cannot fad places that actually have security problems. These will in turn result in inefficient allocation of resources to improve security; thereby hindering the overall effectiveness of the safety management system.

A traffic crossing event is a crossing manoeuvre which may result in right-angle crashes. Each crossing event is associated with different degrees of hazard of a right-angle collision. To measure the degree of hazard, two potential candidates for the non-crash-based safety measure are considered (a) time-to-collision (TTC) and (b) post-encroachment time (PET). The selected measure should consider the following :

• The selected measure should correspond to the type of crashes being studied. For example, the rear-end traffic conflict is well-suited for rear-end collisions while the right-angle traffic conflict is appropriate for right-angle collisions.
• The objective measurement of the selected measure must be feasible and require minimal subjectivity.
• The selected measure should be amenable for future automation of the measurement procedure.
• The selected measure must possess the continuous characteristic, which can represent traffic events during normal traffic operations, as well as crash occurrences on the Seale scale.
• The selected measure should have a crisp boundary between mash and non-crash events.

For this reason, in this document in addition to the analysis of the behavior of cyclists we applied a safety estimation method based on the non-crash using video methodology to detect the possible intersections between cars and cyclists. (F.Mannering).

3. Methodology

3.1 Aim of study

The driver always scans the road scenario with his eyes, therefore drivers is looking for meaningful information on the road infrastructure.

In order to design safe roads becomes essential to know which elements of the road environment are more by users. The correct positioning of the cycle - pedestrian crossing along the route and, of consequently, the correct perception at a safe distance allows the driver to take the necessary precautions in case there are no pedestrians or cyclists on cycle - pedestrian crossing.

Nowadays, the road environment monitoring systems available to technicians and designers are different from the past from the man who materially counted vehicles for hours and attempted to codify the typology we have come to the modern means provided by the satellites, up to the most innovative applications that soon could lead to vehicles capable of moving in traffic without the constant help of man. To this end, Eye Tracking technologies, able to continuously track the gaze of a user driving and V - Box instruments for recording data related to the motion of a vehicle, are a very useful tool.

3.2 Participants familiarization

In such kind of studies the awareness of the participants is very important since if they have a clue that some locations are of importance (2 cross-sections in our case) they might pay much more attention to them and anyone passing from them compared to someone driving under real driving conditions. This was noticed and then verified by (W.Inman) . In this study, we took every care that participants should remain unaware about the aims of the study (i.e., investigating Bicycle safety at particular cross-sections). Participants were told that the aim of the study was to test a procedure using an eye tracking equipment and, at the end of the study, they were not allowed to speak about the experiment with the other participants that were waiting for their turn.

3.3. Mobile Eye XG (ASL) Instrumentation

The Mobile Eye (ME) is a tool designed for monitoring and tracking the human eye. It presents itself to the user as an elaborate pair of glasses and a set of other devices with which to acquire data. Its specific characteristics are the lightness of the pupil's viewer and the presence of only one cable connection that does not limit the mobility of the wearer. It uses an eye-tracking technique known as "Pupil to CR" tracing. This method uses the relationship between two characteristics of the eye, which are the pupil's black and specular reflexes from the frontal surface of the cornea (Corneal Reflections, in short CRs) for compute the look inside the scene. When the eye rotates in its orbital cavity, the pupil centre moves relative to the Spot Cluster.

Evaluating the vector between the pupil and a corneal reflection (CRs) in the Spot Cluster, the system tracking eye movement can calculate the pointing direction eye. The system is then able to relate these angles with the image of the second camera that records the external environment, the "camera scene", to compute the point look at the visual field of the latter.

It should be noted that the Mobile Eye uses inconsistent light and is not used in the Source: system of coherent light like lasers. The difference between these two types of light Source: s from the point of physical view is that the inconsistent light is polychromatic and has no phase coherence, while light coherent (laser) is monochromatic, has phase coherence, high energy density and highly directional that is, the phase of each photon is maintained in space and time (Figure 3-1).

Figure 3- 1 Radiation – Incoherent and coherent light

Source: https://physicslabs.ccnysites.cuny.edu/labs/208/208-wave-optics/wave-optics.php

One of the most complete and authoritative Source: s on the safety of light Source: s is the manual entitled Safety with Lasers and other Optical Sources, by David Sliney and Myron Wolbarsht, published for the first time in 1980 by Plenum Press. Quoting page 147 of this book "Safe chronic ocular exposure values, particularly for IR-A, probably they are on the order of 10 mW / cm2 or less ". IR-A refers to the spectral band between 760 and 1400 nanometre, the interval in which he ASL Mobile Eye Optics Modules operate (Figure 3-2).

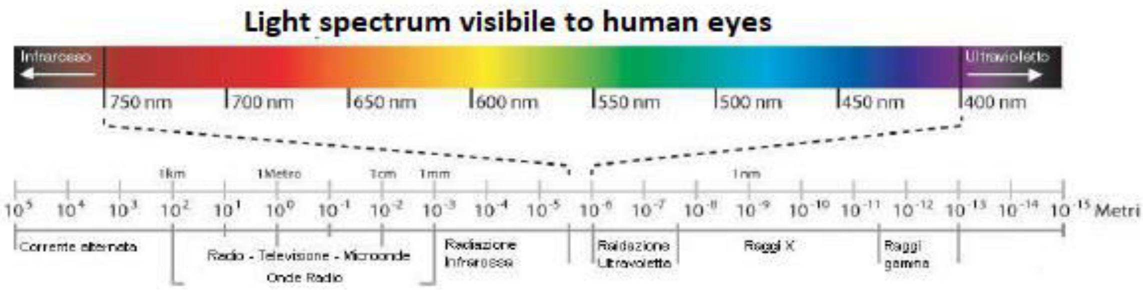

Figure 3- 2 Light spectrum visible to human eyes

Source: http//www.fmboschetto.it/lavori_studenti/tesine_17_18/Tesina_Bosello.pdf

As a precaution Mobile Eye Optics Modules operate at least one order of magnitude below this level. Their power of the LEDs used varies a bit from sample to sample. The greatest value of irradiance that can be produced with the ASL Mobile Eye Optics is 0.50 - 0.60 mW / cm2 (wavelength 880nm) in the plane of the eye.

Figure 3- 3 Mobile Eye Apparatus XG of ASL

Source: https//www.niu.edu/fvsa/brown

3.3.1. Mobile eye tracking components

• Mobile Eye XG Spectacle Mounted Unit (SMU)

Includes the eye camera, the camera scene and the hot mirror mounted on the glasses. In particular, the "Eye camera" sees the reflection of the eye from a fixed warm mirror on the lens capable of reflecting the infrared spectrum but not the visible light, so that nothing can obscure the normal field of view of the subject; the "camera scene" is turned instead directly forward (Figure 3-4).

Figure 3- 4 Mobile Eye XG Spectacle Mounted Unit

Source: https//www.niu.edu/fvsa/brown

- Display / Transmit Unit (DTU), small and therefore easily transportable (Figure 3-5);

In the DTU all the screens, which are touch screens, appear with a row of 5 buttons on the right side, with the information icons at the bottom left and with the image of one of the two cameras or the control panel in the central part. After a few seconds from the ignition, the ASL logo is replaced with the image of the camera that captures the eye or with the camera image that captures the scene. You can switch from the screen that displays the eye to the one that displays the shooting scene with the "Eye / Scene display" button located in the row of buttons on the right. The DTU allows you to work in two modes live mode and playback mode. The switching to one or the other mode is allowed by the "live / playback" button. This operation makes the DTU completely independent of the ME PC, which is very important in the phase of relief because it makes the instrumentation more versatile. In fact, with live mode you can start recording of eye and scene data by simply pressing the record button. These files are automatically named with the date and time and saved with the extension ". avm". The "playback" mode allows you to manage the files recorded in the live mode. You can access from the file button the folder that contains these files. To reproduce the desired file you simply select it by touching it on the screen and then press on the "play" icon on the left side of the screen to play it.

- Mobile Eye PC (ME PC), has the size of a normal laptop CAT cable 5 (for the connection between ME PC and DTU) (Figure 3-6);

Figure 3- 5 Mobile Eye PC

Source: https//www.niu.edu/fvsa/brown

- DTU battery and battery charger;
- Current transformer for DTU;

- Software license with a USB key to be inserted when using the Eye Vision application;
- SD card;
- Containers.

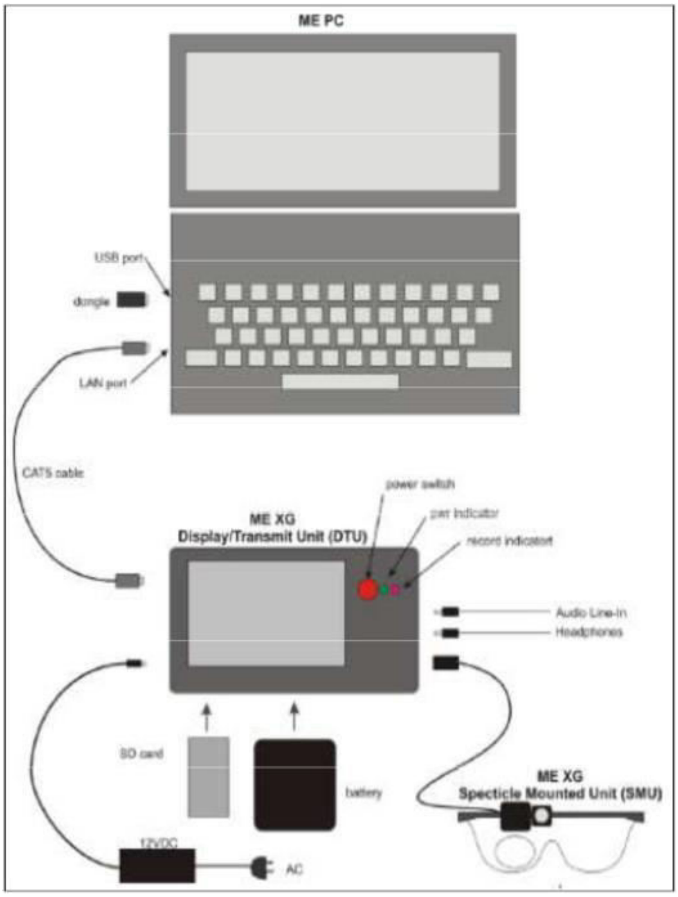

Figure 3- 6 Inter-connection between components

Source: https//www.niu.edu/fvsa/brown

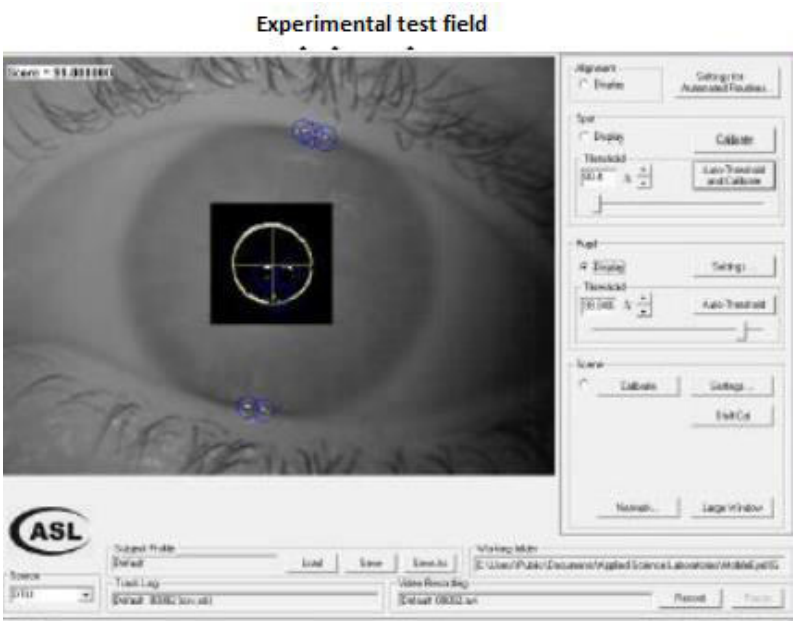

Figure 3- 7 Pupil during the calibration phase

Source: https//www.niu.edu/fvsa/brown

3.3.2. Eye Tracking calibration and recording

3.3.2.1. Recording the image of the eye and scene image

- make sure that the battery of the ME XG DTU is charged and that the SD card is installed;
- connect the ME Optics optical unit to the DTU;

Use the Eye / Scene display button to view the image taken by the camera of the eye and then, with the help of this image, adjust the camera, together with the monocular lens, to obtain a correct image eye.

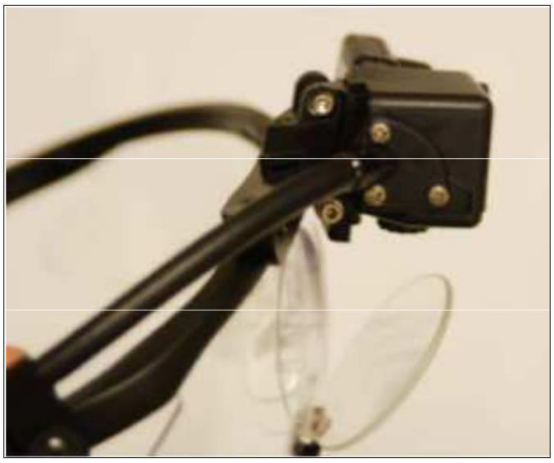

Figure 3- 8 ME Optics (SMU)

Source: https//www.niu.edu/fvsa/brown

The adjustment of the glasses (Figure above) on the user to align the image of the eye on the monitor it follows the following steps

- raise the monocular lens;
- rotate the monocular lens;
- move it until the three reflected points become visible;

A scene camera adjustment is also performed to obtain the scene image desired, after pressing the Eye / Scene display button to view the image of the scene on the screen. At this point we can continue with the following operations:

Start recording the files of the eye and scene image by tapping the record button. During recording, the record button changes to become the stop button. Make the display shows the image scene so that you can check the phase of the recording in which the subject looks at several points that affect the whole field visual of the camera of the scene; these must be easily identifiable in the scene image (it is advisable to mark them on a sheet) because they will be used for the calibration during the playback phase. The subject who undergoes the experiment can start the test. When the proof is complete, press the stop button to finish the recording.

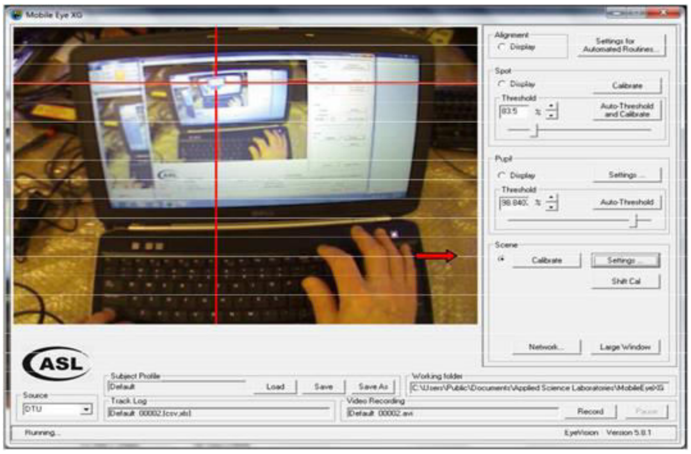

Figure 3- 9 Calibration screen of the eye tracker ASL

Source: https//www.niu.edu/fvsa/brown

3.3.2.2 Reproduction of the recording of the eye image and scene image

First connect the DTU with ME PC using the CAT5 cable or via Wi-Fi connection. Also make sure that the key that provides the license of the ASL is inserted into the USB port of the ME PC. After opening the Eye Vision application on the ME PC, the folder containing the recorded files opens. select the file desired and pressing the play button starts playing the video. In this way the video with the images of the eye and the scene appears in the Eye Vision program, in the same way that happens when, being the DTU connected to the ME PC, the software Eye Vision receives live video. In the previous point, the phase was described, during the recording, in which the subject looked at easily identifiable points. This phase is essential because it allows you to perform the calibration procedure with your Eye Vision on the video section where you looked at the points. Once this has been performed, it will be valid for all the video performed by the subject during the test. The operation of calibration will be described in the next paragraph "Eye vision processing software". Recorded videos can be paused, forwarded or backward with the commands present on the DTU screen. Finally, if desired, the Eye Vison program, imported the files, can provide the data look and the relative video respectively in the formats ".csv" and ".avi". This procedure will be explained later.

3.3.2.3 Copy recorded video of the eye

The SD card of the DTU can be inserted directly into the ME PC, just like any other mass storage device. The files can be copied to your computer. At this point you can import one of these files into the Eye Vision program by changing the Source: from DTU to File in the "Source: " dropdown menu. Another way to proceed is to record the videos of the eye and the scene directly on the ME PC using Eye Vision. To do this the DTU and the ME PC must be connected via Wi-Fi or CAT5 cable.

3.3.2.4. Compute the gaze in real time

Connect the DTU to the ME PC (in live mode), with the use of the Eye Vision program possible, for each user, to correctly recognize the pupil and the reflections of the cornea and calibrate the subject in real time. This operation has the advantage of avoiding the section of video during the recording in which they looked at the remarkable points, indispensable for the calibration.

3.4. The V-Box instrumentation (Vehicle Trajectory)

The V-Box equipment is used to record data relating to the motion of a vehicle during a certain route. The data provided by the instrument are vehicle speed, accelerations transversal and longitudinal and tracking of the position in a possible predefined path. To test the sample data, the vehicle to be tested must be equipped with a device the video, the Video V-Box Pro, which combines a powerful GPS with a high multi-camera quality, consisting of two coupled cameras working in synchronization with each other.

Figure 3- 10 Video VBox Pro

Source: http//www.dragtimes.com/parts/Racelogic-VBOX-Video-HD2-2-Camera-System-VBOX-Video-HD2-10Hz-GPS-data-logger_112503961047.html

Features

- Dual Camera 1080p system
- Recording of GPS data at 10 Hz

- Record on SD or USB card
- Predictive lap time (with OLED display)
- High definition real-time graphic overlay
- Video and MP4 audio recording
- Internal power backup for reliable recording
- Powerful data analysis software
- Up to 32 channel CAN inputs
- USB 2.0 host interface (for recording on USB flash drive)
- Camera preview via Wi-Fi
- Bluetooth LE connectivity

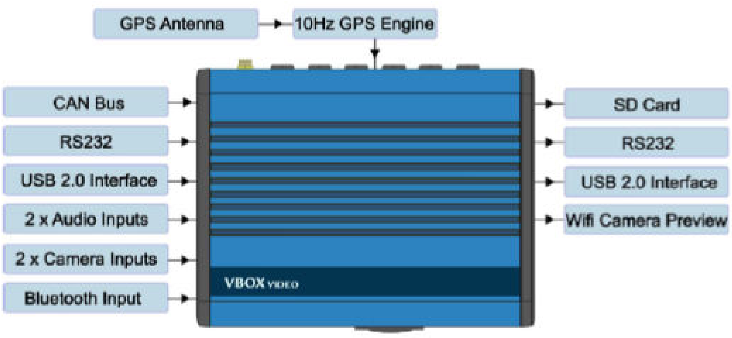

Figure 3- 11 Video interface V-Box Pro and input and output related parameters

Source: http//www.dragtimes.com/parts/Racelogic-VBOX-Video-HD2-2-Camera-System-VBOX-Video-HD2-10Hz-GPS-data-logger_112503961047.html

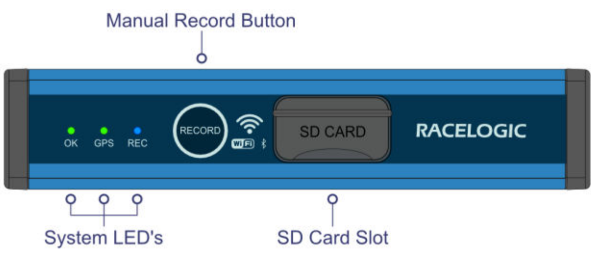

Figure 3- 12 V-Box Interior panel

Source: http//www.dragtimes.com/parts/Racelogic-VBOX-Video-HD2-2-Camera-System-VBOX-Video-HD2-10Hz-GPS-data-logger_112503961047.html

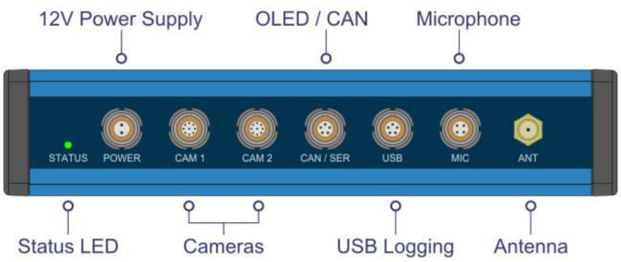

Figure 3- 13 V-Box Exterior panel

Source: http//www.dragtimes.com/parts/Racelogic-VBOX-Video-HD2-2-Camera-System-VBOX-Video-HD2-10Hz-GPS-data-logger_112503961047.html

VBOX Video HD2 is designed to disperse heat from internal components through the lid of the box so that the unit will become warm to the touch during the execution. The enclosure is designed to use the airflow to cool the unit, therefore make sure that the top of the HD2 is left open to air. If VBOX Video HD2 is used in extreme environmental conditions (temperature of the cab above 50 ° C), the Harsh room fan accessory can be used to reducing the temperature of the unit. If the HD2 is used in combination with a radio communication system of the driver, make sure there is a minimum separation distance of 20 cm between the system radio and camera units and cables to avoid any interference problems video.

3.4.1. Installation of the V-Box system

1. Mount the GPS antenna in the middle of the vehicle roof, away from roof rails and other Antennas.
2. Connect the GPS antenna to VBOX Video HD2.
3. Attach one of the cameras to the windshield using the camera holder facing in forward. Maintain the level of the camera is making sure that 'Race logic' is facing towards the high.
4. Connect this camera to "CAM1”.
5. Connect the second camera to the window or the desired mounting position.
6. Connect this camera to "CAM2”.
7. Connect the microphone to the "MIC" input.
8. Connect the power supply via the "POWER" socket; the HD2 takes about 45 seconds to start completely

9. Insert the SD card into the SD card slot - the OK LED should be solid green meaning a scene file has been saved on the card, the scene will be loaded on the unit.
10. Open the VBOX camera preview software on your computer and adjust
11. the setting of the two positions of the camera.

3.4.2. Available parameters from the V-Box system

The analysis and subsequent processing of the data detected by the Video VBox device Pro are performed using the appropriate Performance Tools software, which allows you to process the information collected by examining the parameters of interest and monitoring, at the same time, the video recorded during the test. The program interface provides, in addition to the video and the graph previously mentioned, also the map of the track route and selection of available parameters.

- Distance [m];
- Time [sec];
- Speed [km / h];
- Lateral acceleration [g];
- Longitudinal Acceleration [g];
- Direction [degrees];
- Height [m];
- Relative height [m];
- Vertical speed [km / h];
- Satellites [n °];
- Latitude [first];
- Longitude [first];
- UTC time;
- Bending radius [m];
- Deviation from the central line [m];

The interesting data can then be exported in Excel format so you can have it for subsequent reprocessing. The objective measurement of the selected measure must be feasible and require minimal subjectivity.

3.5. Synchronization

We had to perform firstly the synchronization between the UTC time of V-Box with instants of Mobile eye as the time in M.E was in seconds and in V-Box in UTC. For example to convert a UTC time when driver looks at the signal, we performed following calculations. We multiplied 5 by 60 then adding 3 with the result and after the decimal point the last number was added which is 30 so in this way we get the result 303.30 in seconds and utilize this time to look at the exact time where same actions were performed by the drivers (both in V-Box and M.E) the UTC time converted could be found in Figure 3-15 (highlighted with red rectangle).

3.6. Driver performance measure and surrogacy measures

3.6.1. REACTION TIME

Reaction time is an important measure in understanding the behaviour of a driver in the conflict situation with a cyclist at crossing. The reaction time in other scenario's has been investigated in order to evaluate the result of the more hazardous situation (bike crossing), with a reaction time for the traffic light.

We have conducted as a part of this research the determination of driver's behaviour at three different scenarios namely

- Reaction time between traffic signal getting red and application of brakes.
- Reaction time between traffic signal turned green and application of accelerator.
- Reaction time between Driver's visualization of cyclist and application of brakes.

3.6.1.1. Reaction time between traffic signal getting red and application of brakes.

Figure 3- 14 Visualization of Signal getting red by M.E tracking and V-Box

Although both of the above figures are taken from the video files of two different users but its just to explain how we determined the values of reaction time when signal gets red and driver start applying brakes as could be seen in figure 3-14 as before application of brakes the speed was 19 Km/h. Moreover the work performed on excel at the instant of Figure 3-15 could be seen highlighted with a red rectangle in the figure below showing what things we accounted for and determined in our work to calculate the reaction time for this first scenario.

	REFRENCE				
driver looks at the signal(red) in seconds		160.26		303.3	
driver looks at the signal(red)	ME	02:40.26	7527	05:03.30	11810
driver looks at the signal UTC	VBOX(UTC)	09:27:23.80		09:29:46.90	
driver starts applying brakes	VBOX(UTC)	09:27:27.26		09:29:48.00	
driver stops applying brakes	VBOX(UTC)	09:27:32.10		09:29:52.67	
Reaction time(when signal turns red and driver brakes)	VBOX(UTC)	00:00:03.46		00:00:01.10	
driver pushes the accelerator	VBOX(UTC)	09:27:48.26		09:30:04.43	
waiting time	VBOX(UTC)	00:00:16.16		00:00:11.76	
Signal turns green	VBOX(UTC)	09:27:46.63		09:30:00.20	
Reaction time(when signal gets green and driver accelerates)	VBOX(UTC)	00:00:01.63		00:00:04.23	

Figure 3- 15 Determination of Reaction time red through excel

3.6.1.2. Reaction time between signal opens(turned green) and application of accelerator.

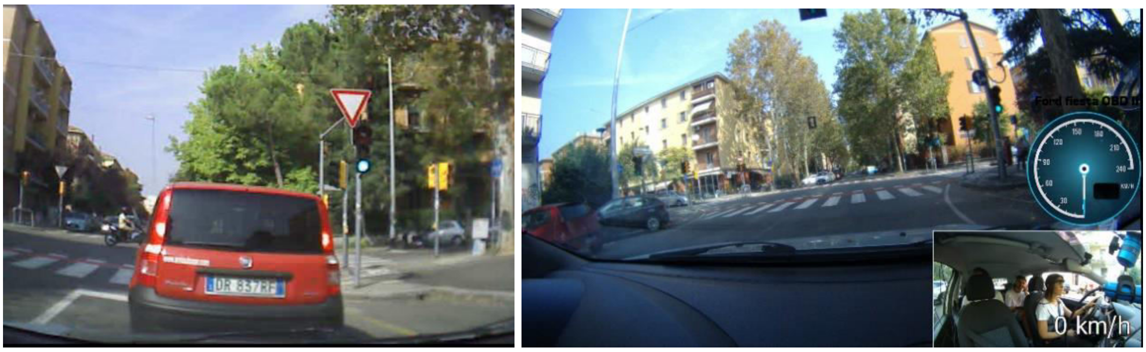

Figure 3- 16 Visualization of Signal getting green by M.E tracking

The Figure above is the screenshot of the 2nd scenario when the signal opens and the driver starts to accelerate the car. The same synchronization was done to determine the reaction time of 2nd scenario.

3-Reaction time between Driver's visualization of cyclist and halting of the car

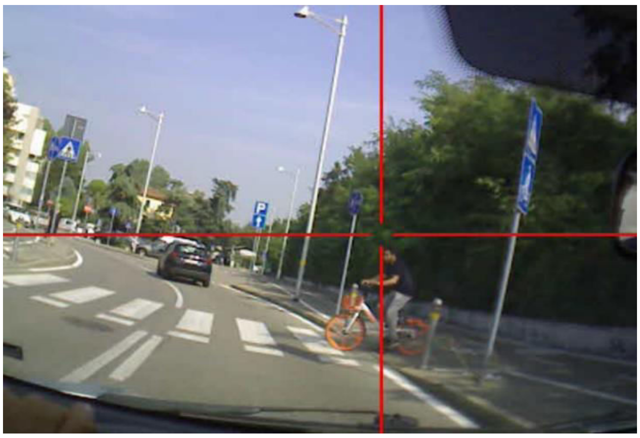

Figure 3- 17 Visualization of cyclist by M.E device

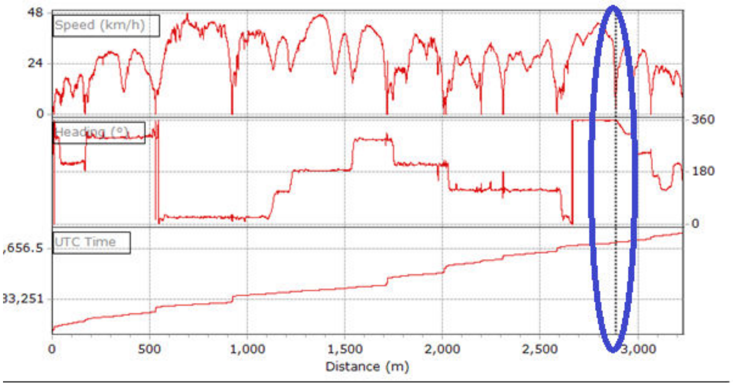

Figure 3- 18 Noticing the brake application from V-Box instrumentation

Reaction time in this case was determined by first using the M.E videos to understand when the visualization of our driver is fixed on the cyclist demonstrating that he / she has noticed the presence of the cyclist as could be seen in figure? and subtracting this time with the time of the instant at which he / she started applying brakes as can be seen in Figure 3-18 that speed is almost near to 0 when driver sees the cyclist.

3.6.2. Post Encroachment Time (PET)

This section introduces the basic concepts of the proposed method including the risk of an accident, and the crash rate. it applies here to vehicles moving along paths that intersect at a point of conflict. As long as vehicles of different paths pass place conflict at considerable distance from one another, the steps may be considered safe. On the other hand, a snail moment of separation between the vehicles indicates a less safe passage. In a small but negative value of the time of separation, the two vehicles collide. The continuum of traffic events is mapped on the separation continuum of time, it referred to as a post Encroachment time (PET) in this study. The post encroachment time here, or any other characteristic selected traffic event, must have values in crash situations and without incident.

Different crash types require different proximity accident measures. The right-angle collision has been considered here since the travel routes can be easily defined for the vehicle before the collision and after the collision at the intersections. Collisions have been classified with angles of intersection by two main types:

(1) straight and at a right-angle crash

(2) turn to the left that has an intersection at a right angle.

However in our study the focus was on the first type of collision since the driver is going straight and collision could occur since our cyclist is arriving from the right-angle of the driver's direction.

The proximity of the right-angle collisions between two vehicles is measured with the post Encroachment time. PET is the time that elapses between the time t1 , when the Fast vehicle leaves the place of conflict and the time t2 when the second vehicle enters the point of conflict. The positions of the two vehicles at t1 and t2 are presented in Figure 3-19 where PET is determined by t2 – t1, however in our case t1 was of the bicycle and not of the car as shown in Figure 3-19. The smallest PET value implies a higher collision proximity. According to the literature, a PET less than two seconds represents conflicts with a risk of collision and an interaction between road users (Tang, Implementing the Concept of Critical Post-Encroachment Time for All-Red Clearance Interval Design at Signalized Intersections). Also a value of PET of zero or less would indicate a crash event. (Songchitruksa)

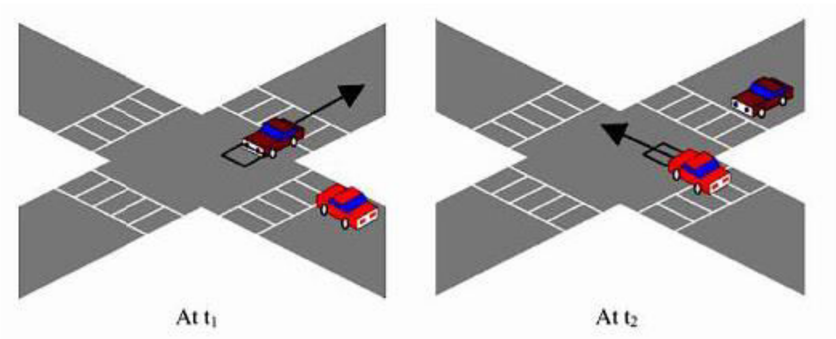

Figure 3- 19 Illustration of PET evaluation

Source: (P.Songchitruksa)

According to mentioned studies the PET indicator is the most promising among the other surrogacy measurement tools in the literature, for its relative ease of measurement and the safety implication.

During the analysation of the videos to determine PET 2 cases were found and are mentioned below

Case 1-Bicyclist arrives when the centre of the vehicle is in the centre of the potential area of collision.

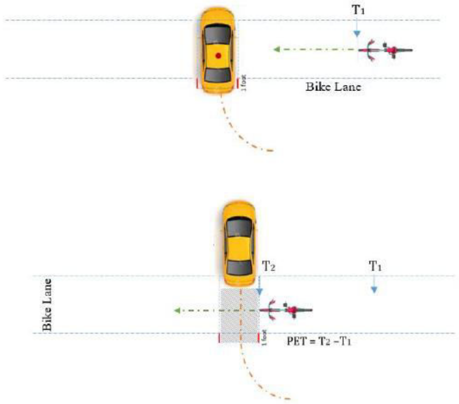

Figure 3- 20 Bicyclist arrives at conflict area after vehicle occupation of conflict area (Case I).

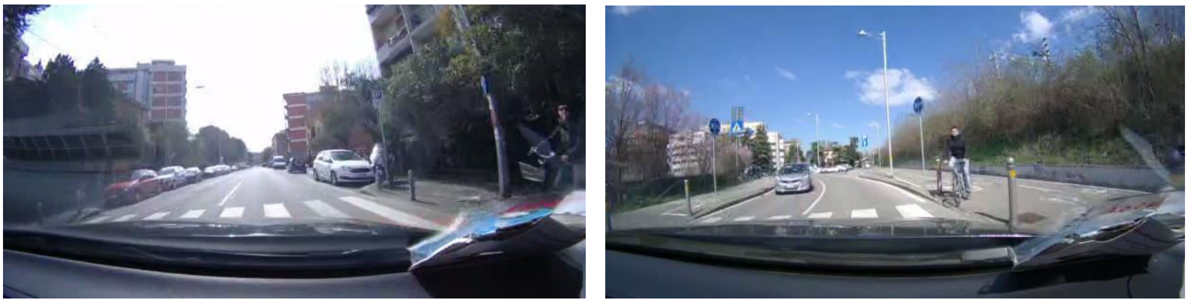

Figure 3- 221 Case I observed on both the cross-sections.

Case 2- Both the bicycle and vehicle arrive at the same time although the driver applied brakes and stopped. This is the most dangerous case as not stopping of both parties can probably lead to a collision.

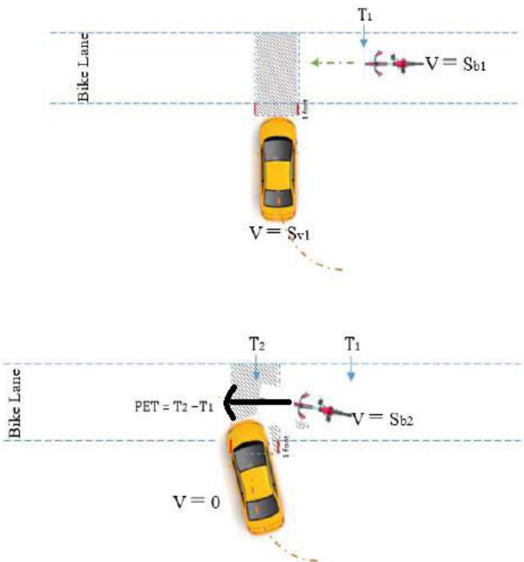

Figure 3- 22 Motorist stops giving way to bicyclist (Case II).

Figure 3- 23 Case II observed on both the cross-sections.

Frequency of PETs is a key factor in determining the expected number of right-angle collisions and different safety levels across locations. In this research however, we haven't focused too much in differentiating between both types of PETs. We used the Circuit tools in order to measure PETs as it was necessary to estimate for all the 19 users and understand if both of the cross-sections considered under our study are safe for the bicyclists or not.

For the determination of PET we had to carefully analyse the videos of V-box synchronized with M.E videos. For determination of PET we had to subtract T2 by t1 where

- t1 = cyclist arrives on cross-section
- t2 = cyclist leaves on cross-section
- T1 = Driver entering the cross-section
- T2 = Driver leaves the cross-section

Via Azzura with cyclist					
Users	**PET**	**t1**	**t2**	**T1**	**T2**
user1					
user2	6.16	143238.64	143242.9	143243.2	143244.8
user3	1.82	110629.48	/	110630.5	110631.3
user4	9.78	145813.41	145820.4	145821.3	145823.2
user5	2.99	151615.81	/	151617.2	151618.8
user6	8.24	134348.19	134354.4	134354.2	134356.4
user7	1.63	140145.57	/	140146.2	140147.2
user8	1.97	114130.83	/	114131.5	114132.8
user9	5.64	131426.26	/	131430.2	131431.9
user10	8.19	102405.19	102411.1	102410.4	102413.4
user11	6.43	81322.79	81327.62	81327.97	81329.22
user12	1.53	84238.47	/	84239	84240
user13	7.17	91530.82	91536.87	91537.26	91537.99
user14	9.18	92909.12	92916.65	92916.8	92918.3
user15	7.69	94935.91	94941.87	94942.4	94943.6
user16	1.46	110305.94	/	110306.9	110307.4
user17	0.46	123613.76	/	123614	123614.2
user18	1.18	131908.82	/	131909.1	131910
user19	6.87	140026.83	140032.3	140031.7	140033.7

Figure 3- 24 Determination of PET through excel

3.6.3. Time to Collision (TTC)

Time-To-Collision (TTC)— is the time required for two vehicles to collide if they continue at their present speed and on the same path. The lower the TTC, the higher the collision probability will be. A minimum TTC during an interaction (TTCmin) of 1.5 s or less is considered as critical.

A conflict between a car and cyclists may entail much more serious consequences than a conflict between two cyclists, considered their relative vulnerability and speed. On the other hand if a cyclist has a conflict with a car that drives <20 km/h, consequences might again be relatively less serious. In Table 1 an overview is provided of what and how the different elements define the seriousness level of conflict. In this study, interaction with TTC inferior to 1.5 s at least at one instant were marked as "critical". In Table 3.1 an overview is provided of what and how the different elements define the seriousness level of a conflict. Never-the-less, the technique contains a subjective component, since the observer always has also to take into account the behaviour of the road-users (do they for example undertake a controlled or uncontrolled evasive action) and extent of the consequences if a collision had taken place

(Laureshyn)

Seriousness of injury	Probability of collision					
	TTC_{min}, sec.					
	no TTC	>2	2–1.5	1.5–1	1.0–0.5	0.5–0
very small	X	X	X	1	1	2
small	X	X	1	2	2/3	3
fairly large	X	1	2	2/3	3	4
large	1	2	2/3	3	4	5

Table 3- 1 Overall severity of a conflict

Although the V-box provided us with a whole data of the test drives taken place for all the users, but we had to utilize only the data 150 meters before the cross-section since it was important for our work and utilizing this helped us in determining all the time to collisions 150m before cross-section.

		Via Azzura							
User 11	UTC TIME	PET[s]	T1(150m)	V(150m) in km/h	V(150m) in m/s	Distance		TTC	MIN TTC
cyclist enters the cycle path(t1)	81322.79	6.43	81311.8	39.625	10.976125	5625.04	150.06	13.67149	3.010677087
cyclist goes out of the cycle path(t2)	81327.62		81311.9	39.751	11.011027	5626.15	148.95	13.52735	
vehicle enters the cycle path**(T1)**	81327.97		81312	40.043	11.091911	5627.25	147.85	13.32953	
vehicle goes out the cycle path**(T2)**	81329.22		81312.1	39.87	11.04399	5628.36	146.74	13.28686	
Note:			81312.2	39.852	11.039004	5629.47	145.63	13.19231	
			81312.3	39.978	11.073906	5630.58	144.52	13.0505	
			81312.4	40.295	11.161715	5631.69	143.41	12.84838	
			81312.5	40.176	11.128752	5632.81	142.29	12.7858	
			81312.6	40.352	11.177504	5633.93	141.17	12.62983	
			81312.7	40.626	11.253402	5635.06	140.04	12.44424	
			81312.8	40.734	11.283318	5636.19	138.91	12.3111	

Figure 3- 25 Determination of TTC through excel at Via Azzurra

The figure 3-25 showed the sheet of the excel file made for one user for determination of TTC at cross-section at Via Azzurra similarly there were numerous files made for other users and utilized to determine the time to collision at the before mentioned distance from the cross-section on both the streets. Through this TTC we determine the minimum TTC which had the highest level of risk in comparison to other TTCs found out, and also, we determine the corresponding data (min distance and min velocity at min TTC) as could be seen in Figure 3-26.

Via Azzura with cyclist				
Users	Min TTC	Corresponding distance (m)	Corresponding Velocity (km/h	Corresponding time
user1				
user2	2.10	7.97	16.78	143237,80
user3	1.39	15.82	21.96	110629,70
user4	6.16	9.35	57.59	145815,20
user5	2.19	10.52	23.05	151615,50
user6	2.98	3.22	9.60	134354,40
user7	1.57	9.59	15.03	140145,60
user8	2.37	15.05	35.72	114129,80
user9	3.71	10.46	38.75	131426.3
user10	3.50	7.29	25.53	102405,00
user11	3.01	20.04	6.66	81323.9
user12	1.97	17.20	8.74	84238
user13	1.31	7.24	5.52	9153690
user14	3.67	31.31	8.53	92910.1
user15	2.89	27.11	9.38	94936.3
user16	2.13	22.21	10.44	110305.7
user17	1.12	9.43	8.42	123848.3
user18	1.40	7.39	5.26	131908.7
user19	1.96	14.93	7.63	140027

Figure 3- 26 Determination of min TTC through excel at Via Azzurra

4. Experimentation

The aim of the experimentation is to analyse the vehicle - cyclist interaction comparing two different types of cycle - pedestrian crossings and searching for one correlation between the location of the intersections and the behaviour of the users driving the vehicles. As confirmed in the "Guidelines for the management of infrastructure road security " the incidental event is not always directly related to shortcomings in infrastructure. It is, therefore, necessary to analyse the road system as a whole through an analysis of the relationships existing between the different elements of the system itself, that is "man - vehicle - environment - infrastructure", in order to correctly assess the causes. Man holds a central role in the system as it is the only element that can adapt the its own behaviour to that of the other elements and for this reason it often represents, with his incorrect conduct, the main cause of the incidental event. The correct one perception on the part of man of the information, geometric and managerial, of the infrastructure road is of great importance in the incidental phenomenon man must adapt his behaviour, in a given infrastructure, depending on the vehicle being driven and the conditions of environmental aspects in which the infrastructure is inserted. Each of the participants guided the entire track under analysis, wearing the Mobile Eye XG Eye Tracking instrumentation capable of tracking the eye and its movements and to record these and the external environment. The used car has been equipped with V-box instrumentation supplied by the DICAM-Road Department of the University of Bologna, fundamental for data acquisition and able to detect accelerations, the speed and position (coordinates provided by the GPS) of the vehicle.

The average time in which the distance was covered was 20 minutes. The mean speed of all participants was 18.44 Km/h. Mean maximum speed was 67.51 Km/h. The experiment carried out between hours 8 to 10 and between 12.00 to 14.00 to avoid peak rush hours and the weather condition was mildly cloudy or sunny during all the sessions.

4.1. Participants

Nineteen participants participated in the experiment, including nine men and ten women, with the age between 20 and 40 years. The relevant group has always been composed of members of the DICAM Road Department, with the task of coordinating the test and checking the correct use of the instrumentation.

The participants were asked to drive for the entire route being analysed, wearing the Mobile Eye instrumentation for the duration of the test detect the tracking of the human eye viewing point.

Following are the 19 users submitted to the trial; to each of them, at the beginning of the driving test, a questionnaire was completed with the relevant data, showing

- sex and age;
- category of driving license;
- usual scope of driving;
- usual scope of driving;
- driving frequency;
- claims made and / or suffered.

The questionnaire is of fundamental importance for analysing and understanding how the differences in age, sex and previous knowledge of the route can influence the vision of the signage from part of users. The 19 randomly selected subjects (Table 4.1) were completely unaware of the desired objective pursuing, they had never experienced the Mobile Eye equipment. They also have declared to have never travelled the route in question, another important factor to evaluate the actual reaction to the first vision of the urban and extra-urban framework.

Participants	19
Gender	9 M & 10 F
Age	20-40
Duration	20-30 min
Driving license's category	B
Section of license	Urban

Table 4- 1 Information about experiment conducted

4.2. Vehicles used for experimentation

The car used for testing is a Ford Fiesta series with petrol and manual transmission. (Figure 4.1) this choice is been operated to avoid excessive confidence with the means that could infect the visual perception data that, instead, have an important value for the case study.

Figure 4- 1 Test vehicle ford fiesta

Instrumentation For each survey session conducted, the car used was suitably equipped with the V-Box instrumentation with the task of detecting speed, acceleration and position data of the vehicle (coordinates provided by the GPS). In particular, above the roof of the vehicle, at the edge of the upper part of the windscreen, the two cameras have been positioned (Figure 4.2), equipped with appropriate suction cups for a correct fixing and positioning, while inside the vehicle was housed the GPS.

Figure 4- 2 V-box camera

In addition to the V-Box with which the test vehicle was equipped, the experimentation has foreseen the use of the Mobile Eye Detector instrumentation. Each participant was asked to wear the eyewear necessary for tracking the human eye for the duration of the test, which preliminarily requires an accurate calibration procedure on the individual subject.

First of all, each participant was asked to position himself comfortably within the car, to adjust the seat and the mirrors to their liking and to wear the glasses for to proceed with the calibration.

The calibration procedure described earlier in more detail, provided that the Participant, at the request of the operator, should have a look at specific points inside of the visual field. The operator, equally seated inside the vehicle, tried to select the points, from time to time required to fix to the subject, on the computer screen. When the cursor turns green, there is a coincidence between the point viewed and the selected one therefore, it is considered valid by the operator and it is possible to proceed with the calibration of other points. There procedure is considered completed only with the calibration of at least a dozen points arranged in homogeneous manner within the visual field (Figure 4.3).

Once the calibration has been completed ME and the V-Box for each participant, the driving test was started on the section under examination

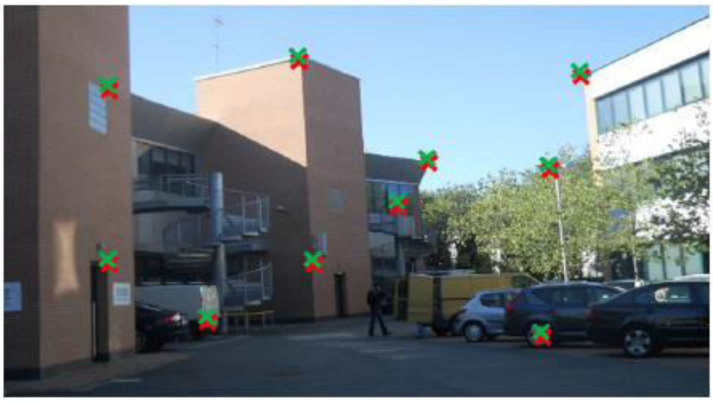

Figure 4- 3 Points calibrated correctly

The impact of the Mobile Eye Detector equipment on pilots was very good the subjects they found the instrumentation a little heavier than a regular pair of glasses. Moreover, the tool allows full mobility of the head and observation of points not strictly relevant to the route, such as the panorama or the odometer. It is necessary to specify that the eyewear Mobile Eye provides reliable results only if worn by users without vision correction devices (eyeglasses, contact lenses).

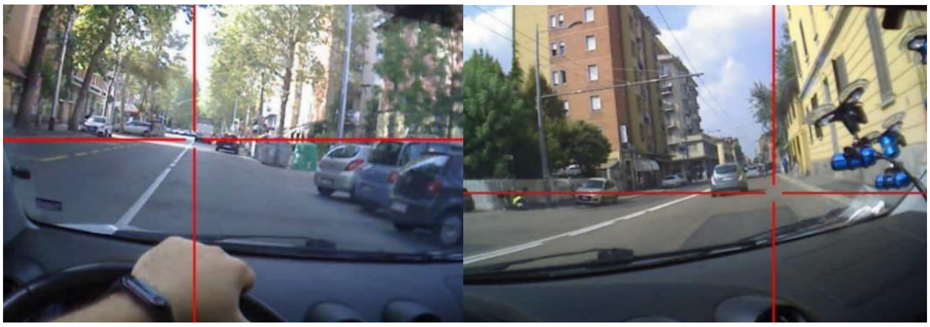

Figure 4- 4 Examples of frames in which the driver exploits full mobility allowed by the tool

4.3. The test circuit

The area under study (Figure 4.5) is located in the southeast area of Bologna, not far away from the Sant'Orsola - Malpighi Hospital. and includes Via Mazzini, from which it began experimentation starting from the parking lot of the shopping centre located in the street, Via Pietro Menegoli. In particular, two pedestrian crossings were analysed, respectively in Via Azzurra and Via Pietro Mainoldi, diversified by geometric characteristics, street furniture and colour of the flooring. Each user has completed two laps of the entire circuit in order to evaluate the circuit behaviour due to the presence or absence of a cyclist arriving at the crossing

pedestrian.

1) cycle / pedestrian crossing located in Via Azzurra

2) cycle / pedestrian crossing located in Via Mainoldi

Figure 4- 5 Circuit considered for the experiment

Source: Google maps

4.3.1. Cycle and pedestrian crossing at Via Azzurra

Figure 4- 6 Cycle-Pedestrian crossing at Via Azzurra

Via Azzurra features

Element of the crossing	Presence/properties
Width of the crossing	5.80 m
Length	8.00 m
Pavement colour	Red
Width of the access to crossing	2.45 m
Presence of signaling system	No
Presence of portal	Yes
Presence of pedestrian path	Yes
Presence of cycle path	Yes
Type of cycle path	Cycle path combined with pedestrian path

Table 4- 2 Characteristics of Via Azzura

4.3.2. Cycle and pedestrian crossing in Via Pietro Mainoldi

Figure 4- 7 Cycle-Pedestrian crossing at Via Mainoldi

Via Mainoldi features

Element of the crossing	Presence/properties
Width of the crossing	4.50 m
Length	6.00 m
Pavement colour	Black
Width of the access to crossing	5.16 m
Presence of signaling system	No
Presence of portal	No
Presence of pedestrian path	Yes
Presence of cycle path	Yes
Type of cycle path	Cycle path combined with pedestrian path

Table 4- 3 Characteristics of Via Mainoldi

4.3.3. Main Differences between Cycle and pedestrian crossing in Via Azzurra & Via Mainoldi

Figure 4- 8 Differences between crossings at Via Azzurra & Via Mainoldi respectively

Crossing at Via Azzurra	Crossing at Via Mainoldi
1-portal	1-Non-coloured cycle path
2-bicycle crossing colored in red	2-horizontal bicycle crossing
3-horizontal bicycle crossing	

Table 4- 4 Differences based on the numbers in s above

As could be analysed from the figure above that there was a portal provided on Via Azzurra whereas Via Mainoldi was kept deficient from it. The other two differences found between these cross-sections were that the bicycle path at Via Azzurra was coloured in red but at Mainoldi there was no colour on the bicycle path and also cycle path of Via Mainoldi was not that noticeable with respect to geometrical characteristics as well.

4.4. Stages of data collection

Once the V-BOX instrumentation was mounted on the car, each participant was asked to wear the Mobile- Eye. When the participant has positioned himself comfortably inside the car, he can proceed with the calibration of the glasses, which consists in making the subject look different points within the visual field on which you will have to fix your gaze; at the same time the operator must select the same point on the screen. The cursor on the point will become green when there will be a coincidence between the element watched by the participant and the clicked one operator. At the calibration performed, the driving test on the section under study started by starting the recording of the ME and the V-BOX. The departure took place about 1 km before the start of the infrastructure under analysis and continued for the same distance after the end of the section; allowing the participant to get used to driving with the equipment being used for the test.

4.5. Analysis of the data collected from the experimentation

At the end of the experimentation, the data obtained from the test was collected by the V-box and the Mobile Eye Detector, have been appropriately processed and analysed. The data collected by the V-Box (speed, acceleration, latitude-longitude, etc.) during the 19 driving tests conducted for the experimentation were analysed using the Circuit Tool software (Figure 4.9) the latter allows to diagram on a Cartesian plane, in function or of the time or space, one or more parameters chosen from those recorded by the instrument

Figure 4- 9 Screenshot of Circuit tools

The program screen also includes the video recorded by the two cameras above to the vehicle. The kinematic data of interest for the analyses, particularly related to progress and speed, are been exported from the program in excel format and appropriately processed with Excel. The Mobile Eye Detector has returned, for each of the participants to the experimentation, a film of the test track with the red cross-shaped pointer superimposed which represents the exact point in which the subject aims his gaze while driving. The data recorded by the speed-related V-Box have been extrapolated from the program Circuit Tools and elaborated appropriately to conduct the kinematic analysis of the problem; those relating to the progressive have instead been elaborated integrating them with the data obtained from the Mobile Eye, relative to the observation point while each participant is driving. The analysis of the films was conducted focusing the attention on the pointer near the pedestrian crossings to understand if and how the latter are perceived from users when driving.

To be able to accurately integrate the data of the V-Box with those of the Mobile Eye have taken some points of reference clearly identifiable from the videos arranged along the path, such as the vertical signs or other accompanying elements on the route.

In the following chapters the processing and analysis of the data obtained is described in detail with experimentation.

5. Data Analysis and Results

5.1. Premises

In the previous chapter the experimentation was initially treated, describing the field tests with the related participants, the vehicles used for the guides and the instrumentation used during each test session (the Video V-Box System and the Mobile Eye); the equipment and software necessary for the data processing phase was introduced, and then analysed in detail on the test path.

In this chapter we will show the data analysis phase concerning the driver's point of view, vehicle speed, attention- disattention of the drivers and frame by frame analysis.

The Mobile Eye Detector, initially conceived as a tool for marketing purposes, has seen later its use in various fields including that of road safety. The work carried out using Mobile eye tracker, in particular, the data analysis was divided into several phases before everything was carried out a detailed analysis of the 19 films obtained and subsequently from the processing of extrapolated data, it has been possible to make assessments on the safety of crossings according to what the human eye notices near the bicycle-pedestrian crossings. Subsequently, through the cinematic analysis we tried to understand if, corresponding to the perception and vision of the cycle-pedestrian crossing on the track, there are variations of speed and of what extent they are. It is precisely at those intersections that turn out to be the most dangerous, that it would be necessary to provide for adaptation measures to obtain a decrease in speed, to guarantee the safety of the weak part of the user. The experimentation, therefore, was to evaluate and understand from the data collected, how different elements have an effect related to the bicycle-pedestrian crossings (object of study) on the level of attention of a driver driving a vehicle over the bicycle-pedestrian crossings and identify which of these are more identified and consequently are safer for the cyclist who passes from the crossing.

Furthermore, it is desired to determine and analyse the reaction times of the drivers that elapse from the moment of viewing the road signs or elements of furnishing the road context, characterizing the pedestrian crossing, upon arrival at the bicycle-pedestrian crossings where, a cyclist, preparing to cross the road may cause a situation of danger

5.2. Surrogacy Safety Measures results

The purpose of studying safety measures is to gain an understanding of the frequency and severity of the cyclist- vehicle collisions which might could occur at specific locations (2 in our case). For this thesis two surrogacy measures were chosen as mentioned before which were post encroachment time (PET) and time to collision (TTC).

5.2.1. Post Encroachment Time (PET) Results

In case of Via Azzura the range of PET came out to be from 1.9 sec to 8 sec where median value was 5.9 sec. Also at this cross-section 7 out of 19 users had a PET below 2 seconds indicating a dangerous situation for 37% of the data collected However in case of Via Mainoldi the range of PET determined was from 1.6 sec to 5.9 sec. Where median value was 2.65 sec which shows that since Via Mainoldi was more clearer meaning that there were less environmental factors such as building and trees to distract the drivers the reaction time range was lesser in comparison to the one obtained at Via Azzurra (Figure 5-1). In this case as well similar to Via Azzurra 7 out of 19 users had a PET below 2 seconds indicating a dangerous situation for 37% of the data collected.

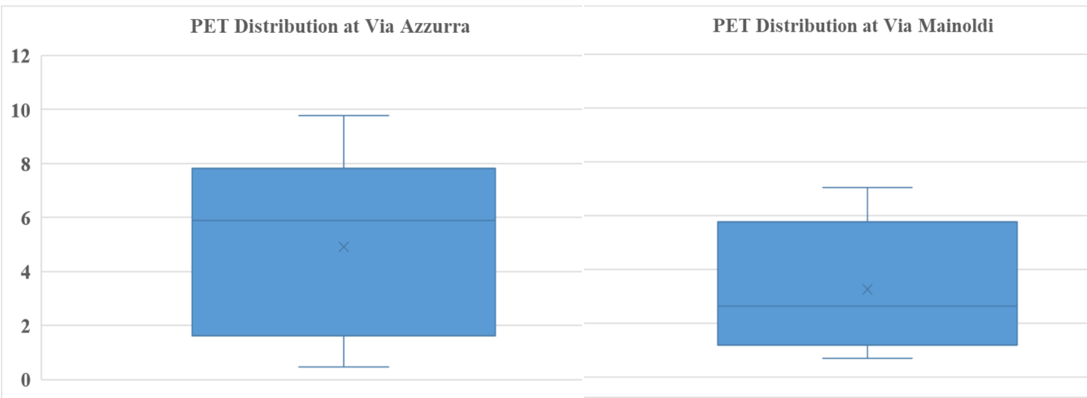

Figure 5- 1 PET range at the crossing of Via Azzurra

5.2.2. Time to collision (TTC) results

In this part we will first discuss the Time to collision on both the cross-sections and then analyse if there is any situation in which our situation was critical on both the cross-sections.

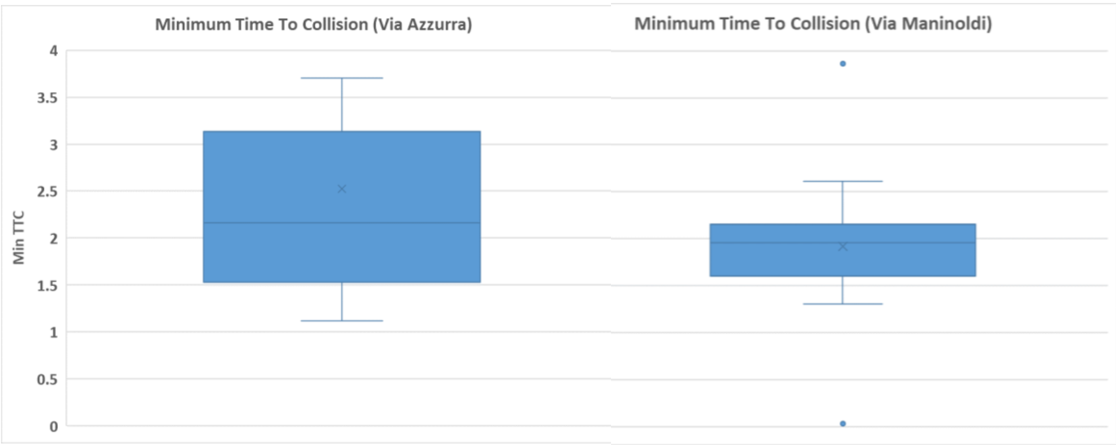

Figure 5- 2 TTC range at the crossing of Via Azzurra

For Via Azzura the time to collision determined was between the range of 1.6 to 3.2 seconds with the median value being 2.16 seconds. But the TTC determined for users 3,7,13,17 and 18 came out to be less than 1.5 seconds and could be risky in case brakes were not applied on time. Although for user 2 the TTC could not be determined as there was some technical error.

For Via Mainoldi the time to collision determined was between the range of 1.6 to 2.3 seconds with the median value being 1.96 seconds. But the TTC determined for users 6 and 10 came out to be less than 1.5 seconds and could be risky in case brakes were not applied on time (Figure 5-2).

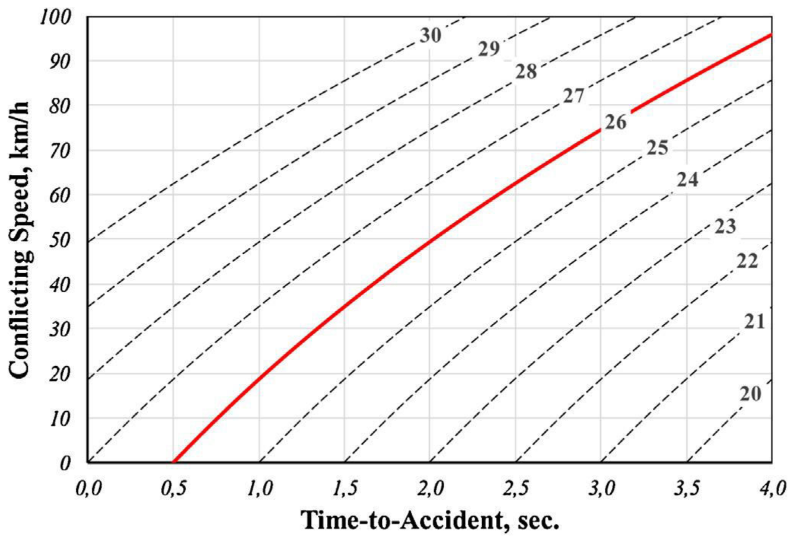

Figure 5- 3 Diagram for classifying conflict severity, adopted (Hydén)

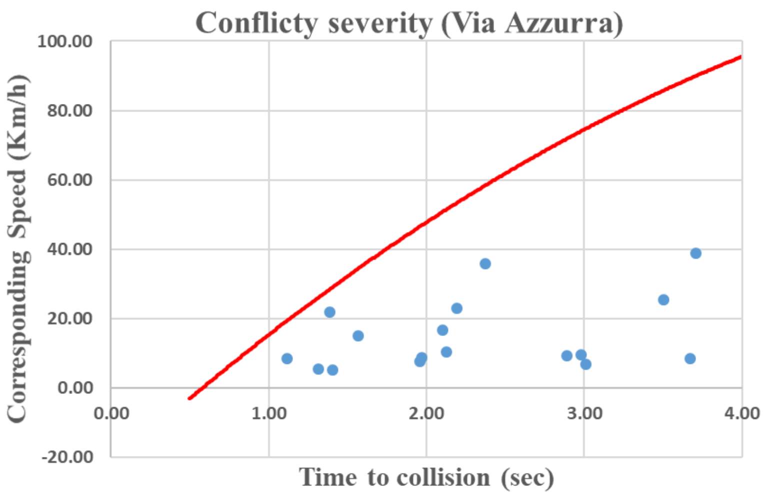

Figure 5- 4 Conflict severity at Via Azzurra

In figure 5-4 we tried to understand if there was any conflict severity at Via Azzurra from the point of view of literature but we couldn't find any situation where we could say that the situation was too severe except in some cases TTC was less than 1.5 sec as mentioned before.

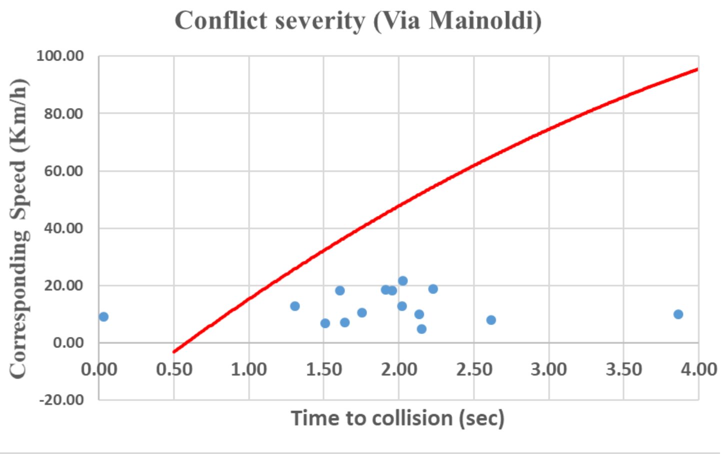

Figure 5- 5 Conflict severity at Via Mainoldi

Similar to approach taken at Via Azzurra as can be seen in figure 5-3 we tried to understand for Via Mainoldi if there was any conflict severity at Via Mainoldi according to (Hydén) but we couldn't find any situation except 1 for the user 6 where TTC was extremely low almost near to 0.03 seconds and a collision was almost near to happen.(Figure 5-5)

5.3. Reaction Time Results

In our work to determine and analyse the reaction times of drivers, three scenarios were considered as mentioned in the previous chapter to obtain the reaction time

- Time when the traffic light gets red and the driver starts to brake. (signal turn red)
- Time when the green light was on and the driver start to accelerate (Signal turn green)
- Time when the driver sees the cyclist and starts to brake (reaction time at crossing)

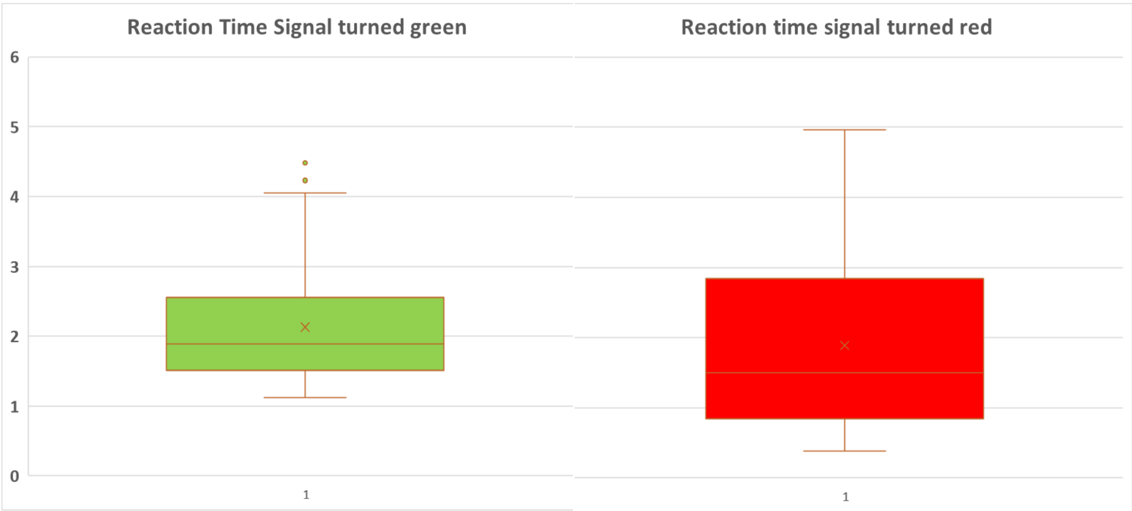

Figure 5- 6 Distribution of reaction times between green signal and red signal

It's a common fact that most of the drivers when passing from the signals which is about to close prefer to be even the last ones to pass before the signal actually gets red. It was visualized in our work that the reaction times between signals getting red and application of brakes by our drivers came out to be in the range of 0.5 sec to 2.5 sec with median value being less than 2 seconds here. In some cases (very few) this range was exceeded more than the range (Figure 5-6).

As could be viewed from the figure above that the range of reaction times determined through the instrumentation considered in this work ranged from 1.4 sec to 2.6 sec with median being less than 2 seconds. However in some cases our range was exceed with a reaction time of above 4 sec but it was very rare to have such an observation (Figure 5-6).

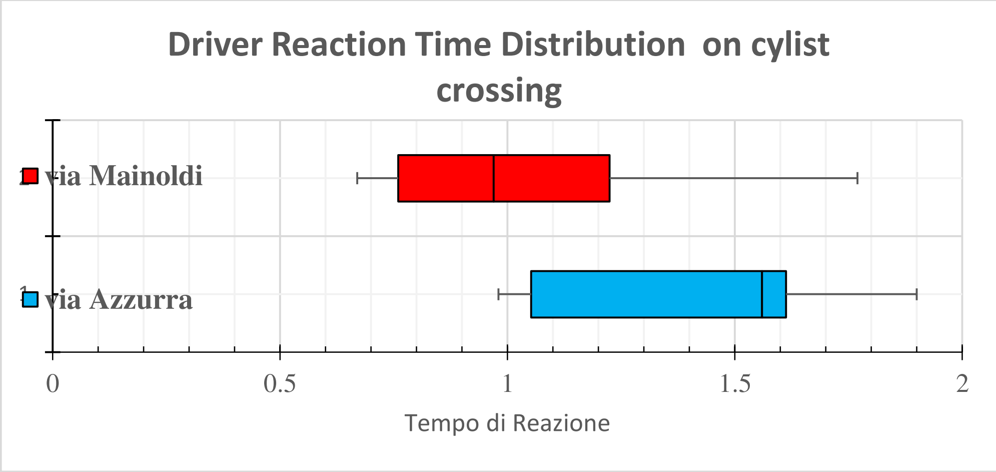

Figure 5- 7 Reaction time at Via Azzurra

The calculation of the reaction time for the cyclist passing scenario was very hard to obtain, due to several reason mainly because the drivers did not brake when they saw the cyclists. However the median results obtained for both the cross-sections were:

Reaction time (in case of cyclist at Via Azzurra) (Figure 5-7) = **1.56 seconds**

Reaction time (in case of cyclist at Via Mainoldi) (Figure 5-8) = **0.99 seconds**

5.4. Attention – Disattention Analysis

The participants in the trial for the duration of the test wore the glasses Mobile Eye allowing to obtain, for each of them, a video related to the track path, taken from the scene camera placed above the glasses, with superimposed on it a red cursor corresponding to the driver's point of view when driving (Figure 5-9).

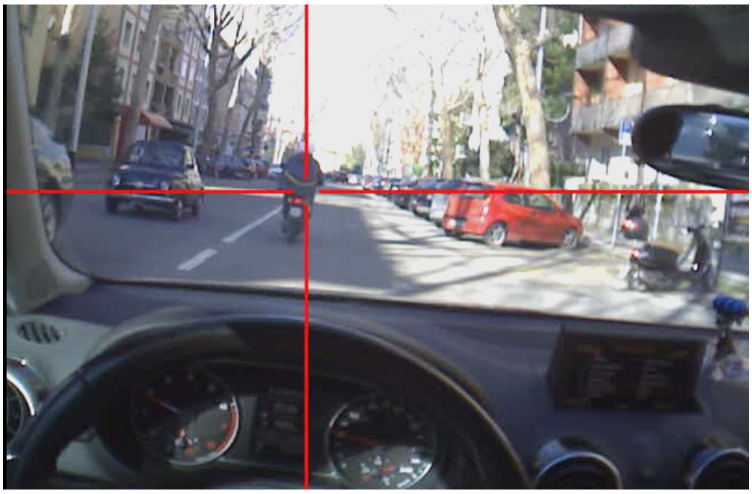
Figure 5- 8 Frame taken from the Mobile eye videos

The significant elements examined in the frame by frame analysis of the videos were chosen because they seemed to be decisive in the behaviour of users driving. These parameters are listed below (Table 5-1). The analyses performed and illustrated in the next paragraphs are expressed in relation to the stretch of road (150 meters) before the Bicycle-pedestrian crossings and not in relation to the whole test circuit. We have opted for this type of evaluation, to avoid an excessive workload on analysts and as it would have been in vain for the purpose of the study conducted.

Elements	Description
Parked vehicles	Cars parked on the street side in both directions of travel
Tree or Building	includes driver’s focus on the environment rather than road
Side of the road	part of the roadway reserved for transit pedestrian
Street	includes roadway and signage horizontal where not specified
Pedestrians	pedestrians along the stretch of road not on the sidewalk, but on the carriageway
Inside of the car	includes the dashboard, the steering wheel and
Sky	Sky seen on the front
Vehicles on same side	Vehicles travelling in the same direction
Vehicles on opposite side	vehicles before the user with the opposite direction of travel
Vertical Sign	signs to recognize the presence of bicycle-pedestrian crossing
Pedestrian path	horizontal signage referred to the passages
Bicycle arriving	cyclists covering the cycle path road side in the direction of travel
Bicycle on the line (crossing)	cyclist about to cross the pedestrian stripes
Empty frames	technical problems and reckless movements of the user make unrecognizable the point of vision (Figure 5.8)
Side mirror	Includes driver’s gaze on side mirrors

Table 5- 1 Examined elements (during frame by frame analysis)

In the first instance for each user the video "frame by frame" (1 frame = 33msec) was viewed, attributing when frames were available to the items listed above. In following for each section the frames related to the same category of elements are counted all users (**). In a second moment the elements were grouped into three macro sets attention, disattention and empty. (Table 5-2).

Element	**Attention**	**Disattention**
Street	✓	
Vehicles on the same side	✓	
Vehicles on the opposite side	✓	
Verical signal	✓	
Crossing (bike or pedestrian)	✓	
Bicycle arriving	✓	
Bicycle on the line	✓	
other bicycle	✓	
another cycle on track	✓	
Parked vehicles		✗
Tree or buildings		✗
Pedestrians		✗
Pedestrian path		✗
Inside of the car		✗
Sky		✗
other cycling track		✗
side of the road		✗
side mirror		✗

Table 5- 2 Elements division based on attention & disattention

Figure 5- 9 Difference between detected and empty (lost) frames

Due to some technical issue we had empty frames sometimes where the pointer could not be seen on the screen and thus we cannot say confidently where the driver was watching (Figure 5-10). Now Moving on to frame by frame analysis performed for each individual user with the help of Kinovea software, they were obtained overall the following graphs related to the four case studies

- Via Azzurra without cyclist (control study)
- Via Azzurra with cyclist (experimental study)
- Via Mainoldi without a cyclist (control study)
- Via Mainoldi with cyclist (experimental study)

5.4.1. Via Azzurra without cyclist eye tracking results

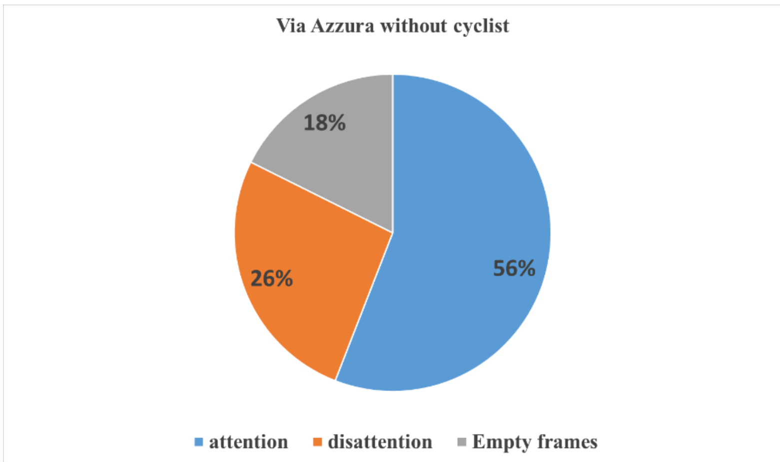

Figure 5- 10 Attention / Disattention in % at Via Azzurra without cyclist

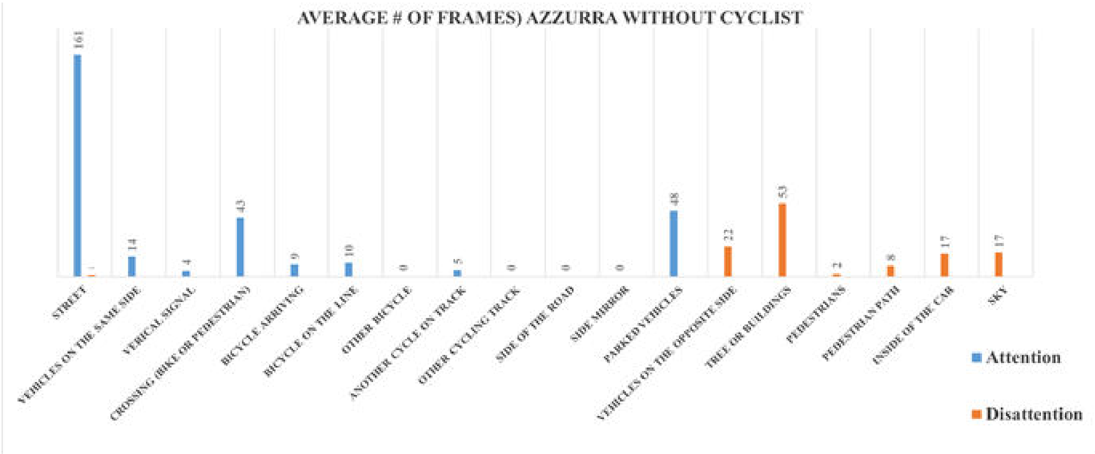

Figure 5- 11 Average number of frames for each element of attention and disattention (without cyclist)

From the control study which is Via Azzurra without cyclist as can be seen from the images (Figures 5-11 & 5-12), excluding the lost frames (18%), the driver's level of attention is 56%. If you look at the elements that most characterize the analysis, such as street (#of frames street = 161). For the elements of "disattention", on the other hand environment (tree or buildings) plays a major role in distracting the attention of the driver.

5.4.2. Via Azzurra with cyclist eye tracking results

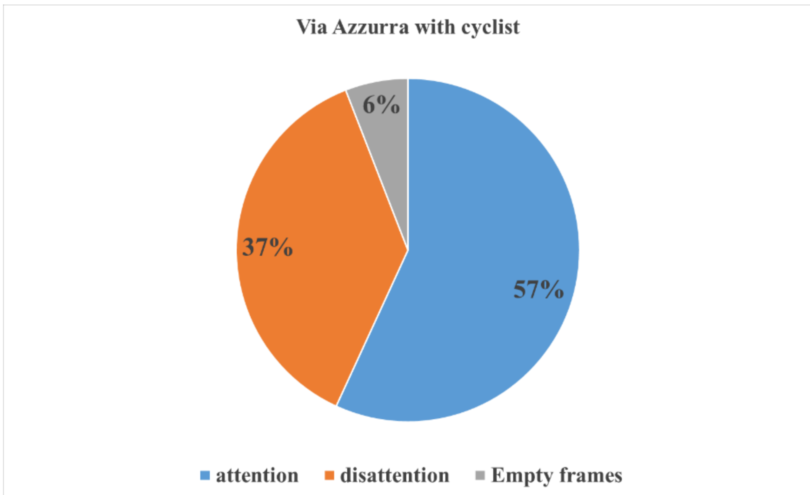

Figure 5- 12 Attention / Disattention in % at Via Azzurra with cyclist

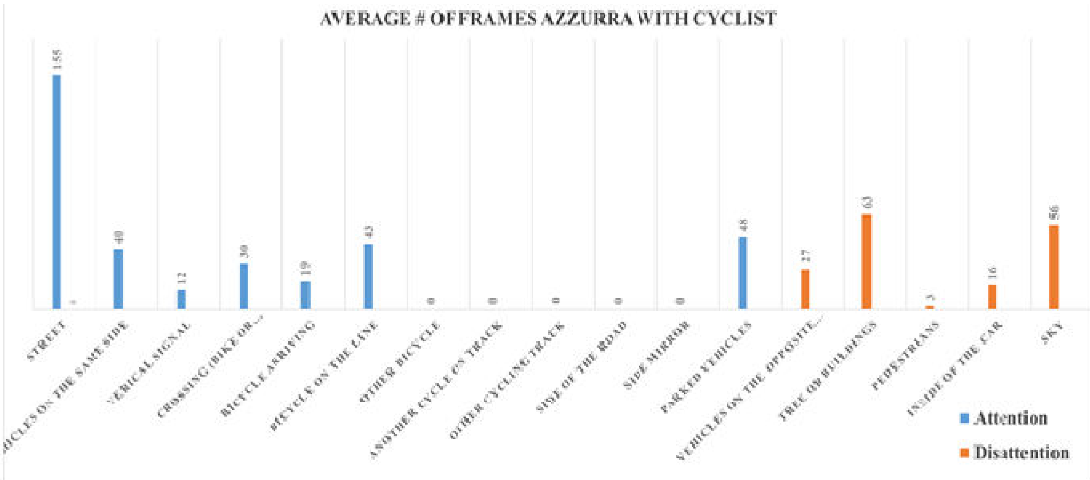

Figure 5- 13 Average number of frames for each element at Via Azzura (with cyclist)

From the experimental study with the presence of cyclist the greatest number of measurements were obtained inherent to the level of attention of the participants, all 19 in total; as can be seen from the images (Figures 5-13 & 5-14) excluding the lost frames (6%), the driver's level of attention is 57%. If you look at the elements that most characterize the analysis, such as street (#of frames street = 155) followed by other elements as can be seen in the figure above. For the elements of "disattention", on the other hand, environment (tree or buildings) again plays a major role again to control study of Via Azzurra.

5.4.3. Via Mainoldi without cyclist

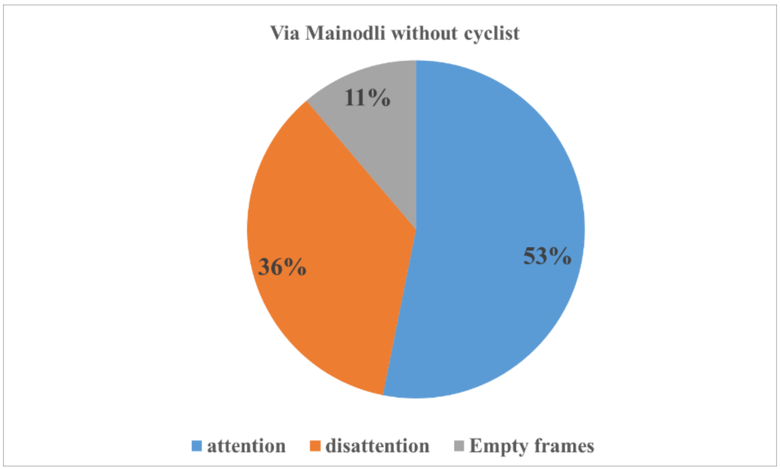

Figure 5- 14 Attention / Disattention in % at Via Mainoldi without cyclist

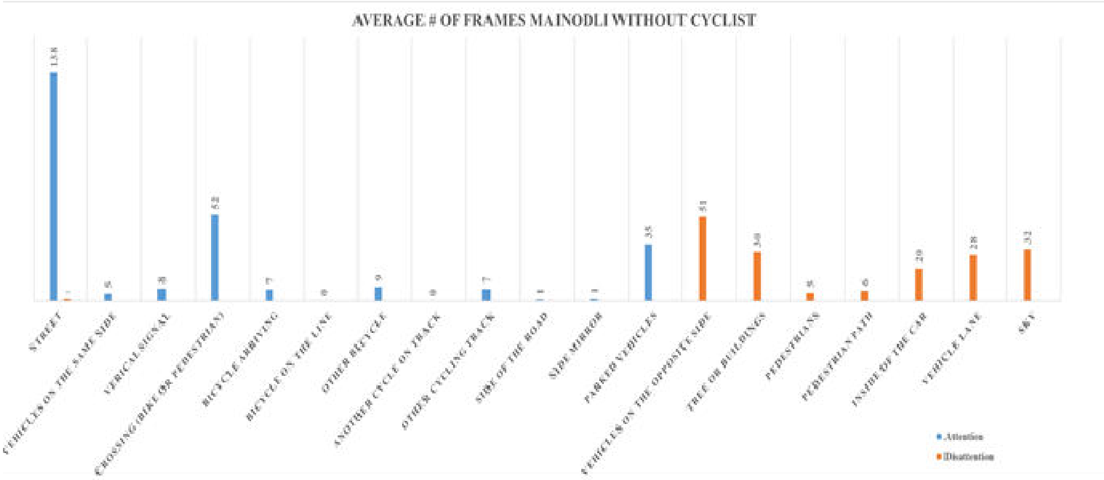

Figure 5- 15 Average number of frames for each element at Via Mainoldi (without cyclist)

Moving on towards our second crossing situated at Via Mainoldi. Same as in Via Azzurra we first performed a control study without the cyclist to understand the behaviour of driver when there is no risk of collision.

In the control study as can be seen in (Figures 5-15 & 5-16) without cyclist the driver's attention was 53% with most of their focus on the street (#of frames street = 138).However for disattention our drivers mostly focused on vehicles coming from opposite side (#of frames vehicle on opposite side = 51) which is a disattention since there is a very less chance of getting hit by the opposite-side vehicles.

5.4.4. Via Mainoldi with cyclist

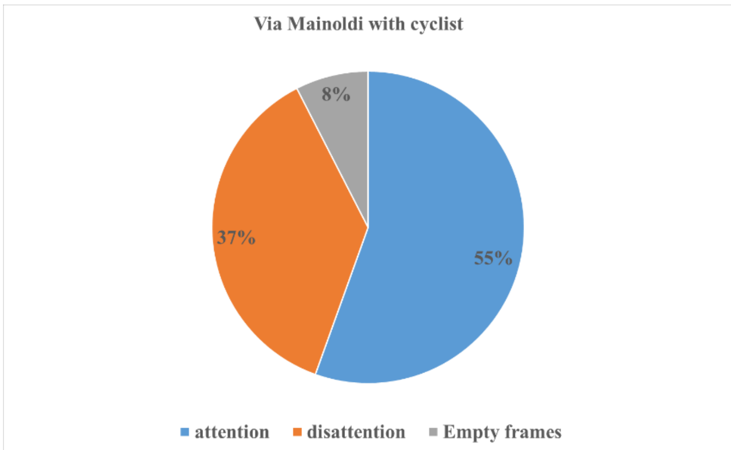

Figure 5- 16 Attention / Disattention in % at Via Mainoldi with cyclist

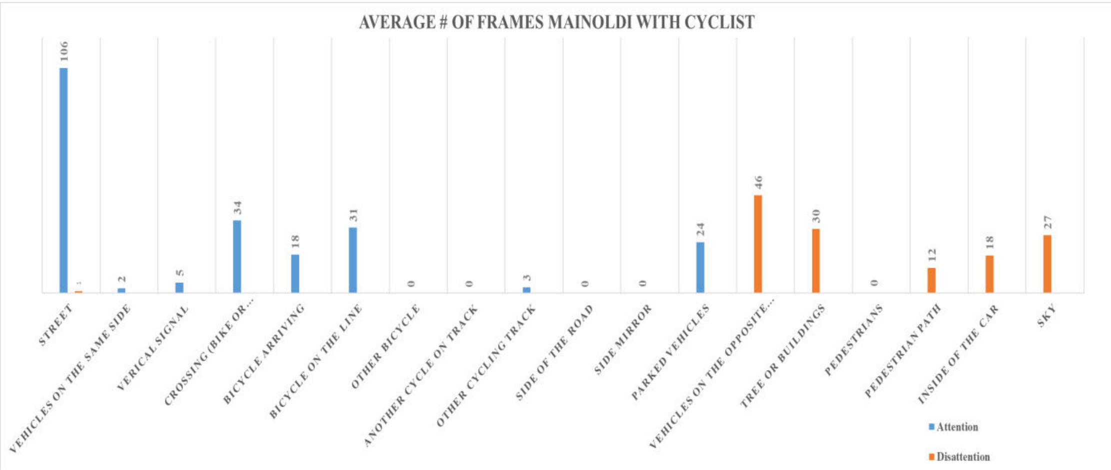

Figure 5- 17 Average number of frames for each element at Via Mainoldi (with cyclist)

Lastly moving on to experimental study of cross-section at Via Mainoldi with cyclist we found drivers' attention to be 56% with 8% being the lost frames. Disattention found was 37%. (Figures 5-17 & 5-18).

5.5. Result of frame by frame analysis

If we carefully analyse the study conducted by frame by frame we find drivers' focus being higher on the street (#of frames street = 106). For disattention we found higher values for vehicle on opposite playing the major role (# of frames vehicle on opposite side = 46).

In short if we want to conclude the frame by frame analysis carried out on two cross-sections on two different roads namely "Via Azzurra" and "Via Mainoldi". We can say that 150 m before the cross-section the major player for driver's attention was the street but dis-similarities could be found when considering the disattention part with Environment being the key player for disattention for Via Azzurra and vehicles coming from opposite side being major player for Via Mainoldi.

6. Conclusion

The experimentation illustrated in this thesis is aimed at evaluating safety of two existing infrastructures, focusing on cycle-pedestrian crossings, through the use of innovative methodologies, such as the V-Box and the Mobile Eye Detector, allowing to analyse the behaviour of users while driving.

The work, included in the project for the "Call for scholarships ASAIS - EVU" was addressed to the study of the recognition and reaction times of the drivers of vehicles in proximity of two bicycle-pedestrian crossings, differentiated by geometrical and structural characteristics.

After the careful analysis of the data determined from the videos following results were determined

- 37% of the Post encroachment times determined to be at dangerous level (i.e. PET< 2 seconds) in both the cross-sections of Via Azzurra and Via Mainoldi.
- Different ranges of TTC were found for both Via Azzurra & Via Mainoldi and in the case of some users it was noticed that the TTC was less than 1.5 sec which is a dangerous value. Additionally time vs speed graphs were plotted for both the cross-sections to analyse if there was any risk of conflict severity being more than the limit and only in one out of 19 drivers at the second cross-section (Via Mainoldi) this limit was exceeded.
- During the evaluation of reaction times on signals it was found that the average time for the driver to visualize the signal getting red and apply brakes was 1.44 seconds which is normal from the studies conducted before by other researchers. However, in case of application of accelerator by the drivers an average value of 2.09 seconds was determined.
- Last part of this research dealt with careful visualization of the videos recorded specially at a distance of 150 m from the cross-sections on Via Azzurra and Via Mainoldi through an analyzation software to determine all the elements of attention and disattention. This study enabled us to declare which of the elements were visualized more by the drivers and which were visualized rarely by taking the average of all the drivers' visualizations.

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