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Some analysis on visibility from driver seat

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Abstract

Many experimental surveys allow to know driver's behaviour. This latter is conditioned both by the psychophysical state and by the road environment. Several studies have been conducted on the interaction between drivers and the environment, as well as other studies have examined some psychological aspects of the driver behaviour. The road vehicles have been improved over time and the manufacturers have adapted the car structural safety features to the current needs of people's safety.
Some accidents are caused by blind spots due to vertical structural elements of the passenger compartment. This work tries to highlight how these elements are an obstacle to the conditions of frontal visibility from the driving seat, and how are an implicit problem for the safety.
It was decided to investigate the possibilities of free vision for a sample of about 500 cars produced between the year 2007 and year 2016 and marketed in Italy. The cars analysed were divided into displacement classes and for each class the clear and blind viewing angles from the driving seat were determined: in the direction of travel, to right and to left. The displacement classes of the cars investigated were weighted based on the real presence in the Italian vehicle fleet.
Over time there have been a decrease in the free angle on the driver's left and an increase in the free angle to the driver's right due to changes in the pillars and the size of the windscreen.
The results were used to check some typical driving situations about at-grade intersections, to verify the actual safety conditions and to show which type of rule is more suitable for the different intersection angle of the roads.

Keywords: road safety, visibility, driver seat, accident analysis, blind spot

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1. Introduction

Every year about 1.3 million deaths are recorded on the roads, and people that suffer serious non-fatal accidents are estimated at between 20 and 50 million. To make an estimate of the economic damage of the accidents, we can refer to the «Global status report on road safety» (WHO, 2018) on road safety in which the global losses due to road accidents amount to over 500 billion dollars (of which almost 18 referring only to the national territory) and cost each government 1 to 3 points of Gross Domestic Product (GDP).

The main factors that can determine a car accident are three: the environment, the vehicle and the driver. Among these factors, the most relevant is certainly the human one: it is estimated that in 20-40% of fatal accidents the driver's psychophysical conditions are the main cause or a co-factor. Studies on human factors and their interaction with the vehicle may be useful for road safety (Abbondati et al., 2016a; 2016b; 2017a; 2017b; Capaldo et al., 2011; 2012a; 2016a; 2016b; De Luca et al., 2016, Babić et al., 2017). Other studies concerned the safety of driving manoeuvers (Capaldo, 2012b) and the changes over the years of the driver's eye height (Capaldo, 2012c; 2012d). In particular this work considers the driver's ability to see and to control the environment from the driving seat.

2. The vision and behaviour of drivers

The Field of View (FOV) is defined as the section of the three-dimensional space in which a critical object can be observed and represented, either directly or through devices for indirect vision. The field of view can be limited by the maximum detection distance of the devices used. When a vehicle moves, most objects fall into the driver's direct field of view. The indirect field of view provides information almost exclusively on the vehicles that follow or that move by side. The field of view is measured in degrees from the center (line of sight forward). A normal healthy eye would be able to see about 95 degrees and about 60 degrees in the nose. The eye should also be able to see 60 degrees above and 75 degrees below the front of the line of sight. This means that each monocular eye provides a horizontal field of 155 degrees. The binocular vision covers a viewing angle of approximately 200-220 degrees (Figure 1).

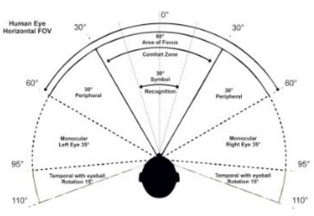

Figure 1 – Human eye horizontal FOV

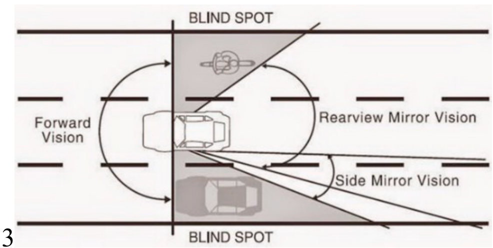

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Figure 2 – Driver visibility and door pillar blind spots

2.1. The blind spot and the safety

The driver's FOV is limited within the vehicle by the width of the windows. The limits change from vehicle to vehicle. Windows are sized differently and some combinations of windows and pillars can negatively affect visibility while driving. Moreover, for reasons related to aerodynamics, pedestrian safety and visibility, the same model of car over the years also undergoes changes in the position and size of the windows.

The unnoticed presence of vehicles in transit by side or behind (DOT, 2011) can cause safety problems. The position of the windows and the pillars, and the arrangement of the side and rear mirrors determine the areas in which the driver may have difficulty in seeing vehicles from the side: these areas are called blind spots (Figure 2). Considering the new designs and the possible adjustments of the mirrors, this problem has been very limited in passenger cars. Some cars use ultra-wideband radar sensors that cover areas that are not visible and assist the driver during lane changes, when he overtakes vehicles or is overtaken from those vehicles hidden from his view.

2.2. The road and the vision

The driver's view is also conditioned by physiological phenomena. As the vehicle speed increases, the field of view shown in Figure 1 tends to shrink and the driver tries to focus his gaze as far as possible, as shown in Figure 3. The FOV angle tends to about 35 degrees at a speed of about 60 mph.

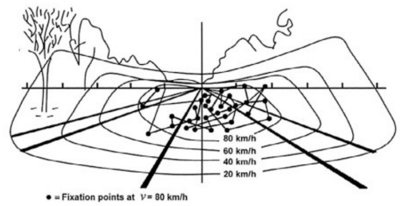

Figure 3 – Stare areas at different speeds (Babkow, 1975).

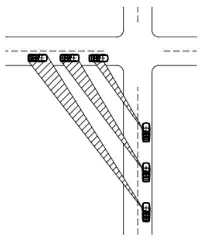

Figure 4 – Blind view for at-grade intersections with 90° arms

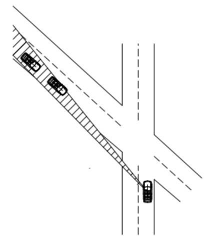

Figure 5 – Blind view for at-grade intersections with 130° arms

2.3. The frontal view

This study is focused on the driver's frontal vision and its implications on road safety problems.

Even the design rules provide control rules for the driver's vision of the road in the different geometric conditions that can occur along the route, in curves or when at-grade intersections. Along the route it must be checked the free viewing distances for stopping manoeuvers and for overtaking on single carriageway and two-way roads. These checks require limited angles of side vision. On the other hand, for visibility checks when at-grade intersections the necessary viewing angles to the right and to the left are considerably wider and they also depend on the intersection angle from the streets. The same lateral blind angle can be more or less dangerous depending on the intersection angle of the roads (Figures 4 and 5). These angle of views can be free or blind depending on the vehicle structure.

3. The surveys

This study collected data on about 500 cars taken from QuattroRuote (the oldest and most authoritative magazine in the car world in Italy, Ed. Domus, 2016) checking the numbers from the year 2007 to the year 2016. In the road tests section it is possible to find almost all the technical specifications of the tested car models and above all the measurements of the angles of visibility from the driver's seat (Figure 6). These measurements are realised with laser technology (Figures 7 and 8).

3.1. The classes of cars and the corners chosen

The cars were recorded by year and by category of displacement. It was decided to use five categories compliant with those used by Automobile Club Italia (ACI, 2017) for the description of the Italian car fleet. The first two classes have been grouped together (0-800 and 800-1200 cc) into one, due to the presence of few models in the lower displacement class. The used categories are: 0-1200, 1200-1600, 1600-2000, 2000-2500 and over 2500 cc.

To homogenize the number of blind spots, it was chosen a measurement model with only two front blind angles for the driver's side. The choice is justified by the consideration that some cars have double front pillars or have headrests that generate additional blind spots (Figure 8). Using the example of Figure 8, the two upper angles of 12 degrees and 11 degrees are combined in a single angle of about 30 degrees which also includes the small angle of visibility between the two. Anyway this choice does not condition the present work which considers only the front visibility angles of the driver.

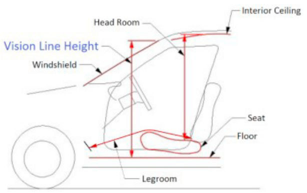

Figure 6 – Vision line height from driver seat

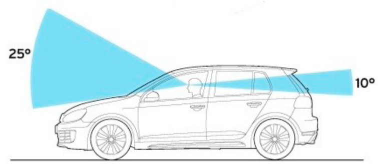

Figure 7 – Examples of vertical view angles

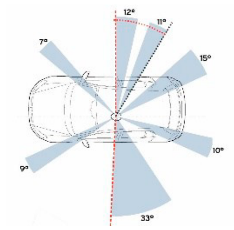

Figure 8 – Examples of horizontal view angles

Table 1 shows the data related to some random examples about the viewing angle recorded for cars of the year 2016. The data are shown in degrees and the last column is a sum column utilised for congruency control.

Table 1. Example of data recorded for random cars of year 2016 (total in the year: 36)

Angle N#	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*Sum*
Displacement 0 - 1200														
DS 3	52	9	39	13	26	16	28	15	27	25	83	10	17	360
Displacement 1200 - 1600														
Fiat Tipo	53	9	29	31	14	19	32	14	43	30	57	9	20	360
Displacement 1600 - 2000														
Toyota Prius	50	7	36	27	18	17	34	11	35	31	71	8	15	360
Displacement 2000 -2500														
Porsche 911	58	8	40	20	4	18	39	18	9	23	93	10	20	360
Displacement over 2500														
Lexus RX	58	11	28	26	12	22	30	16	29	31	68	9	20	360

3.2. The results

The average blind angles to the left and to the right of the driver were calculated for each year of survey and for each displacement class (Figures 9 and 10). Likewise, the view angles to the left and to the right of the driver were evaluated (Figures 11 and 12).

As far as the left blind angle is concerned, it can be noted that for the displacement classes 1200-1600 cc and for 1600-2000 cc, the trend over the years is more or less constant, with a slight tendency to reduce the angle. For the categories 0-1200 cc and over 2500 cc, one can note changes in the angle, but overall there is a tendency to reduce this over the period of time analysed. For the higher categories (2000-2500 cc and over 2500 cc) there are changes in the angle, with increasing trends. The most marked lines are the values averaged between all the classes of displacement and these show over time the tendency to decrease blind spots.

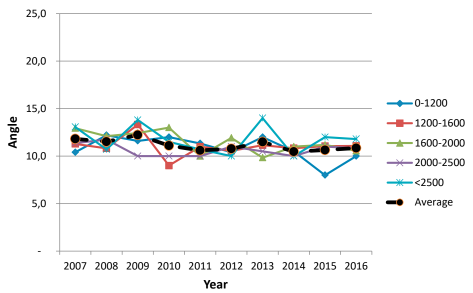

Figure 9 – Average blind angles to the left of driver as function of years and for different displacements

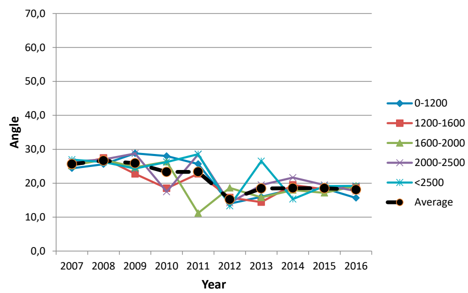

Figure 10 – Average blind angles to the right of driver as function of years and for different displacements

The average angle of visibility to the left of driver tends to decrease over the years. Differently, the angle of visibility to the right of driver shows a positive trend over the years. The probable justification can be searched in the different structure of the front pillars which on the one hand tend to become larger and on the other tend to be more inclined from the vertical.

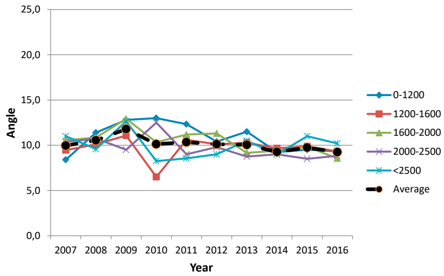

Figure 11 – Average view angles to the left of driver as function of years and for different displacements

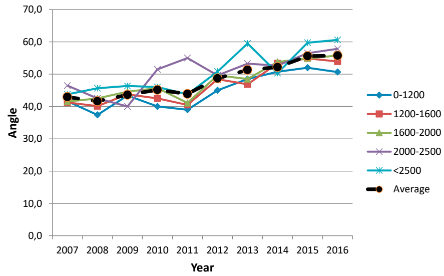

Figure 12 – Average view angles to the right of driver as function of years and for different displacements

As far as the left blind angle is concerned, it can be noted that for the displacement classes 1200-1600 cc and for 1600-2000 cc, the trend over the years is more or less constant, with a slight tendency to reduce the angle. For the categories 0-1200 cc and over 2500 cc, one can note changes in the angle, but overall there is a tendency to reduce this over the period of time analysed. For the higher categories (2000-2500 cc and over 2500 cc) there are changes in the angle, with increasing trends. The most marked lines are the values averaged between all the classes of displacement and these show over time the tendency to decrease blind spots.

The average angle of visibility to the left of driver tends to decrease over the years. Differently, the angle of visibility to the right of driver shows a positive trend over the years. The probable justification can be searched in the different structure of the front pillars which on the one hand tend to become larger and on the other tend to be more inclined from the vertical.

3.3. Correction of displacement classes for their presence in the car fleet

The samples recorded were weighted on the displacement classes of the vehicle fleet for the years 2007-2016. Figures 13 and 14 show only the average blind angles to the right of driver and the angles of visibility to the right compared to the corresponding values weighed as a function of the car fleet. The differences are very modest. We found similar results for the angles to the left of driver.

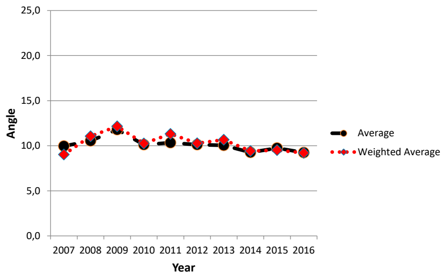

Figure 13 – Average and weighted blind angles to the right of driver as function of years and for different displacements.

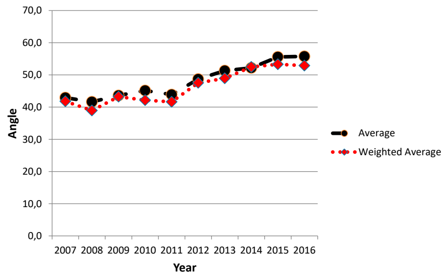

Figure 14 – Average and weighted view angles to the right of driver as function of years and for different displacements.

Table 2 shows a summary of the values for the driver front visibility calculated for the average angles weighed on the car fleet with some statistical parameters.

The calculation examples for some situations of visibility at intersections were carried out with the values of the 85th percentile for blind spots and the 15th percentile for the free view angles with safety advantage (Figure 15). The blind sections for three different intersection angles between the roads were calculated with different distances from the conflict points (distance to the left and distance to the right, Figures 16 and 17). The calculation distances take into account a shoulder width of 1.00 m, the width of a half lane from 1.88 m (for d_l) plus the width of an entire lane from 3.75 m (for d_r). A length of 2.00 m has been added to these measures to consider the distance of the driver's eye from the front of the car.

Table 2. Weighted average angles on vehicle fleet, angles in degrees

Values	***Angles in degrees***			
	Blind to left	***View to left***	***Blind to right***	***View to right***
Average	10.9	21.2	10.3	46.3
Std. Dev.	0.8	4.2	1.0	5.1
Coef, Var.	0.1	0.2	0.1	0.1
85° perc.	11.9	26.6	11.6	53.0
15° perc.	10.0	15.9	9.1	40.7
Min	9.1	15.2	9.0	39.0
Max	11.9	27.4	12.2	53.3

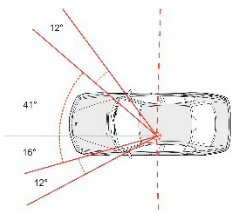

Figure 15 – Vision line height from driver seat

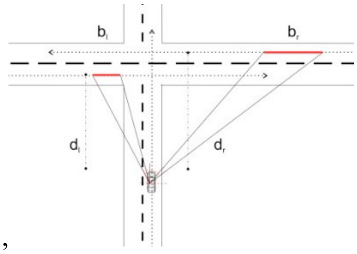

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Figure 16 – Blind view for at-grade intersections with 90° arms

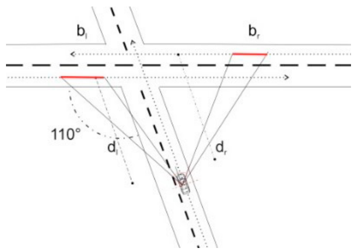

Figure 17 – Blind view for at-grade intersections with 110° arms

The blind sections were calculated using the trigonometric relationships between the triangles. For example, for the intersection at 90 ° the blind section b_l, in the upper left corner in Figure 16, is considering the values of the angles indicated in Figure 15:

$$b_i = d_i \; tan\beta - \; d_i \; tan\alpha \qquad b_i = d_i \, (tan\beta - tan\alpha) \qquad \text{where} \quad i = l \text{ (left) or } r \text{ (right)} \qquad (1)$$

To left the values are $\beta = 28°$ (16° + 12°), and $\alpha = 12°$. The values of d_l are in Table 3. In the calculations for the blind sections to the right b_r , in the upper right corner in Figure 16, the values of the angles are $\beta = 53°$ (41° + 12°), and $\alpha = 12°$, with d_r values also reported in Table 3.

The other values, shown in Table 3, consider the different intersection angles between the roads.

4. Some examples

Current legislation in Italy by Ministry of Infrastructure and Transport (MIT, 2006) prescribes «*for intersections at-grade the angle between the axes of the roads must not be less than an angle of value equal to 70 degrees*». Other rules (AASHTO, 2011) indicate that «*a skewed intersection leg should not be more than 30 degrees from perpendicular (i.e., from approximately 60 to 120 degrees)*». For the examples, the visibility was controlled with intersections between perpendicular roads and between intersecting roads with angles of 70 and 110 degrees.

The values of lengths of the blind sections on the right and on the left are shown in Table 3. In this table all the measurements are in meters. The graphs of Figures 18 and 19 summarize the results of the examples shown in the Table 3.

Road vehicles have very different sizes. The most common standard vehicle length measurements are: Car, 4.50 m; Van, 5.00 m; Truck, 10.00 m; Tractor-Semitrailer combination Truck, 18.00 m. Pedestrians and motorcycles have much smaller sizes.

Table 3. Blind section for different intersection

Car distance from intersection	d_l	*On the left* 70°	90°	110°	d_r	*On the right* 70°	90°	110°
3	7.88	1.66	1.93	3.02	11.63	17.05	5.32	3.09
20	24.88	5.24	6.09	9.55	28.63	41.99	13.10	7.60
40	44.88	9.44	10.99	17.24	48.63	71.32	22.26	12.91
60	64.88	13.65	15.89	24.92	68.63	100.66	31.41	18.22

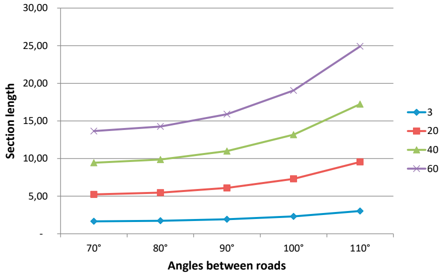

Figure 18 – Blind sections to the left as function of the angle and for the different distances from the intersection.

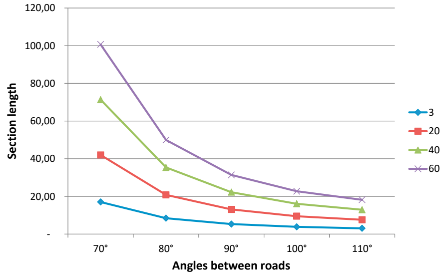

Figure 19 – Blind sections to the right as function of the angle and for the different distances from the intersection

Figure 18 shows how, starting from distances of about 20 m from the intersection, the left front pillar can hide the approach of a car coming from the left for a very short time. For larger distances from the intersection, the worst situation is always due to intersections between roads with an angle of 110 degrees (note that the AASHTO standard also allows 10 degrees more than the MIT standard). At about 60 m from the intersection there is a blind hole of about 25 meters on the left of the driver. A similar visual barrier can prevent the sighting of a Tractor-Semitrailer combination Truck too. It is noted that the distance of 60 m is a reasonable distance to stop at the intersection traveling at a speed of about 60 km/h.

The situation worsens for the visual obstructions on the right (Figure 19) that can even reach about 100 m of length for a distance from the intersection of 60 m and an angle of intersection between the roads of 70 degrees. A tractor-semitrailer combination truck traveling at 60 km/h moves 16.7 m in one second. In a 100 m stretch it can remain completely hidden from the driver's view for about 3.5 seconds. Being 2.5 sec a time close to the reaction and action time of a driver. A car, in the same driving conditions, remains invisible even for a time of about to 5 sec.

It is necessary to pay attention because these are limit values taken in geometric conditions from a given position: the driver vision condition is not binocular and the vehicle that controls the view does not move. The real situation is better but still critical. All the calculations have been carried out in the hypothesis that the driver field of view remains free from obstacles of any kind, for a height higher than the driver's eye. This is of fundamental importance if the roads are of the same importance and are regulated only by the rule of precedence for the vehicles coming from the right (for countries with right-hand drive). The intersections for roads of different importance and low traffic flows must be regulated with the putting of precedence signals or STOP signals.

It is clear that especially for skewed intersections between roads of different importance, it is absolutely not recommendable to put only the prescription of «give precedence» with a specific signal, but it is essential to impose a regulated precedence with a STOP signal. The STOP signal must oblige the driver to stop before engaging the intersection, and check, well and with due calm, the vehicles that can come from the two directions and those that can manoeuver at the intersection.

5. Conclusions and research evolution

This work showed the results of a survey on the evolution of the cars, in terms of different layout of the cockpit structures. The changes are due to the need of comfort and traffic safety. This also affects the visibility of the driver from the driver seat. In the last decade, car manufacturers have reduced blind spots due to vertical pillars and free viewing angles and we must hope that this trend continues.

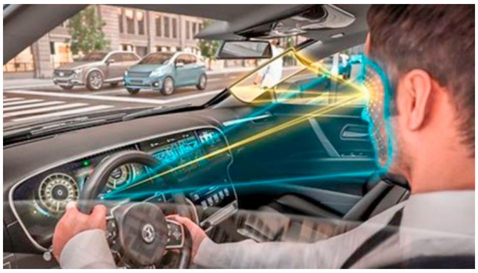

Figure 20 – Virtual vision systems by Continental

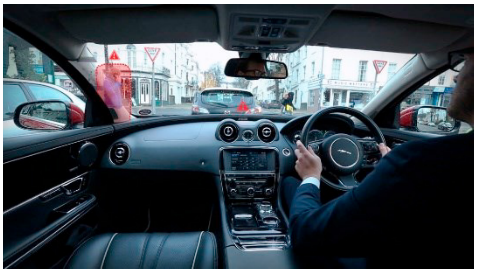

Figure 21 – Virtual vision systems by Land Rover Jaguar

However the results show that, despite the improvements, visibility at intersections can remain a problem. This should prompt road managers to reflect on the rules of precedence to impose on the at-grade intersections: the visibility for intersections with angles different from 90 degrees can be critical. And often the existing intersections have roads that intersect with angles even greater than those considered: these intersections must be reviewed and corrected.

Finally, it is important to continue to follow this type of measures in the coming years to understand if the trends recorded will be confirmed and try to correlate the data with the accident rates at the intersections. And recently different car manufacturers are studying some virtual vision systems through door pillars (Continental, Figure 20, Land Rover Jaguar, Figure 21, etc.)

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