



# Visibility Issues of Right-Hand Drive Vehicles on the Right-Side Traffic

Vidas ŽURAULIS<sup>1</sup>, Robertas PEČELIŪNAS<sup>2</sup>, Paweł DROŹDZIEL<sup>3</sup>, Saugirdas PUKALSKAS<sup>4</sup>

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- <sup>1</sup> vidas.zuraulis@vilniustech.lt, Department of Automobile Engineering, Vilnius Gediminas Technical University, Vilnius, Lithuania  
<sup>2</sup> robertas.peceliunas@vilniustech.lt, Department of Automobile Engineering, Vilnius Gediminas Technical University, Vilnius, Lithuania  
<sup>3</sup> p.drozdzziel@pollub.pl, Department of Sustainable Transportation and Powertrains, Lublin University of Technology, Lublin, Poland  
<sup>4</sup> Corresponding author, saugirdas.pukalskas@vilniustech.lt, Department of Automobile Engineering, Vilnius Gediminas Technical University, Vilnius, Lithuania



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## ABSTRACT

This paper analyses road safety issues related to the operation of right-hand drive vehicles in right-side operated traffic conditions. The problem is statistically valid, especially in regions where the states border with road traffic organised on different sides, or due to economic considerations, when it is much cheaper to purchase a vehicle adapted to the traffic of the other side. This article focuses on visibility issues of different driving positions in the case of the most dangerous overtaking manoeuvre by geometrically based situation analysis and safe distance to opposite obstacle evaluation. An additional part of the study is the functional testing of special indirect vision equipment in real traffic conditions. This is related to the technical regulations in force in the European Union Member States for vehicles adapted to the traffic in the other direction when constantly participating in traffic. An overview of these technical requirements, as well as the existing requirements not to restrict the free market of vehicles, is also covered in the paper.

## KEYWORDS

right-hand-drive; visual observation; indirect vision; periscopic mirror; traffic safety.

## 1. INTRODUCTION

Road traffic accidents are the twelfth leading cause of death worldwide. In 2021, 1.19 million people died in road traffic crashes. Approximately 69% of those killed are between the ages of 18 and 59. About 2/3 of these deaths are male [1]. These indicators encourage a review of all potential risks on the roads and measures to minimise them. Vehicles are the central axis of the mobility system and the biggest source of serious road accidents; therefore, their safety potential needs to be ensured both in the design stage and during exploitation [2, 3].

Historically, in some parts of the world, vehicle traffic has been organised either on the left-hand or on the right-hand side [78 and 174 countries, respectively], and it is settled and legally established that left-hand drive (LHD) vehicles are used in the countries with right-hand traffic [4]. There are times when vehicles designed to drive on one side of the road are used to drive on the other side of the road. Drivers travelling to and from different traffic rule zones may face different driving safety or mental workload issues [5]. As is well known, anxiety and stress can lead to adverse driving consequences, i.e. risk-taking, aggressiveness and poor driving behaviour [6, 7]. Therefore, in some countries, driving a vehicle adapted to drive on the other side of the road is forbidden, in others it is allowed without restriction, and in some, there are certain restrictions. The Canadian port city of Quebec has a ban on registering right-hand drive (RHD) vehicles, with exceptions for cars more than 25 years old, vehicles purchased before 2009 and public service vehicles like garbage trucks. A 2009

study by Quebec's insurer found RHD vehicles had 30% greater crash likelihood [8]. Prince Edward Island bans driving them on roads, with some similar exceptions as in Quebec. In 2007, the Insurance Corporation of British Columbia (ICBC) analysed accident data and found RHD vehicles were up to 40% more likely to be involved in accidents [9]. Other studies suggest that left-hand traffic is safer, especially for those who learnt to write from left to right at school [10, 11]. The conclusions of the British Columbia study were challenged by statistics researchers at the University of British Columbia, who found, among other things, errors in comparing the small number of RHD vehicles to the millions of other cars on British Columbia roads. It was also found that the average time for a crash to occur after first purchasing an RHD vehicle was 223 days, which is 68% sooner than for left-hand drive (LHD) vehicles, i.e. 705 days [12].

There is also a pronounced problem of right-hand drive vehicles in Georgia, Kyrgyzstan and Russia (especially in the eastern regions), where imports of vehicles from Japan are significant [13]. In Kyrgyzstan, the accident rate is twice as high for RHD vehicles compared with LHD vehicles. The same road safety issue with vehicles imported from Japan and the UK also exists in some Canadian provinces [14]. After a detailed case study of Sweden, where in 1967 the traffic organisation was boldly changed from left to right-side traffic, it was found that 30% of accidents could be avoided by banning the use of vehicles that are not in the correct steering position [13]. This is particularly important for neighbouring countries where traffic is organised on opposite sides. Adding to this, despite the fact that road infrastructure and transport regulations in Rwanda are designed for LHD vehicles, the study demonstrated that RHD vehicles have clear operational and financial advantages. This also explains the reasons for the dominance of RHD vehicles (99%) prior to the imposition of import restrictions on them in 2005 [15].

The likelihood that visibility for vehicle drivers affects merging or lane-changing crash risk was addressed by Sivak et al. [16, 17]. In North America, the critical merge or lane-change direction is to the driver's left. This represents merging into the traffic stream after parallel parking, merging onto freeways and changing to the fast lane on multi-lane facilities. Sivak et al. [16, 17] found that the position of vehicle 'A' and 'B' pillars relative to the driver's forward line of sight affected the risk of having a lane-changing crash. The greater the angle to the 'A' pillar and the smaller the angle to the 'B' pillar, the greater was the ratio of lane-change-to-total crashes. The researchers used a variety of North American, Japanese and European makes/models, all with an LHD system. Taking the average 'A' and 'B' pillar measurements from their study and shifting the driver seating position from LHD to RHD has the effect of increasing the relevant average 'A' pillar angle from 24.9° to 51.5° and decreasing the 'B' pillar angle from 122.5° to 101.3°. The net effect is a reduction in the unobstructed left-side visual field between 'A' and 'C' pillars of about 40%. On the basis of the results of Sivak et al. [16, 17], this would be expected to result in a substantial increase in lane-change risk [18].

For men aged 16 to 34, the "Sports – Right-Hand Drive" category presented, with respect to the "Comparable – Left-Hand Drive" category, increased risks of 22% and 41% for the years 2007 and 2008, respectively. Thus, the average increased risk for those two years was 32% [8].

A number of confounding effects, including sex and age, were taken into account in order to compare the accident risk for the two categories of vehicles as objectively as possible. Leaving aside distinctions of sex and age, the increased risks for "Sports – Right-Hand Drive" vehicles compared with "Comparable – Left-Hand Drive" vehicles were 101% and 137% for the years 2007 and 2008, respectively. Thus, for those two years, the average increased risk was 119% [8].

From the relative crash culpability risk analysis, the RHD vehicles had a 44% increased risk, compared to LHD vehicles, of crashing over a 4-year period (the average time from first policy date to data extraction). For their first two years, the increased risk of culpable crash causation from the Poisson regression was 46% and, based on survival analysis, the average time to first culpable crash for the RHD vehicles was 223 days (68% sooner) when compared to the time for the LHD vehicles which was 705 days. These results, taken together, clearly point to a driver-vehicle issue that produces high initial risk and which does not appear to ameliorate to any extent over several subsequent years. The problem would thus seem to be more than driver adjustment to a new control configuration and may reflect a continuing operational hazard [9].

Rupture diaphragm following blunt trauma occurs with an incidence of 3 to 8%, with right-sided rupture recognised with increasing frequency. This study aimed to investigate the influence of occupant position in right-hand drive (RHD) vehicles on the side of diaphragmatic injury. A retrospective analysis of the Scottish Trauma Audit Group database was performed to gather data on blunt diaphragmatic lacerations. Police records were also searched to ascertain the point of impact in the accidents studied. In total, 35 patients were studied, 25 drivers and 10 front-seat passengers. The incidence of right-sided rupture was 40% in drivers and 20% in FSPs. The incidence of associated pulmonary contusion, rib fracture and liver injury was also higher in drivers.

Given the small sample size, these differences were not statistically significant, but they show an interesting trend. The right side of a driver's body is more exposed to injury in RHD vehicles, a fact that explains the significant association between driver's side impact and right-sided rupture. As right-sided injury is more difficult to detect, it is important that a high index of suspicion is maintained, especially when managing drivers from RHD vehicles [19].

Collisions in the oncoming lane are one of the most common road accidents, with potentially devastating consequences [20, 21]. This manoeuvre is usually performed when passing an obstacle or overtaking a slower vehicle. To perform this manoeuvre safely, the driver must assess the situation beforehand and, in particular, make sure that the lane to be overtaken is clear and will not obstruct oncoming vehicles. In order to perform this manoeuvre, the driver must have the best possible view of the road and be able to correctly assess the distances to other vehicles or obstacles and their variations [22].

Another aspect of different side traffic and safety in relation to an ageing society was analysed by Foerch and Steinmetz [23]. They agree that the side of traffic directionality does not influence only neurologically healthy road users; however, due to the hemispheric lateralisation of neuropsychological functions as a result of ageing, an increasing number of individuals have attentional deficits that are more pronounced on the left side of the environment. The study found that this has a negative impact on right-hand traffic. Similar neurophysiological aspects such as handedness, eye movement bias and hemispheric lateralisation on driving safety at left- or right-side traffic were analysed by Lewis et al. [10]. The authors are confronted with the limitations of accident data when comparing differently oriented traffic systems, but the neuro-physiological aspect of human behaviour remains important. In general, it is found that both younger and older drivers react faster to right-sided obstacles [24], and older drivers drive safer on left-side traffic because of higher obstacle probability in the centre of the road.

In general, several key risks to the operation of RHD vehicles on the right-hand traffic are identified. This concerns visibility issues in overtaking or cases of driving at junctions (left turn) [25, 26]. Moreover, an increased probability of the driver's mistake is possible because of a lack of adaptation to vehicle control devices, as gear shifting and the handbrake are on the opposite side. In addition, the "blind spot" over a driver's left shoulder is sometimes mentioned by owners of RHD vehicles operating in a right-side roadway environment [27]. These factors cause insurance and repair costs to increase in countries not fitted to operate such vehicles.

However, the European Commission considers that if a vehicle meets the European Union's type-approval requirements, it can be driven safely in all Member States, regardless of whether the steering wheel is on the left or the right-hand side [28]. Commercial goods movement within Europe has given rise to situations where British heavy goods vehicles (RHD-HGVs) regularly operate on the Continent and Continental LHD-HGVs in Britain. The impact of the latter situation can be assessed from reported UK crash statistics [29], which point to an increased risk of turning and weaving collision involvements for LHD vehicles in the RHD environment. Foreign LHD-HGVs in 2005 were over 4.5 times more likely to be involved in crashes while turning, overtaking or lane changing (537 out of 1031 total collisions) than were domestic RHD-HGVs (2,340 out of 12,120). In addition, almost all (99%) of RHD-HGV side-swipe crashes involved lane changes to the right, compared to 52% for LHD-HGVs. While at least some of these differences could be due to unfamiliarity with UK driving conditions, the authors of the statistical report expressed their belief that they were "a consequence of the reduced direct field of view for drivers of left hand drive HGVs to the side and rear on the right (passenger) side of the vehicle" [18]. Brexit has disrupted the previously seamless flow of goods between the UK and the EU, creating new customs barriers, paperwork, delays and costs. These changes have had a significant impact on trade, but it continues to take place, so the problem of traffic safety has not essentially disappeared [30, 31].

National legislation generally allows the unrestricted use of a left-side traffic designed vehicle on its territory when it has been technically modified by moving the controls from the right to the left side or when fitted with the prescribed optional equipment [32]. In addition to the requirements for the installation of headlamps and a rear fog lamp, such a vehicle shall be fitted with additional indirect visibility devices – a video camera with a monitor and (or) a pair of mirrors which mirror the view as per the periscope principle. Mirrors should be certified and marked as a vehicle indirect visibility device. The video camera with monitor should ensure visibility in daylight and in the night or bad visibility conditions and must fulfil specific technical requirements such as resolution, capture angle, recording lighting, screen frequency and others.

In addition, it must be ensured that the additional equipment installed at the time of the accident does not interfere with the deployment of the airbags and that the equipment is installed in such a way that it reaches

the area of the windshield swept by the windshield wipers. Periscope mirrors must also provide glare protection. The requirements for the video camera are also problematic: the distance to objects transmitted by the camera must be the same as the actual distance, and the periscopic windshield mirrors and the camera with monitor must not cover more than 10% of the area of the windshield wiped by the wipers of the driver's and passenger's front windshields.

Information from the UK Ministry of Transport on the modifications that must be made before the vehicle can be driven is summarised briefly [33]. Specifically, it states that rear-view mirrors must provide proper visibility for left-hand traffic. The Irish Road test instructions do not mention the camera and monitor device, and when mirrors are mentioned, the steering position is not taken into account [8].

European Union type approval legislation for indirect vision systems has existed since 1971, with the first directive being 71/127/EEC [34]. This Directive has been replaced by several subsequent Directives which have added more and more advanced mirrors, required more types of vehicles to be equipped with them, established common mandatory requirements for mirrors, and allowed the use of other indirect vision systems [35].

The primary regulation for the use of the exterior wide-angle mirror, the exterior close-proximity mirror, the indirect vision camera and monitor device, and the periscope front mirror is contained in Regulation No. 46, adopting uniform provisions for indirect vision devices and for the motor vehicles on which these devices are mounted. The actual regulation of the exterior wide-angle mirror, the exterior close-proximity mirror, as well as the indirect vision camera and monitor device in Regulation No. 46 [36] is, in most cases, designed for both left-hand drive and right-hand drive vehicles. The only differences are in the explanatory figures for the exterior rear-view mirror (*Figures 1 and 2*). Their interpretation of right-hand drive vehicles would require them to be rotated vertically about the horizontal axis. This is done in accordance with Regulation No. 46 and is presented in this chapter.

After a comprehensive literature review, we found that there is a significant lack of research in this area, so the aim of this article was to assess the accident risk for right-hand drive vehicles and compare it with the accident risk for comparable left-hand drive vehicles. An additional part of the study involves functional testing of special indirect vision equipment under real traffic conditions.

## 2. RESEARCH FRAMEWORK AND METHODS

In this research, the visibility evaluation tests are conducted in order to assess the driver's ability to observe the traffic situation during an overtaking manoeuvre. The driver must have the best possible sight distance of the road and be able to correctly estimate the distances to the vehicles ahead and to oncoming obstacles, as well as to keep track of their positions in time. The aim of this research is to evaluate the use of auxiliary equipment to compensate for the limited visibility of RHD vehicles in left-side traffic conditions. Following this, the research is organised according to these three main phases:

- 1) Literature review. A comprehensive literature review was carried out on the topic, including traffic safety statistics, regulation of RHD vehicles, driver visibility issues and traffic accident analysis.
- 2) Graphical analysis. The difference in visibility of RHD vehicles during an overtaking manoeuvre was evaluated using geometric dependencies of the driver's gaze lines and obstacle visibility for calculating the visual distance.
- 3) Experimental tests. Field tests were carried out using RHD vehicles with additional indirect vision equipment in order to assess their performance in real traffic conditions.

Two different vehicles, a BMW X3 (RHD) and a Toyota Prius (LHD), were used during experimental tests in order to compare different driver positions on sight distance. A periscope mirror and a video camera with a monitor were used as indirect vision tools inside the test vehicle.

The tests were conducted in three phases:

- 1) Static visibility test. The dependence of the sight distance using the periscope mirror and the camera on the distance to an obstacle was determined.
- 2) Dynamic visibility test. The usability of indirect vision equipment in real traffic conditions during overtaking manoeuvres was investigated.
- 3) Comparison of visibility performance. The differences in visibility between the periscope mirror and the camera image on the monitor were compared.

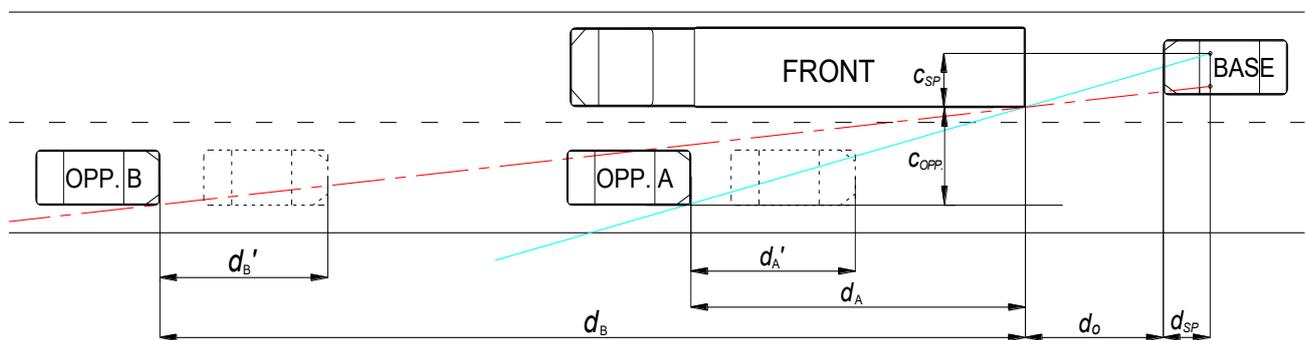
Although the tests were carried out in different modes, the study has several limitations:

- 1) Only two light vehicle models were used, so the findings may not be fully generalisable to the entire RHD fleet.
- 2) The effectiveness of indirect vision equipment depends on various environmental conditions (lighting, weather conditions), which were not fully standardised during the study.

This methodology allows for investigating the visibility issues of RHD vehicles in right-side traffic conditions and assessing the impact of special indirect vision equipment on road safety.

### 3. CASE ANALYSIS FOR VISUAL DISTANCE DURING OVERTAKING

The driver’s position in the car is important for a good viewing angle, which is usually adjusted according to the direction of traffic organisation. The situation for a pre-collision manoeuvre from the perspective of a left-hand drive vehicle and a right-hand drive vehicle (BASE) is shown in *Figure 1*.



*Figure 1* – Scheme for comparison of vision geometry of RHD and LHD vehicles in right-side operation traffic: BASE – base vehicle, OPP.A – opposite obstacle (oncoming vehicle) seen from the position of the RHD vehicle driver, OPP.B – opposite obstacle (oncoming vehicle) seen from the position of the LHD vehicle driver or indirect vision equipment, FRONT – front obstacle (chased vehicle)

In addition to the driver’s position in the car, the width and distance of the front obstacle are important for the best possible angle of vision. In the driving situation shown in *Figure 1*, the front obstacle is a truck that is wider than the car (2.55 m). On a single-lane road (3.5 m wide) in each direction, the angle of view and the obstacle detection distance of the approaching obstacle from different driving positions (LHD and RHD vehicles) differ significantly ( $d_A < d_B$ ) when the car approaches the obstacle within its width. To compensate for this lack of visibility, RHD drivers tend to drive as far as possible to the left of the obstacle in front of them (the quorum car) before overtaking. The oblique lines in the figure, drawn from the driver’s position of the RHD vehicle and the driver’s position of the LHD vehicle (or from indirect vision equipment), show the lines of sight of oncoming cars. These lines of sight are geometrically limited by the size of the vehicle FRONT; however, the main influencing factor is the position of the driver (RHD or LHD vehicle sitting position).

In many cases, the car will even cross into the oncoming lane to adequately assess the situation, increasing the risk of an unexpected collision. Another alternative to assess the situation is to look at the traffic flow while staying as close as possible to the obstacle in front. In this case, however, the overtaking manoeuvre takes longer, a larger safety distance is required, and the above-mentioned situation assessment is still performed when approaching the obstacle to be overtaken by pulling out to the left of the obstacle.

The traffic simulation assumes that all cars drive in the middle of the lane. Then, according to the current objects’ positions (*Figure 1*), the distance  $d_i$  from the base vehicle BASE to the opposite obstacle OPP. is:

$$d_i = \frac{(c_{SP} + c_{OPP.})(d_o + d_{SP})}{c_{SP}} - d_{SP} \tag{1}$$

where:  $i$  – indicator of opposite obstacle A or B (*Figure 1*);  $c_{SP}$  – lateral distance from base vehicle sensing point to left side of front obstacle;  $c_{OPP.}$  – lateral distance from left corner of front obstacle to opposite obstacle outside;  $d_o$  – distance from base vehicle front to front obstacle;  $d_{SP}$  – distance from base vehicle sensing point (SP) to its front.

Lateral distances are calculated according to obstacles and traffic line lateral dimensions:

$$c_{SP} = \frac{(b_{FRONT} - b_{BV})}{2} + (b_{BV} - b_{SP}) \tag{2}$$

$$c_{OPP.} = \frac{(b_{tr.l.1} - b_{FRONT})}{2} + \frac{(b_{tr.l.2} - b_{OPP.})}{2} + b_{OPP.} \tag{3}$$

where:  $b_{FRONT}$  – width of front obstacle;  $b_{BV}$  – width of base vehicle;  $b_{SP}$  – lateral distance from base vehicle sensing point to its left side;  $b_{tr.l.1}$  – width of base vehicle’s traffic line;  $b_{tr.l.2}$  – width of opposite obstacle’s traffic line;  $b_{OPP.}$  – width of the opposite obstacle.

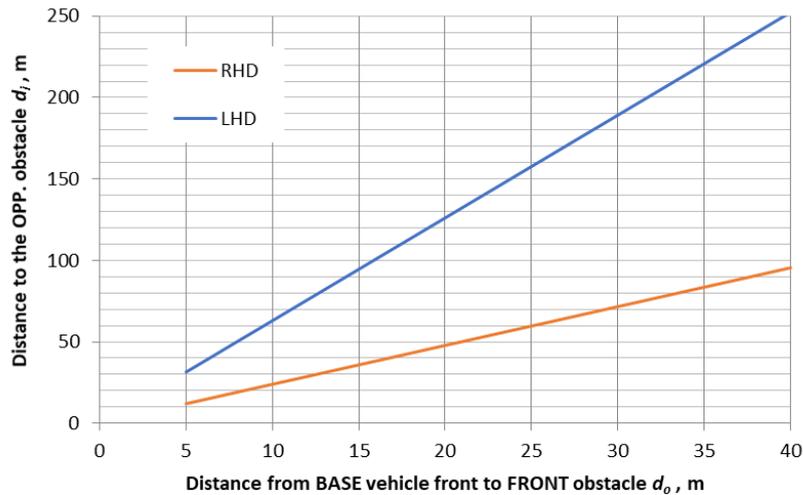


Figure 2 – Relation between distance to the opposite obstacle  $d_i$  and RHD / LHD vehicle in right-side operation traffic

Since the lateral position of the vehicles relative to the road ( $c_{SP}$ ,  $c_{OPP.}$ ) and the longitudinal sensing point of the base vehicle ( $d_{SP}$ ) are assumed to remain unchanged, the main indicator is the distance of the base vehicle to the front obstacle ( $d_{SP}$ ). The dependence of the look-ahead distance to the opposite obstacle on the initial distance to the front obstacle is shown in Figure 2.

Figure 2 shows that as the distance to the obstacle increases, the LHD vehicle has a faster increase in visibility than the RHD vehicle. This means that despite the increase in visibility, the negative effect of the RHD vehicle increases.

Adding to this, perception-reaction time is considered as urgency for both approaching and braking conditions [37]. The conducted research proves that drivers are more likely to apply harder brakes if they observe a higher level of urgency. This is applicable to this study on right-hand drive car handling and traffic visibility issues. In psycho-physiological terms, every driver has an individual reaction time. For example, higher traffic density may lengthen a driver’s reaction time [38], so that an approaching obstacle is recognised with a delay, i.e. the obstacle is approached by an additional distance  $d'$  during the reaction and visual perception time:

$$d' = v_{OPP.}(t_r + t_p), \tag{4}$$

where:  $v_{OPP.}$  – speed of the opposite vehicle;  $t_r$  – base vehicle driver’s reaction time to visual obstacle;  $t_p$  – base vehicle driver’s visual perception time.

#### 4. THEORETICAL VISUAL DISTANCE USING SPECIAL INDIRECT VISION EQUIPMENT

Based on the aspects of some countries’ legal frameworks discussed in the introduction, if right-hand drive (RHD) vehicles are allowed to drive on the right without restriction, additional equipment shall be provided to compensate for the reduced visibility of oncoming traffic. This includes measures such as interior periscope mirrors or rear-view cameras with monitors (Figure 3) to provide a left view for the driver seated on the right side of the vehicle. In this case, the additional time required for the driver to react and perceive the image through the indirect vision devices used must be considered.

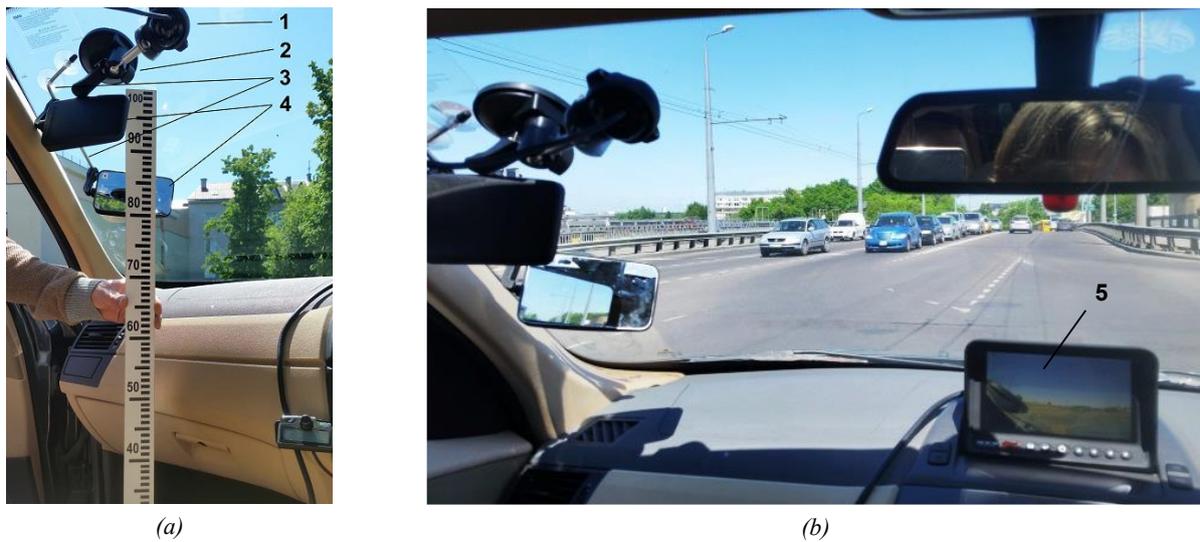


Figure 3 – Indirect vision equipment for RHD vehicle in right-side operation traffic: a) 1 – Camera, 2 – Camera mount, 3 – Periscopic front mirror mount, 4 – Periscopic front mirror; b) 5 – Camera monitor

The addition of indirect vision devices to the driver’s visual chain shifts the line of sight from the RHD to the LHD vehicle position (Figure 1, red line). The driver’s response to indirect vision devices then increases the distance travelled by an additional distance compared to direct vision:

$$d_B' = v_{OPP,B}(t_r + t_p + t_{eq}), \tag{5}$$

where:  $t_{eq}$  – the base vehicle driver’s visual perception for traffic identification using indirect vision equipment.

The additional reaction to perceive the indirect image ( $t_{eq}$ ) reduces the effectiveness of the additional tool – the approaching obstacle is seen and perceived at the additional distance  $d_B'$ . The dependence of the distance to the oncoming obstacle on the additional reaction time (+0.4 s, +0.8 s, +1.2 s) is shown in Figure 4.

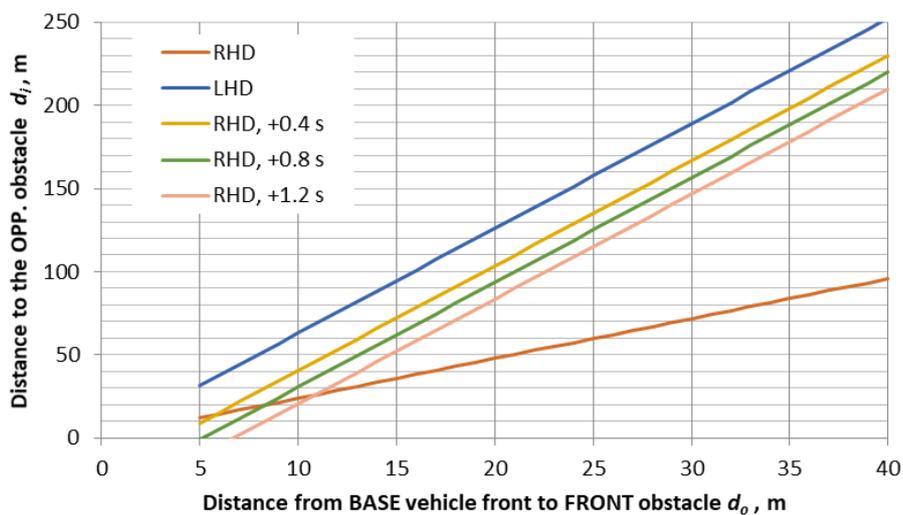


Figure 4 – Relation between distance to the opposite obstacle  $d_i$  and RHD / LHD vehicle in right-side operation traffic, including additional time delay for indirect vision driving at a speed of 90 km/h

Figure 4 shows that the opposite obstacle identification distance decreases with the length of the additional response to indirect image perception ( $t_{eq}$ ). This means that the driver has a shorter distance to manoeuvre. A long reaction time of the driver and the perception of the image by the indirect vision devices can lead to a late detection of the approaching oncoming car with a zero or negative distance. The difference in obstacle identification distance for direct and indirect vision (additional required distance of vision), depending on the delay time and the distance to the obstacle, driving at 90 km/h, is shown in Figure 5.

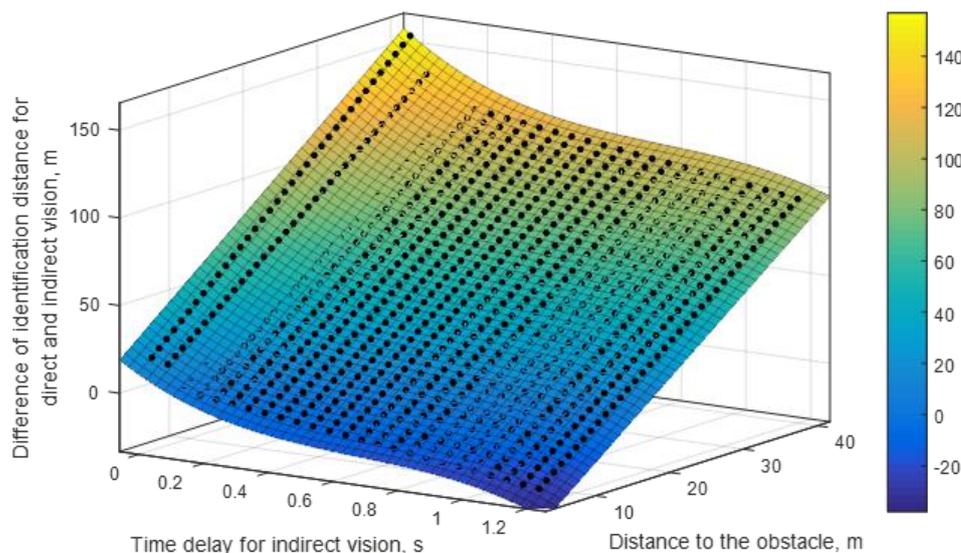


Figure 5 – Difference in obstacle identification distance for direct and indirect vision driving at 90 km/h

Increasing the driver's reaction and perception time when using indirect vision devices reduces the safe distance to the obstacle (reduces the time to collision) in all cases of distance to the obstacle. The additional reaction and perception time involves complex psychophysiological abilities of the driver since the accurate identification of a potential obstacle in an indirect vision device is complicated by the specificity of the device and the environmental conditions. The periscope mirror must be viewed accurately in a specific area of the mirror because, as shown in *Figure 3(b)*, the driver's overall field of view is affected by considerable visual noise, such as the two mirror housings and the constantly changing road and traffic environment. The camera and monitor system are dependent on lighting, direct sunlight, etc. All of these can significantly affect the analysed incremental reaction time.

## 5. FUNCTIONAL TESTING OF OBSERVATION QUALITY USING A PERISCOPIC MIRROR AND A CAMERA

A practical test of the indirect vision equipment for a right-hand drive car in right-hand traffic was carried out under real traffic conditions in two light-duty cars: a BMW X3 (built in 2004, designed for left-hand traffic and with a steering wheel on the right side) and a Toyota Prius (built in 2005, with the optional equipment fitted and the visibility conditions monitored with the driver sitting on the right side of the car).

For the practical visibility tests, a periscope front mirror was used, which is not a defined term in the legislation and therefore, there is no requirement to mark such an indirect vision device. The device consists of two mirror surfaces of  $135 \times 75$  mm, adjustable by means of hinges, and a common metal frame fixed to the glass by means of vacuum clamps. A further test was carried out using an MXN22CW camera and an MXN-P7 monitor, certified according to [36, 39, 40], connected by an analogue or digital signal transmission cable.

The tests were carried out indoors, under urban and off-road conditions:

- The purpose of the static detection evaluation test was to determine the dependence of the field of view of the periscopic mirror and the camera mounting position on the distance of the vehicle to an opaque obstacle in front. By mounting the camera and the periscopic mirror in a single line parallel to the longitudinal axis of the vehicle, the field of view bounded by the oncoming obstacle is analysed without any difference in the field of view;
- The static detection distance estimation test was designed to assess the ability to discriminate selected objects from their surroundings using a periscopic front-view mirror, camera and monitor. The test consists of parking the vehicle in front of a non-transparent obstacle in such a way that the driver on the right side of the vehicle has difficulty in seeing the simulated oncoming traffic. The camera monitor does not provide sufficient visibility to detect the obstacle, while the periscope mirror does detect the obstacle, but only on a small part of the mirror surface. The majority of the surface consists of extraneous primary and secondary images;

- The traffic detection test was designed to determine the ability to monitor other moving vehicles using a periscope, front view mirror and camera. During the test, the vehicle with the additional indirect vision equipment was parked on a city street, at the side of the road, at 7.5 m from another vehicle in front. Comparing the image on the monitor screen with the image in the periscope's front mirror, the image captured by the cameras distorts the natural geometry of the space. Objects (vehicles, etc.) in the captured image appear much further away than they are. This negative effect is greatly reduced when viewed through a periscope front mirror.

On the monitor screen, the camera's wide field of view makes it easy to see a vehicle in proximity (Figure 6 (a)), while the vehicle is not yet visible in the periscope mirror. When the vehicle is further away, the image of the vehicle on the monitor screen is significantly reduced, while the image in the periscope mirror remains clear and natural enough (Figures 6 (b) and 6 (c)). Vehicles further away are very difficult to identify on the monitor screen and are still quite visible in the periscopic front view mirror (Figures 6 (d) and 6 (e)), but the detection and perception time is increased due to the double face-to-face and the relatively narrow target view area. As in the previous cases, it should be noted that the counter-image in the periscopic front mirror does not cover the entire mirror surface. The periscopic mirror must be carefully adjusted to obtain a sufficiently large part of the front view, which is uncomfortable from the right-hand driving position.

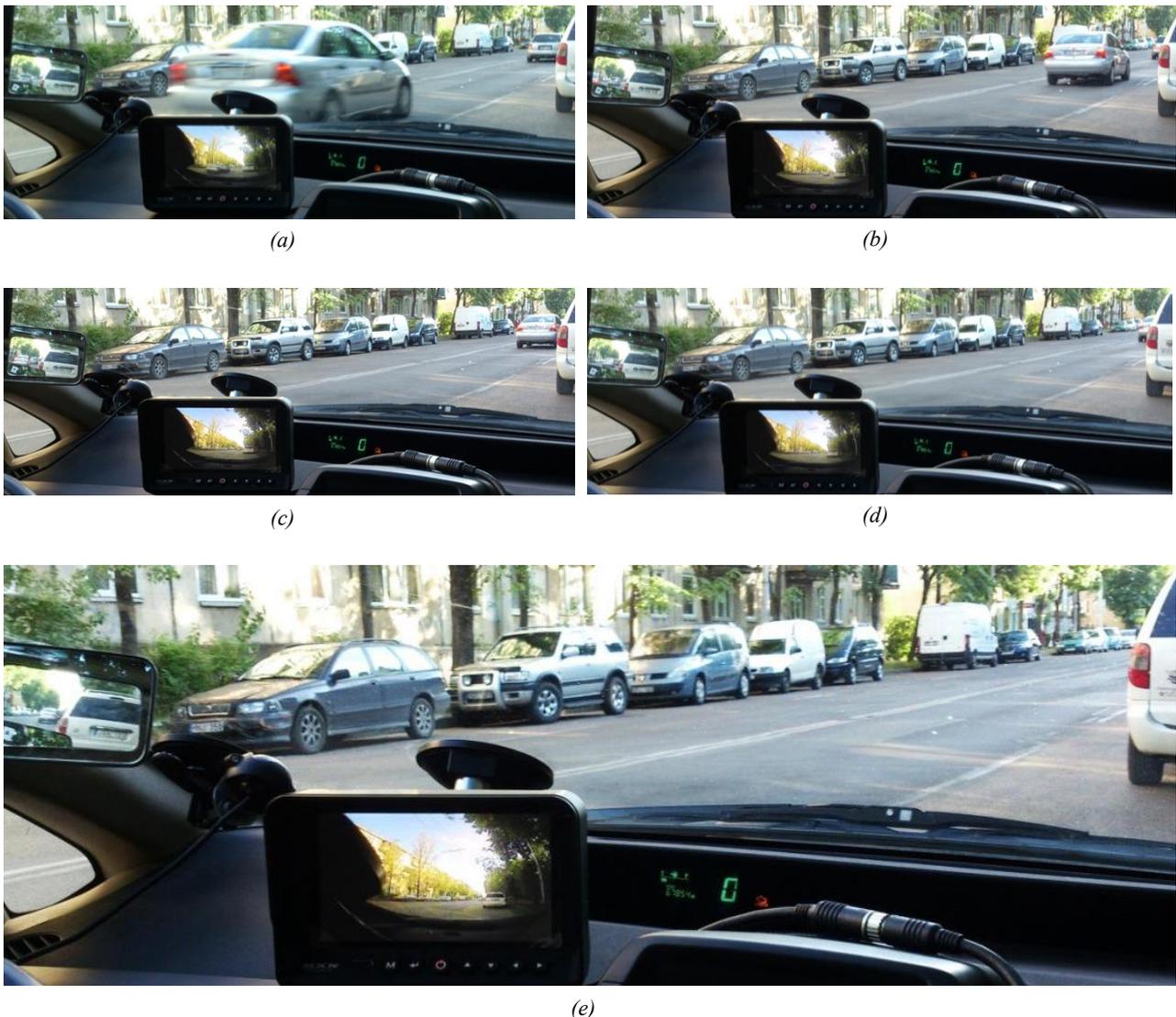


Figure 6 – Comparing the image of vehicles at different distances in a periscope mirror and on a monitor



Figure 7 – Image comparison using: a)  $0 \times$  zoom; b)  $2 \times$  zoom; c)  $4 \times$  zoom

Having compared the cameras and identified the negative effect of zooming out, a zooming-in alternative is presented (Figure 7). This solution eliminates the zoom-out effect and concentrates the distant image, which is relevant to the problem of visibility of left-hand drive vehicles with right-hand steering.

## 6. DISCUSSION

In terms of visibility for the driver, it is self-evident that LHD vehicles are designed with right-side traffic operation in mind and vice versa for RHD; therefore, some difficulties in mixing design and operating criteria can be expected.

When analysing the situation of overtaking manoeuvre with LHD and RHD vehicles in right-side operation traffic, the driver of the BASE vehicle aligns with the left gauge of the front obstacle (vehicle FRONT) (Figure 8). This is done in order to improve the visibility of a possible oncoming obstacle, i.e. to extend the distance to the OPP. vehicle. In the case of the movement scheme (Figure 1), the visibility distance to the oncoming obstacles OPP. A and OPP. B increases by +13.7 m and +50.5 m, respectively (when the BASE vehicle approaches the FRONT vehicle by 5 m before overtaking). At time  $T_1$ , the RHD vehicle approaches the FRONT vehicle, but cannot start overtaking, because OPP. A aligns with the FRONT vehicle and forms a direct collision. OPP. A aligns with the BASE vehicle at time  $T_2$ .

In the case of a LHD vehicle or RHD with additional vision equipment, the OPP. obstacle is already visible at position OPP. B, and this vision distance is sufficient to start the overtaking manoeuvre (time point  $T_3$ ). In this case, the required time interval  $T_4 - T_3$  is sufficient for the BASE vehicle to complete the overtaking manoeuvre. The last time point of the situation,  $T_5$ , shows the overtaking of OPP. B by the FRONT vehicle.

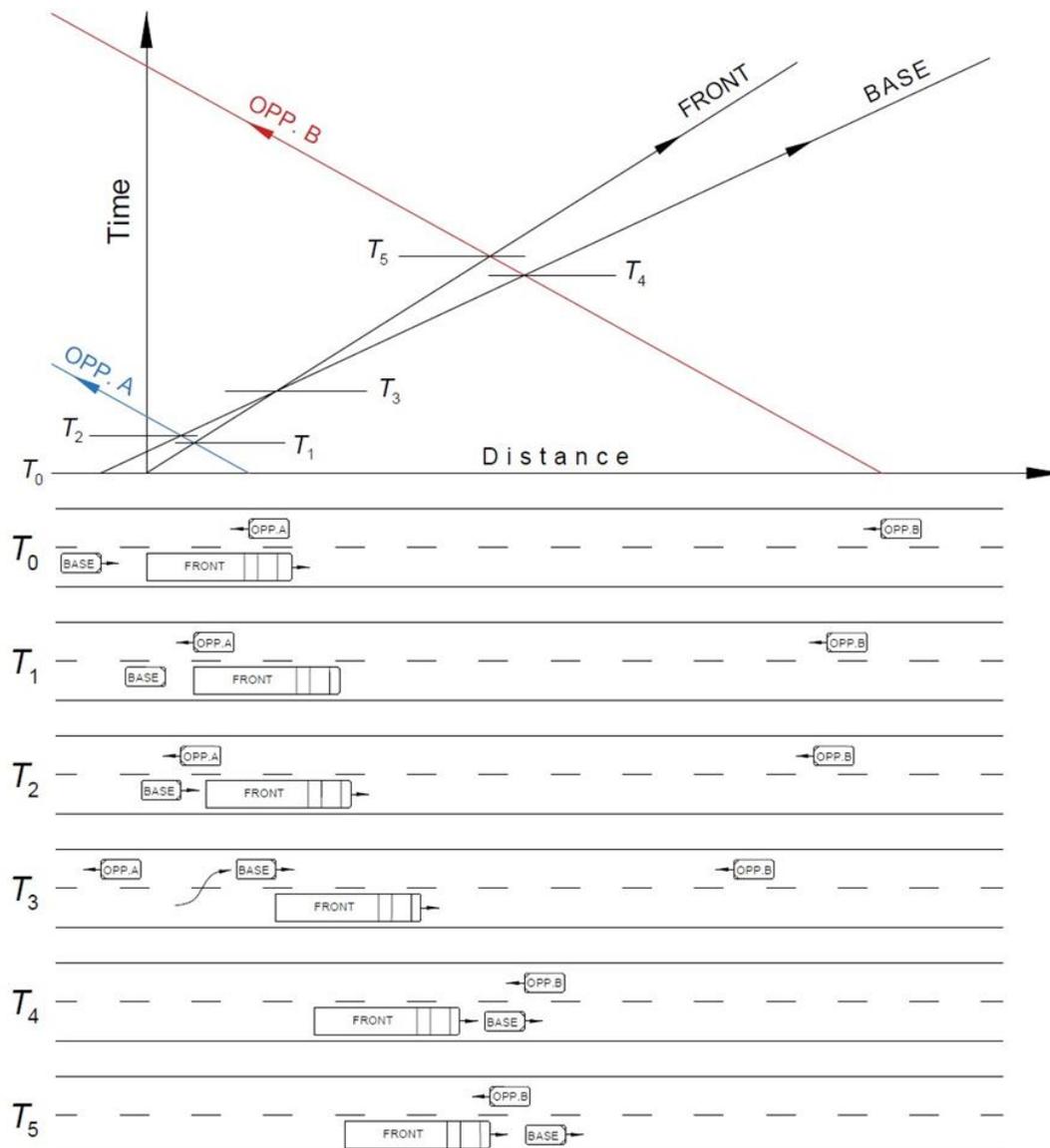


Figure 8 – Analysis of the right side traffic situation during overtaking manoeuvre with LHD and RHD vehicles

The periscope’s front mirror allows easy identification of objects (the size of a benchmark) at distances of 35 m and 65 m and, unlike cameras, does not distort the image. The periscope mirror selected for the tests requires careful adjustment to minimise the presence of extraneous images on the secondary surface of the mirror during the transmission of the frontal image, which cannot be completely avoided due to the specific nature of this device. Adjustment from the right-hand driving position is not possible, and the driver must bend down and reach for the mirror with their hand. Such actions while driving pose a serious risk to road safety.

Small objects (the size of a cone) up to 35 m from the driver seated on the right-hand side of the vehicle are difficult to see with the cameras and monitors selected for testing, including those certified to the requirements for indirect vision devices.

Due to the wide field of view of the cameras used in the field tests (120–170°), the image on the monitors used distorts the natural image, and other vehicles can only be seen at close range, up to 10 meters. The periscope’s front mirror, when adjusted for distant vision, does not provide a close-up image.

The certified camera used in the field tests is the best at capturing images in the darkest hours of the day, with the least colour balance distortion and the ability to identify close objects in total darkness.

In right-hand traffic, a comparison of the overtaking manoeuvre of LHD and RHD vehicles shows that the distance from the reference RHD vehicle to the oncoming obstacle is 2.7 times shorter than the distance from the reference LHD vehicle to the oncoming obstacle.

For RHD vehicles, the use of additional equipment to compensate for the reduced visibility of oncoming traffic and the resulting additional time for driver reaction and visual perception increases the distance from

the baseline RHD vehicle to the oncoming obstacle by a factor of 1.4 but is still about two times less than the distance from the baseline LHD vehicle to the oncoming obstacle.

The observed compensation of the negative zoom effect of cameras by zooming in requires further investigation. This requires an assessment that goes beyond the specific image capture equipment used in vehicles. An analysis of alternative CCTV systems and monitors would allow the provision of technical equipment for high-quality frontal area imaging.

It is recommended that the periscopic mirror and camera be mounted in a line parallel to the longitudinal axis of the vehicle due to the different fields of vision created. A prerequisite for selecting the mounting position is that the supplementary indirect vision equipment must transmit the image through the area cleaned by the vehicle's windscreen wipers.

To avoid any possible impact of the supplementary equipment in the event of airbag deployment, the camera shall be mounted below the periscopic front view mirror.

The concept and definition of a periscope windshield mirror and periscope in general could not be found in the transportation legislation of either the European Union or the United Nations Economic Commission for Europe. It should be noted that the periscope mirror has the following disadvantages:

- It may not be possible to install them in such a way that the driver has a sufficient field of vision in accordance with the requirements of [41];
- The resulting field of view is relatively small due to the limited maximum area of the mirrors;
- Difficult to adjust the field of view from the driver's seat to the right of the steering wheel;
- Even a small change in the driver's seating position would result in an inadequate field of view;
- Additional barrier in the event of a passenger impacting the front panel;
- Possible obstacle in case of airbag deployment;
- Lack of standardisation – not certified;
- A new definition is required.

With respect to wide-angle exterior mirrors, close-proximity exterior mirrors, as well as indirect vision camera and monitor devices, the United Nations Economic Commission for Europe (UN/ECE) Regulation No. 46 on uniform provisions concerning the approval of devices for indirect vision and of motor vehicles equipped with such devices applies to right-hand-drive vehicles equipped with a steering wheel located on the right side of the vehicle. The periscope front mirror is not a legally defined and currently problematic means of providing the driver of a right-hand-drive vehicle with a sufficient field of indirect vision on right-hand-drive roads.

## 7. CONCLUSIONS

This research, both from theoretical and field perspectives, has shown that, although the RHD vehicle meets the requirements for type-approval, its operation from a safety point of view varies considerably from the traffic organisation side. The main problems are related to visibility, in particular the visibility of oncoming traffic, and the retrofitting of equipment to compensate for the difficulties is also problematic. These are mainly related to the specific characteristics of the equipment and their suitability for long-distance oncoming traffic. In addition, any additional device in the interior of the vehicle can be a potential source of danger in the event of an accident (e.g. the safety airbag deploys).

It is well known that the driver behaviour, which is related to knowledge and driving skills, has the main influence on road accident avoidance; however, human behaviour is naturally based on physical and mental abilities. For road traffic cases, those psychophysiological skills are mainly associated with reaction time and perception of a specific obstacle. Legal RHD vehicle operation on right-side traffic requires formally specified equipment, such as a video camera with a monitor and a periscopic view mirror. These devices must help drivers in terms of better traffic observation; however, device adjustment, operation under various lighting conditions and interaction with humans raise new issues. One of these is related to the driver's reaction time to the screen or mirror image, as it needs to follow a specific image zone for correct possible obstacle recognition. Moreover, video camera and monitor usage create additional challenges, such as the camera's exposure to the Sun and, most crucially, the perspective of the distant image. The research shows that different camera optics settings can significantly change the driver's perceived distance to the object on the monitor. This is a critical risk when preparing for an overtaking manoeuvre on country roads, where speeds are higher and the variation of the viewing distance directly influences the driver's actions.

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