Connected Motorcycle Consortium

Powered Two Wheeler Conspicuity

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Index

1 Introduction

This white paper aims to investigate the status quo of passenger car Advanced Driving Assistant Systems (ADAS) detecting Powered Two Wheelers (PTWs). The focus is to analyze current research, academic papers, technical reports, and other studies dealing with the detection of PTWs. The research questions which shall get analyzed in this white paper are:

a) What are the characteristics of existing synthetic PTW targets and what is their intended use?

b) What are the weaknesses and limitations of current sensor systems regarding PTW detection?

c) What are the differences between PTW conspicuity and other road users (cars, bicycles, pedestrians) conspicuity for current sensor systems?

d) What are the similarities between PTW conspicuity and other road users (cars, bicycles, pedestrians) conspicuity for current sensor systems?

e) What methods are proposed to improve PTW conspicuity for such sensors?

The mentioned research questions are approached from different perspectives, such as consumer protection, legislation, vehicle manufacturers and a scientific point of view.

2 Consumer Protection

2.1 Research Questions Addressed

The following chapter describes consumer protection requirements that are about the detection of PTWs. The content of this chapter shall also give a better understanding of the characteristics of existing PTW synthetic targets and their intended use.

The European New Car Assessment Program (Euro NCAP) will integrate use-case scenarios containing the detection of PTW by car ADAS (i.e. Autonomous Emergency Braking, Forward Collision Warning, etc.) in their assessment program.[1]

To assess the performance of this car ADASs a synthetic target was developed in the motorcycle user's safety enhancement project (MUSE).[2]

This chapter introduces Euro NCAP and its five-star rating system. Moreover, the characteristics and the development of the Global Motorcycle Target (GMT) are described.

The end of the chapter generates an overview of intended Euro NCAP use-case scenarios that deal with PTW detection by car ADAS.

2.2 The European New Car Assessment Program

The European New Car Assessment Program (Euro NCAP) is a European voluntary car safety performance assessment program. It provides European consumers with information regarding the safety of passenger vehicles. The key feature is a star-based rating to evaluate the performance of vehicles in a variety of crash tests. Taking part in those crash tests is voluntary, with vehicle models either being independently chosen by Euro NCAP or sponsored by the manufacturers.[3]

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[1] Euro NCAP 2025 Roadmap (https://cdn.euroncap.com/media/30700/euroncap-roadmap-2025-v4.pdf, accessed on 27.03.2022)

[2] MUSE Deliverable 2.1 (https://www.utacceram.com/images/utac/metiers/muse/reports/d2-1-motorcyclist-target-specifications.pdf, accessed on 27.03.2022)

[3] Euro NCAP (www.euroncap.com/en, accessed on 29.04.2022)

2.2.1 Euro NCAP Rating

The five-star safety rating system continuously evolves as technology matures and innovations become available. This means that tests are updated regularly, new tests are added, and star levels are adjusted to the current “state-of-the-art". For this reason, the year of the test is vital for a correct interpretation of a car’s rating.[4]

★★★★★ 5-star safety: Overall excellent performance in crash protection and well equipped with comprehensive and robust crash avoidance technology.

★★★★☆ 4-star safety: Overall good performance in crash protection and all-around; additional crash avoidance technology may be present.

★★★☆☆ 3-star safety: At least average occupant protection but not always equipped with the latest crash avoidance features.

★★☆☆☆ 2-star safety: Nominal crash protection but lacking crash avoidance technology.

★☆☆☆☆ 1-star safety: Marginal crash protection and little in the way of crash avoidance technology.

☆☆☆☆☆ 0-star safety: Meeting type-approval standards so can legally be sold but lacking critical modern safety technology.

2.2.2 Background of considering PTW detection in Euro NCAP rating

PTWs have great potential in the future mobility . Not only will the current importance of PTWs in leisure continue, but also they will have a growing role in individual transport and commuting, due to their greater efficiency in urban traffic as a result of their small size and environmental

[4] How to read the stars (https://www.euroncap.com/en/about-euro-ncap/how-to-read-the-stars/, accessed 27.03.2022)

footprint. Unfortunately, according to accident statistics, PTW riders are more likely to be killed or seriously injured in an accident than other types of road users.[5]

The reported number of casualties for PTW riders is high and they are therefore typically included in the Vulnerable Road Users group along with pedestrians and pedal cyclists. PTW riders are considered to be a special case within this group because they share the same roads with cars and travel at similar speeds.

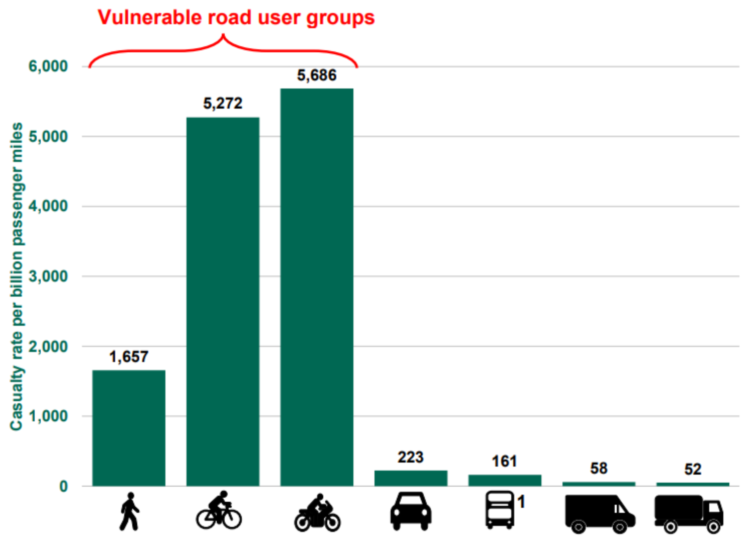

Figure 1: Casualty rate per billion passenger miles by road user type, Great Britain [6]

"In recent years, we have observed a decrease in the number of deaths on the roads. However, this reduction is not equal for all the different road users. If we have a look at the evolution of the mortality depending on the type of road user, we see that, while in the case of cars it has been reduced by 50%, in the case of the motorcyclist this reduction has been only 30%." (European Commission, Directorate-General for Transport 2016)

Concerned by this problem, the French Government decided in 2015 to perform a study in collaboration with UTAC to evaluate the accidentology of the motorcyclists and the possibility of avoiding them or mitigating the consequences using the new ADAS systems. Knowing the importance of Euro NCAP in motivating the OEMs to invest in safety, in May 2016 the Interior Minister Mr. Bernard Cazeneuve, and the transport minister Mrs. Ségolène Royal wrote a letter

[5] ACEM, In-Depth Investigation of Motorcycle Accidents, Version 2.0 of the MAIDS report (http://www.maids-study.eu/pdf/M AIDS2.pdf, accessed on 12.04.2022)

[6] Department of Transport, *Reported Road Casualties in Great Britain: 2018 annual report.* (https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/834585/reported-road-casualties-annual-report-2018.pdf, accessed on 27.04.2022)

to Euro NCAP asking for a safety rating involving PTWs. At the beginning of 2017 Euro NCAP included the scenarios with motorcycles in their Roadmap 2020/2025. [7]

To perform the NCAP - use case scenarios, the so-called Global Motorcyclist target (GMT), a standardised PTW target was developed. The GMT shall be representative of a wide scope of different PTWs, which will be further evaluated in the following chapters.

2.2.3 Motorcyclist target used for NCAP Tests

The use-case scenarios in the following sections use the Euro NCAP Motorcyclist target dressed in black shirt and blue trousers, as shown in Figure 2. The target replicates the visual, radar, LIDAR, and Photonic Mixer Device (PMD) attributes of a typical motorcyclist and can be impacted without causing significant damage to the vehicle under test (VUT).

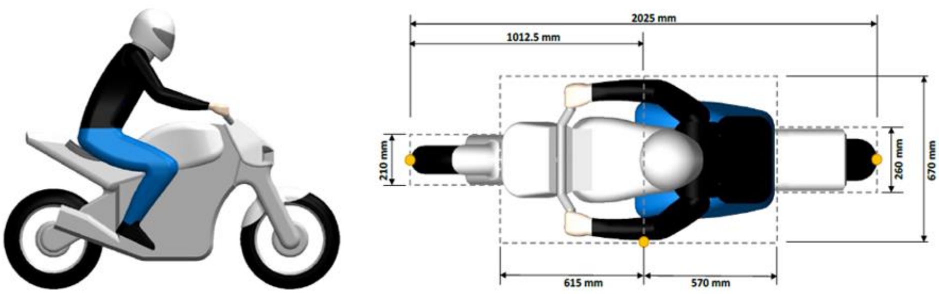

Figure 2: GMT – Global Motorcyclist Target [7]

The Euro NCAP Motorcyclist Target used in this document is specified in the deliverable D 2.1 of the MUSE project. The ISO 19206-5 describes the characteristics of the Motorcyclist target. Surrounding the GMT, a virtual box is defined to determine the impact speed. The dimensions of this virtual box are shown in Figure 2 above with reference points on the side mid-position, the most forward point on the front wheel, and the most rearward point on the rear wheel. To ensure repeatable results, the propulsion system and GMT target must meet the requirements as detailed in ISO 19206 Road vehicles “Test devices for target vehicles, vulnerable road users (VRU), and other objects, for assessment of active safety functions”.

The GMT targets are designed to work with the following types of sensors:

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[7] MUSE Deliverable 4.1 Car to PTW AEB Test Protocol (https://www.utacceram.com/images/utac/metiers/muse/reports/d4-1-car-to-ptw-aeb-test-protocol.pdf, accessed on 12.03.2022)

• Radar (24 and 76-81 GHz)

• LIDAR

• Camera

• Ultrasonic sensors

2.3 NCAP Use Case Scenarios Roadmap

Following the outcome of MUSE accident statistics, the Euro NCAP use case scenario road map was developed. The selected use cases represent accident scenarios, that are mainly caused, because the car driver did not recognize the PTW rider. Therefore, these use cases have the highest potential to improve PTW safety through a better PTW conspicuity.

Table 1: Use case scenario roadmap [8]

	Car-to-Motorcyclist Rear stationary		Car-to-Motorcyclist Rear braking	Car-to-Front turn across path	Car-to-Motorcyclist oncoming	Car-to-Motorcyclist overtaking	Car-to-Motorbike Front
Type of Test	AEB	FCW	AEB/ FCW	AEB	LSS	LSS	AEB
VUT Speed [km/h]	10 - 60	30 - 60	50	10, 15, 20	72	50, 72	10, 15, 20
Target Speed	0		50	30, 45, 60	72	60, 80	30, 40, 50
Impact Location [%]	50		25	50	10	Rear-wheel	18,4
Lightning Condition	Day		Day	Day	Day	Day	Day
est. NCAP implementation	2023		2023	2023	2023	2023	2025

The following sub-chapters explain the NCAP use case scenarios which test ADAS systems like Autonomous Emergency Braking (AEB), Forward Collision Warning (FCW), and Lane Support Systems (LSS) against their ability to detect and react on PTWs.

2.3.1 Car-to-Motorcyclist Rear stationary (CMRs)

The CMRs scenario will be performed in 5km/h incremental steps in speed within the ranges and impact location at 50% of the width of the VUT as shown in the picture below.[8]

[8] European New Car Assessment Program test protocol – AEB/LSS VRU systems (https://cdn.euroncap.com/media/64154/euro-ncap-aeb-lss-vru-test-protocol-v400.pdf, accessed on 12.04.2022)

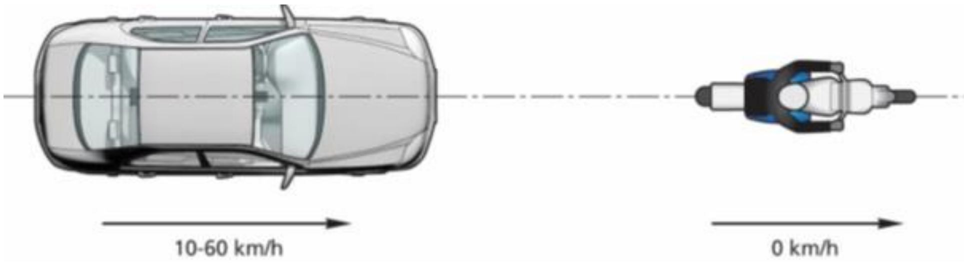

Figure 3: CMRs [8]

2.3.2 Car-to-Motorcyclist Rear braking (CMRb)

The CMRb tests will be performed at a fixed speed of 50km/h for both, VUT and motorcycle target with a 12 and 40m headway. The target decelerates with 4 $^{m}/_{s^2}$ until the vehicle's speed equals 1 km/h. The impact location will be at 25% of the width of the VUT.[8]

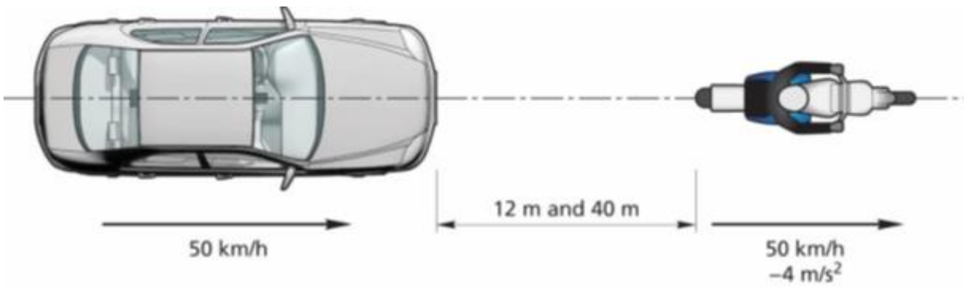

Figure 4: CMRb [8]

2.3.3 Car-to-Front turn across path (CMFtap)

The CMFtap scenario will be performed with all combinations of VUT speeds of 10, 15, and 20 km/h combined with the target speeds of 30, 45, and 60 km/h. Thereby the VUT turns across the target's path following a prescribed line. The GMT will be following a straight line driving in the opposite direction in the lane adjacent to the VUT's initial position. The paths of the VUT and target will be synchronised so that the front reference point of the target impacts the VUT at 50% of the width of the VUT if no system reaction occurs.[8]

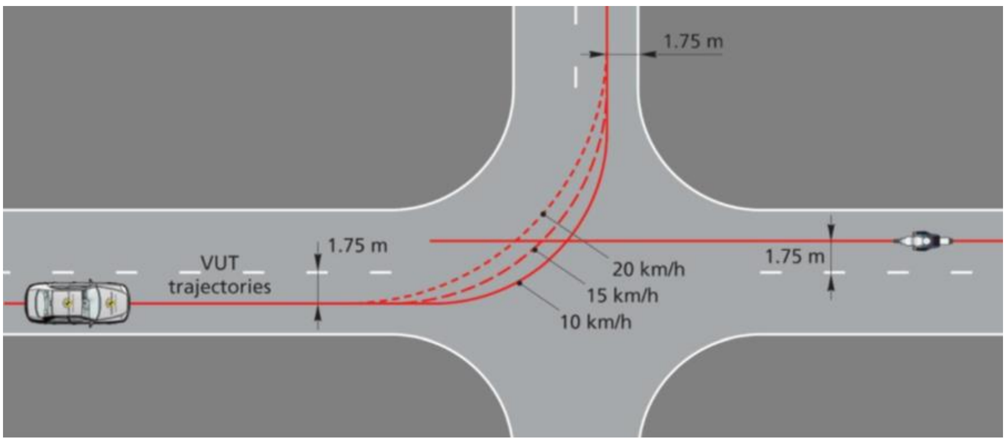

Figure 5: CMFtap [8]

2.3.4 Car-to-Motorcyclist oncoming (CMoncoming)

For the oncoming scenario, the target will be following a straight-line path at 72 km/h in the lane adjacent to the VUT's initial position, in the opposite direction to the VUT, also driving at 72 km/h. At a certain synchronised spot, the VUT will perform an additional lateral velocity with 0.1 m/s incremental steps in a range of 0.2 to 0.6 m/s leading to an impact location of 10% of the width of the VUT.[8]

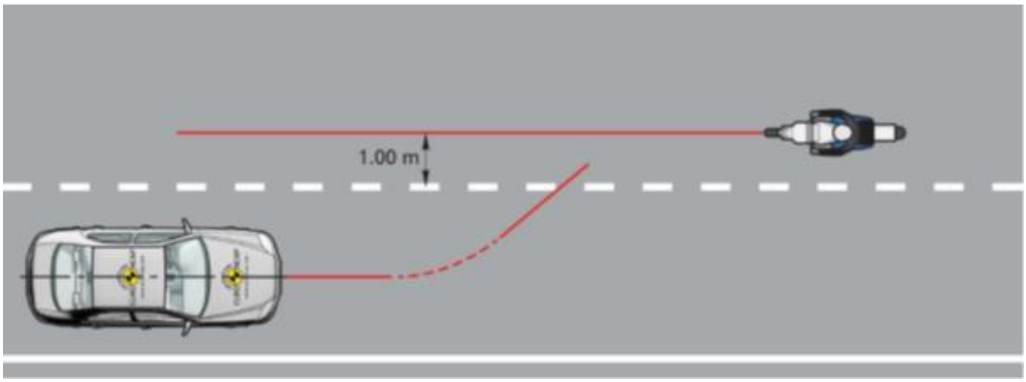

Figure 6: CMoncoming [8]

2.3.5 Car-to-Motorcyclist overtaking (CMovertaking)

For the overtaking scenario, the target will follow a straight-line path in the lane adjacent to the VUT's initial position driving in the same direction. At a certain synchronised point, the VUT will drive with 0.1 m/s incremental steps within the lateral velocity range of 0.2 to 0.6 m/s for unintentional lane change and 0.5 to 0.7 m/s for intentional lane changes. Both unintentional and intentional will be tested in two speed settings. In the first setting, the target will have a speed of 60 km/h to overtake the VUT driving at 50 km/h. In the second setting, the target will have a speed of 80 km/h to overtake the VUT driving at 72 km/h.[8]

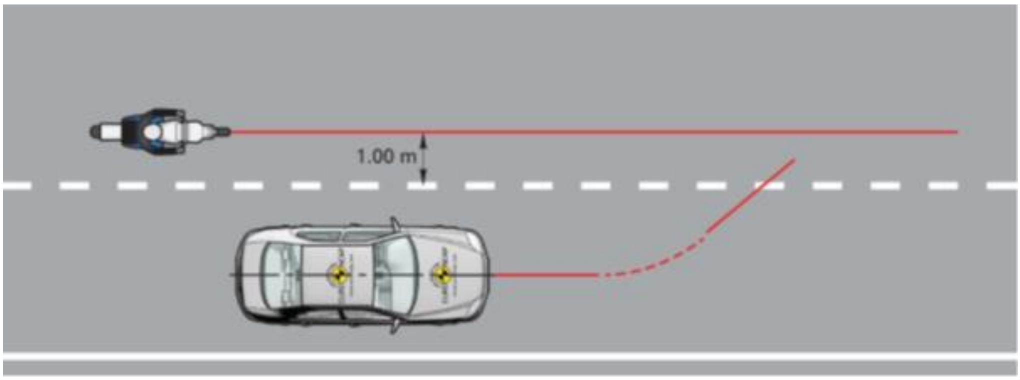

Figure 7: CMovertaking [8]

2.3.6 Car-to-Motorbike Front straight cross path Left (CMFscp-L)

In this scenario, both VUT and target perform a straight-line path. Hereby the trajectories are perpendicular. The paths will be synchronised so that the impact location will be at 18.4% of the VUT's width assuming there's no system reaction. The scenario will be driven with all combinations of VUT speeds of 10, 15, and 20 km/h combined with target speeds of 30, 40, and 50 km/h.[8]

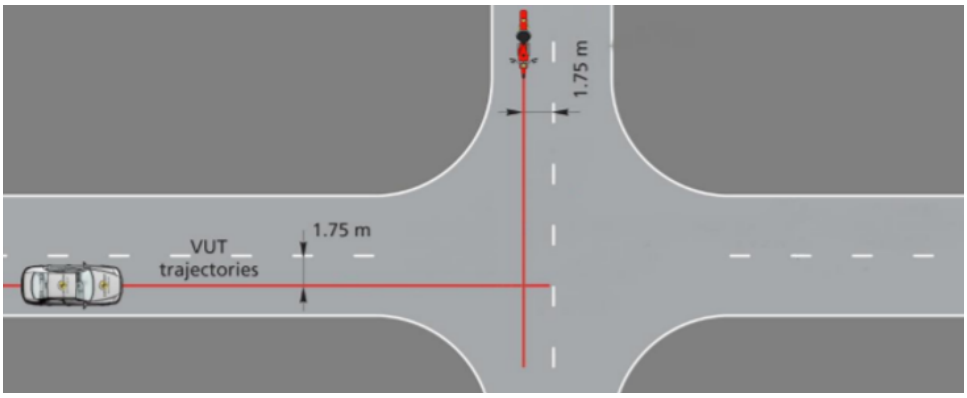

Figure 8:CMFscp-L [8]

2.4 Key Takeaways

The Euro NCAP rating has a high impact on the motivation of OEMs to improve safety systems in the development of passenger vehicles. Knowing about this fact together with statistics proving that PTWs have not only a great proportion of accident casualties compared to other road users, but also increasing importance in individual transport and commuting, Euro NCAP decided to include PTW detection as a criterion for vehicle safety. Therefore, PTW detection is included in the star-based rating, as well as in the use case scenario roadmap.

Taking the motorcyclist target and the various traffic scenarios into account, representative and comparable tests on the conspicuity of PTW and the effectiveness of car ADAS are possible.

The use cases defined by Euro NCAP cover a broad spectrum of real traffic scenarios and are therefore mainly suitable for the testing of assistance systems in the case of cars and PTWs coming together.

3 Regulations

3.1 Research Questions Addressed

The following chapter describes European regulations for the type approval of passenger car ADAS and set the requirements for the performance of test scenarios, also including PTWs. The content of this chapter shall also give a better understanding of the characteristics of existing PTW synthetic targets and their intended use.

To standardise the circumstances of type approvals, the United Nations Economic Commission for Europe (UNECE) developed vehicle regulations, where the requirements for homologation tests on car ADAS are defined. Among other things, the test and use case scenarios for the detection of PTW are included and explained.

3.2 UNECE R79

Regulation 79 was created to provide a common understanding and thus a definition of what a “steering system” fitted to a road vehicle is, from its layout and functionality to the performance of the overall system. As current technology trends show steering systems to be influenced or controlled by sensors and signals generated either on or off-board the vehicle, UNECE R79 sets the requirements for these systems also regarding the detection of PTW.

3.2.1 Motorcycle Target

The approaching vehicle shall be a type approved high volume series production motorcycle of category L3 with an engine capacity not exceeding 600 cm3 without a front fairing or windshield and shall aim to drive in the middle of the lane.[9]

3.2.2 Use case scenario

The only scenario described in the UNECE R79 is a sensor performance test where the described motorcycle target at 120 km/h will approach the VUT from behind on an adjacent straight lane. The test aims to measure the distance from the most forward target point to the VUT’s rear end when the target is detected for the first time.[9]

3.3 UNECE R157

The intention of Regulation 157 is to establish uniform provisions concerning the approval of vehicles regarding Automated Lane Keeping Systems (ALKS). ALKS control the lateral and longitudinal movement of the vehicle for extended periods without further driver command.[10]

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[9] Addendum UN Regulation No. 79, 7.11.2018

As autonomous driving systems are in primary control of the vehicle, they need to fulfill specific test provisions to verify the technical requirements. Besides other types of road users, these requirements are specified for PTWs in the test specifications for ALKS of UNECE R157.

3.3.1 Motorcycle Target

The target used for the PTW tests shall be a test device according to ISO CD 19206-5 or a type-approved high volume series production motorcycle of category L3 with an engine capacity not exceeding 600 cm3. The reference point for the location of the PTW shall be the most backward point on the centerline of the PTW.[10]

3.3.2 Lane Keeping

The scenario shall demonstrate that the VUT does maintain a stable position inside its lane across a speed range and different curvatures. This should at least take 5 minutes whereby the vehicle follows, among other things, a PTW target.[10]

3.3.3 Avoid collision with a road user or object blocking the lane

The scenario shall demonstrate that the VUT avoids collision with another road user or object blocking its lane. Part of the test shall be, among other things, a stationary PTW target.[10]

3.3.4 Following a lead vehicle

The scenario shall demonstrate that the VUT can maintain and restore the required safety distance to a vehicle that decelerates up to its maximum deceleration. The decelerating vehicle shall be, among other things, a PTW target.[10]

3.3.5 Lane change of another vehicle into the lane

The scenario shall demonstrate that the VUT can avoid a collision with a vehicle cutting into the lane of the VUT. The criticality of the cut-in maneuver shall be determined according to Time-To-Collision (TTC), the longitudinal distance between the rear-most point of the cutting-in vehicle and the front-most point of VUT, the lateral velocity of the cutting-in vehicle, and the longitudinal movement of the cutting-in vehicle, as defined in paragraph 5.2.5. of UNECE R157. Under the cutting-in vehicles shall be a PTW target.[10]

3.3.6 Stationary obstacle after lane change of the lead vehicle

The scenario shall demonstrate that the VUT can avoid a collision with a stationary vehicle, road user, or blocked lane that becomes visible after a preceding vehicle avoided a collision by an evasive maneuver. The test shall be executed, among other things, with a PTW target as the preceding vehicle as well as a stationary obstacle.[10]

[10] Addendum UN Regulation No.157, Annex 5, 7.3.2021

3.3.7 Field of View test

The scenario shall demonstrate that the VUT can detect another road user within the forward detection area within a defined range and in the lateral direction up to at least the width of the adjacent lane. The test shall be executed with a stationary PTW target positioned within the ego lane for the forward view. For the lateral view, the PTW target shall approach the VUT from behind in the left adjacent as well as the right adjacent lane. [10]

3.4 Key Takeaways

The requirements for the development and homologation of car ADAS in the European Union are under strong surveillance. To improve the safety in traffic for all road users, pedestrians, bicycles and PTWs are included in the UNECE regulations for tests on the effectiveness of assistance systems on PTWs. While Regulation 79 focuses on the steering system, Regulation 157 defines requirements for ALKS and various test specifications regarding PTWs. The obligation for PTW detection as a requirement for the type approval of car ADAS is an expected improvement of PTW safety in the future. The status quo of PTW conspicuity through active safety systems will be further evaluated in the following chapters.

4 Studies on PTW Conspicuity

4.1 Research Questions addressed

This chapter focuses on the radar detectability of PTWs. In the following, answers to the question regarding the similarities between PTWs conspicuity and other road user's conspicuity are provided. The focus is on the different behavior of the detection by FCW systems.

ADAS play a vital role in most intelligent vehicle technologies by alerting the drivers about possible collisions. However, there are some unintended consequences of ADAS if you look at them from a PTW point of view.

In the European Motorcycle Accident In-Depth Study (MAIDS) [11] it was found that about 72% of all Other Vehicle (OV) to PTW accidents involved an OV driver perception failure. This means that the OV driver failed to see the PTW before the subsequent event that caused the accident. The PTW industry is concerned that the frequency of these types of PTW accidents may increase as drivers will depend more and more upon ADAS, such as Adaptive Cruise Control (ACC), FCW, AEB (Level 2), and Traffic Jam Pilot (Level 3), potentially becoming less attentive to other vehicles around them.

Regarding this problematic prevision, research suggests poor PTWs detection by car ADAS. This trend could be partially explained, in addition to the sensors' limitations (see section 6) in detecting PTW, by the fact that the New Car Assessment Program (NCAP) focused on evaluating the active safety abilities of ADAS technologies to avoid crashes which are car-car, car-pedestrian or car-bicycle. Such assessments, however, do not explicitly address issues of car-PTW accidents. This may be due to an assumption that if a system works adequately for cars, bicycles, and pedestrians, it will work as well for PTWs, but there is little published data to confirm this. Fortunately, the Euro NCAP has announced to introduce PTW detection testing for car ADAS in the future (see subsection 2.2.2).

In this chapter, we will focus on the results of two studies about FCW and ACC involving PTW detection.

[11] ACEM, In-Depth Investigation of Motorcycle Accidents, Version 2.0 of the MAIDS report (http://www.maids-study.eu/pdf/M AIDS2.pdf, accessed on 12.04.2022)

4.2 Response of Forward Collision Warning Systems to PTWs

In October 2016, at the International PTWs Conference in Cologne, Dynamic Research Inc. researchers John F. Lenkeit and Terrance Smith presented a study named “Preliminary Study of the Response of Forward Collision Warning Systems to PTWs”[12].

The goal of this preliminary project was to survey example of current production vehicles equipped with FCW systems in order to determine how well these systems function when the Principal Other Vehicle (POV) is an L3 mid-sized PTW.

To accomplish this, the protocols and two of the three test scenarios described in the US National Highway Traffic Safety Administration’s (NHTSA) Forward Collision Warning System Confirmation Test (February 2013)[13] were used.

An 800cc Sport Touring PTW (Honda VFR800) was substituted for the mid-sized passenger vehicle for use as the principle other vehicle (POV). In the first scenario (Figure 9), a Subject Vehicle approaches a stopped other vehicle in the same lane of travel.

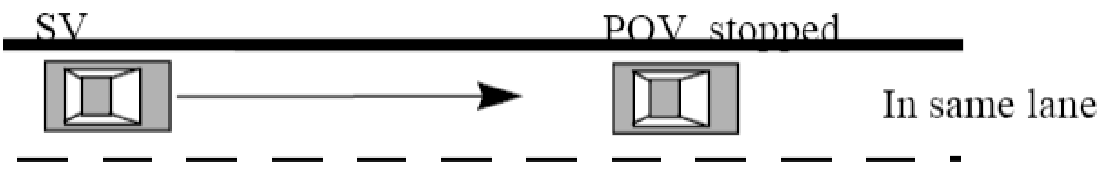

Figure 9: The first scenario - Stopped lead vehicle[12]

Here, since the subject vehicle is traveling at a constant speed of 45 mph (72.4 km/h), the FCW alert should be issued when the TTC is at least 2.1 seconds. The test begins when the SV is 492 ft. (150 m) from the lead vehicle (POV).

In the second scenario (Figure 10), both vehicles are in motion at a constant speed: The car is traveling at 45 mph (72.4 km/h) while the PTW is traveling at a slower speed, 20 mph (32.2 km/h).

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[12] Lenkeit J. F., Smith T., *”Preliminary Study of the Response of Forward Collision Warning Systems to Motorcycles”*, Institut für Zweiradsicherheit (ifz) e.V., 2016, (https://lindseyresearch.com/wp-content/uploads/2019/05/NHTSA-2018-0092-0017-Preliminary_Study.pdf, accessed on 16.03.2022)

[13] National Highway Traffic Safety Administration, *"Forward collision warning system confirmation test”*. Office of Vehicle Safety, Office of Crash Avoidance Standards, National Highway Traffic Safety Administration, Washington DC, 2013

Figure 10: Second scenario – slower lead vehicle[12]

The test begins when the distance between the car and the PTW is 329 ft. (100 m) and this time the FCW alert should be issued when the TTC is at least 2.0 seconds.

In both cases, tests ended when either of the following occurred:

- The required FCW alert occurred (**pass**)
- The TTC to the PTW fell to less than 90% of the minimum allowable range for the onset of the required FCW alert (**fail**).

To meet the NHTSA pass criteria, the FCW system must satisfy the TTC alert criteria for at least five of the seven trials for the scenario. For this study, eight different subject vehicle FCW systems were evaluated. The SVs were all new (less than 500 mi), model year 2016 production vehicles available in the US. Table 2 lists the FCW sensor types for each vehicle. It additionally indicates if the owner's manual for the vehicle addresses the case of PTW detection by the FCW system and whether an AEB system is implemented.

Table 2: Characteristics of the SVs [12]

SV	Sensor Type (s)	PTW Considered in Owner's Manual	AEB Function Provided
1	Camera, Radar	Yes	Yes
2	Camera, Radar	Yes	Yes
3	Camera	No	Yes
4	Camera, Radar	Yes	Yes
5	Camera, Radar	Yes	Yes
6	Camera, Radar	Yes	Yes
7	Camera, Radar	Yes	Yes
8	Camera, Radar	Yes	Yes

Results indicate that stopped PTWs may not be consistently identified as potential collision partners by contemporary production FCW systems. In some cases, no alert was provided; in others, the timing of the alert was later than for those tests for which the POV was a mid-sized passenger car. Table 3 summarises the results of this preliminary test.

Table 3: Summary of the results [12]

	POV	PASS (%)	FAIL, Late Alert (%)	FAIL, No Alert (%)
Stopped lead vehicle	Car	95	4	2
	PTW	32	44	24
Slower lead vehicle	Car	98	2	0
	PTW	93	0	8
Overall	Car	96	3	1
	PTW	59	24	17

It is important to point out that the timing and pass/fail criteria used for the NHTSA NCAP tests are based on studies done with passenger vehicles as the POV. Equivalent pass/fail criteria did not exist for PTW POVs then.

It should also be emphasized that the results of this evaluation are preliminary. They were accomplished with a single, stock example PTW and a small sample of subject vehicles and so further evaluations should be accomplished to get more reliable results.

4.3 Adaptive Cruise Control & PTW Recognition

In October 2016, PTW associations FEMA, KNMV, and MAG NL contacted RDW, the Netherlands Vehicle Authority, expressing concerns regarding the safety of motorcyclists with the admittance of semi-autonomous vehicles on European roadways. To address these concerns, RDW proposed to conduct its test program to evaluate the PTW recognition performance of Adaptive Cruise Control (ACC) systems from a range of vehicle manufacturers.

In 2018, RDW published a report named "Adaptive Cruise Control & PTW Recognition" presenting the development of this investigation on the current situation of ACC technology in recognizing and responding to PTWs. [14]

RDW has performed three different evaluation tests:

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[14] Westerband E. A., et al. *"Adaptive Cruise Control & Motorcycle Recognition"*. RDW, 2018, (https://www.rdw.nl/-/media/rdw/rdw/pdf/sitecollectiondocuments/over-rdw/rapporten/final-report_motorcycle_adas_rdw.pdf, accessed on 13.04.2022)

- Evaluation 1 - Target Vehicle Interruption

This test aimed to verify if the Subject Vehicle responds to an overtaking target vehicle that performs a lane change within the SV's furthest following distance;

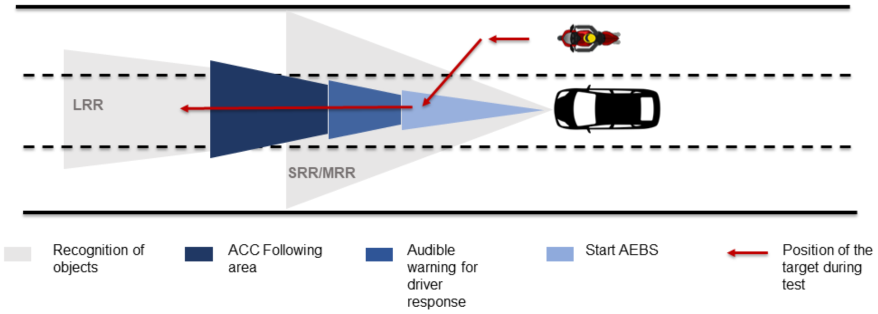

Figure 11: RDW - Evaluation 1 [14]

- Evaluation 2 - Subject Vehicle Approach

The purpose of this evaluation was to observe how the ACC system reacts when approaching a slower-moving vehicle in its lane of travel (Figure 12). Based on response distance, one can observe whether the response distance depends on own speed, target speed, or a combination of both;

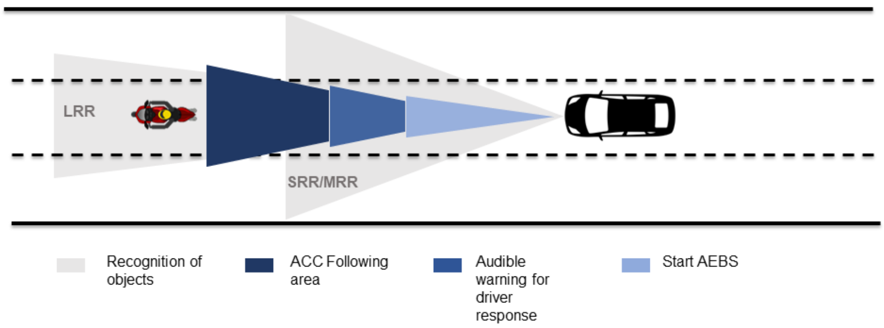

Figure 12: RDW – Evaluation 2 [14]

- Evaluation 3 - Lane Position Detection

The purpose of this evaluation was to observe if a target vehicle's lane position affects the reaction of the subject vehicle's ACC;

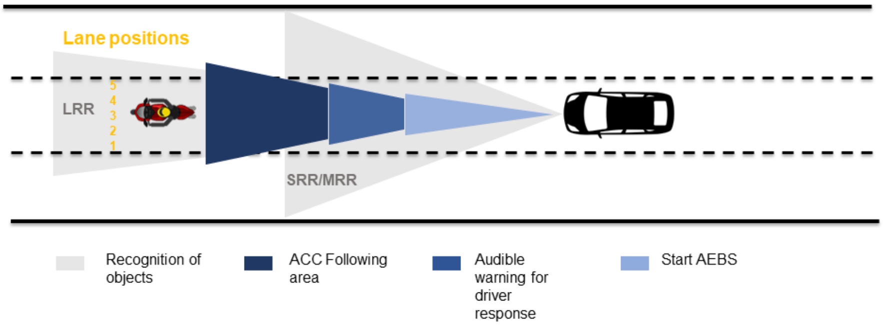

Figure 13: RDW – Evaluation 3 [14]

Since this project aimed to evaluate the ACC system of vehicles from multiple vehicle manufacturers, RDW has selected six different Subject with a considerable market share on Europe roads.

The six SVs selected for testing were:

- Jeep Grand Cherokee (2013) – Fiat Chrysler Automobiles (Italy);
- Hyundai Ioniq Electric (2017) – Hyundai Motor Group (South Korea);
- Skoda Octavia Combi (2017) – Volkswagen AG (Germany);
- Volvo V40 (2012) – Geely (China);
- Volkswagen Golf Variant (2013) – Volkswagen AG (Germany);
- Tesla Model S (2017) – Tesla (USA).

Regarding the Target Vehicles, RDW decided to select five large displacement PTWs, without panniers and equipped with a standard Dutch license plate.

The PTWs used for testing were:

- Suzuki GSX-S1000F (2017);
- Ducati 900SS (1998);
- Triumph Tiger 1050 (2007);
- Yamaha MT-09 Tracer (2017);
- Suzuki V-Strom 650A (2017).

In addition, RDW has used two Target Control Vehicles to consider them as a baseline in the evaluation tests:

- Seat Toledo (2014);

- Volkswagen Polo (2010).

Evaluation 1, performed at different speed combinations of the Subject and Target Vehicle, shows that all the cars successfully indicated via the instrument cluster display the detection of the target vehicle ahead. However, in many instances, the Subject Vehicles would not react to the PTWs ahead as the drivers assumed they would, by slowing down. This behavior was coherent regardless of the target vehicle type.

For what concerns Evaluation 2, results show some cars almost always detected the PTWs later than the target control vehicles: Volvo V40 – 8 out of 9 cases, Volkswagen Golf Variant 4 out of 4 cases, Tesla Model S – 6 out of 6 cases. Other cars show more balanced results: Hyundai Ionic Electric – 4 out of 7 cases, Skoda Octavia Combi – 6 out of 11 cases. These two latter cars show also balanced results considering the reaction to a PTW concerning target control vehicles. Instead, the former cars (except the VW Golf Variant which performed 2 out of 4 cases) together with the Jeep Grand Cherokee (9/11 cases), show late reactions.

The goal of the Evaluation 3 is to answer in what circumstances and in which manner ACC struggles to detect PTWs. This test is similar to Evaluation 2, the differentiating condition is that the PTW rides in five different 0.80 m wide lane positions considering a total lane width of 4.00 m (Figure 13). Results show that subject vehicles struggle to detect the PTW in Lane Position 1 and Lane Position 5, which means when the PTW ride on the far left and far right sides of the lane. This similarity in performance suggests that the ACC system of the tested vehicles projects a strong filter which limits the view of the system. This may be done to limit the interference adjacent traffic may have on the performance of the system.

It should be noted that the PTW never crossed into an adjacent lane during testing. As such, this also suggests that the lane markings of the test track are not considered or used by the vehicle to define the width of the filter. Lastly, in all failed trails, manual application of the brakes was required; without doing so, the motorcyclist certainly would have been rear-ended or, at the least, severely side-swiped.

It is important to point out that, due to the small number of repetitions conducted per evaluation, the results from these tests may have little to no statistical significance. However, these findings should raise concerns about PTW detection by ACC systems and push for some further evaluations and regulations.

4.4 Key Takeaways

In conclusion, according to what was found in the studies described in 4.2 and 4.3, it may be hypothesized that as drivers become comfortable with ADAS, they rely more on technology and will become less attentive to the driving task. A possible consequence of broad ADAS implementation may be an increase in number of car-PTW accidents, even as the number car-car accidents decrease. The studies show a significant share of failures for the detection of PTWs by passenger car ADAS, but are not representative, due to the small amount of test repetitions and PTW types. Therefore, in-depth studies on the detection of PTWs should be conducted in the future. Furthermore, PTWs should be included in future ADAS test procedure development and retroactively introduced into existing ones.

5 User Manuals

5.1 Research Questions addressed

The following chapter the differences between PTW conspicuity and other road users (cars, bicycles, pedestrians) conspicuity for current sensor systems are evaluated in the concern of detection by car ADAS.

To understand what limitations current car ADAS have and how they are explained to the users, CMC randomly selected some market available car user manuals and extracted relevant information as explained in this chapter. The selected cars are all equipped with sensor systems detecting other road users including VRUs, i.e., pedestrians / bicycles / PTWs.

5.2 Limitations of PTW Detection

Following are some descriptions from the selected user manuals which describe the limitations of the systems.

- **"Motorcycles** may not be detected in the same lane ahead if they are traveling offset from the center line of the lane. A vehicle that is entering the lane ahead may not be detected until the vehicle has completely moved into the lane." [15]

[15] Nissan Juke Propilot owner's manual (Publication number: OM20EN-oF16UR)

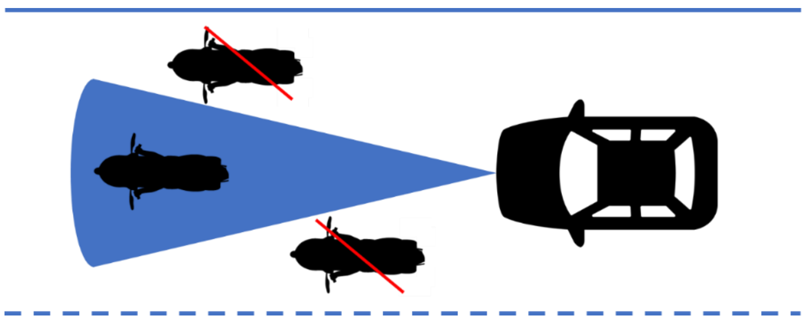

Figure 14: PTW detection limitation in a lane [16]

- " The function does not brake consistently for humans or animals, and neither for small vehicles such as bicycles and **PTWs**. Nor for low trailers, oncoming, slow or stationary vehicles, and objects." [16]

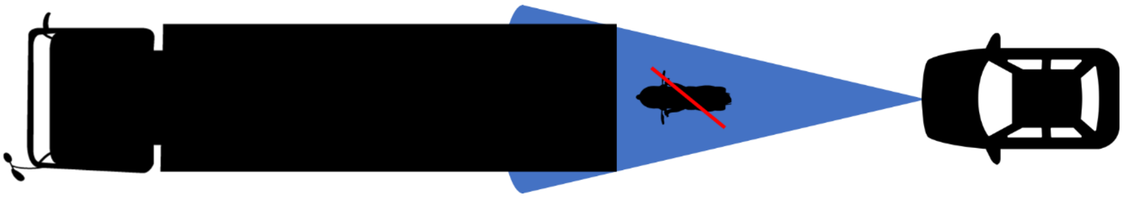

Figure 15: Small vehicle detection limitation [16]

- "A vehicle's size may affect the ability to be detected, e.g. PTWs, which could mean that the warning lamp illuminates at a shorter time window than set or that the warning is temporarily absent." [17]

5.3 Differences in Detection between PTWs and other Road Users

Following are some descriptions from the selected user manuals which describe the differences in detection between PTWs and other road users, i.e., car / bicycle / pedestrian.

- Auto lane change: "Do not use auto lane change on city streets where traffic conditions are constantly changing and where bicycles and pedestrians are present".[16]

PTWs are not mentioned in this manual for an automatic lane change, but it is stated in 5.2. that PTW can remain undetected when traveling offset the centerline of a lane or not central

[16] Volvo XC90 user manuals (https://www.volvocars.com/en-ca/support/manuals/xc90/2021w46, accessed on 6.04.2022)

in front of the car. Automatically changing a lane from a car's point of view, could therefore lead to not detecting PTW.

- "Collision Warning with Auto Brake and Cyclist and Pedestrian Detection" is an aid to assist the driver when there is a risk of colliding with a pedestrian, bicycle or vehicle in front that is stationary or moving in the same direction. [16]

Even though PTWs are included in "vehicles", PTWs can remain undetected when they are driving behind a big vehicle, such as trucks or busses, as mentioned in 5.2. This would lead to delayed auto-braking and a possible accident, if the warning systems only detect the vehicle driving in front of the PTW.

5.4 Key Takeaways

The description in the user manuals described in 5.2 generally states that when an object is located not in front of the vehicle or when they are small in size, there are limitations in the detection of those objects, or they may be misdetected with latency. The referred manuals of Volvo and Nissan raise awareness among their costumers, to not fully rely on ADAS in every traffic scenario. As car manufacturers they urge drivers to take care on vulnerable road users by explaining the limitations of ADAS. This implies that there is a further need to understand within what range current ADAS can detect, e.g., in which angle counting from the forward center can a PTW be detected and to understand if that angle is adequate considering the actual riding scenarios. Also, if a PTW is detected with latency in certain cases, it needs to be evaluated whether that latency is acceptable for a driver to react in time to avoid a collision.

Regarding the differences in detection between a PTW and other road users described in subchapter 5.3. "Collision Warning with Auto Brake and Cyclist and Pedestrian Detection", there is no specific differentiation between PTWs and other road users. But it is assumed that generally the treatment for PTWs would be the same as for other road users, implying that PTW position is constantly changing, and that certain attention to those road users is required, due to constantly changing traffic conditions.

Summarising the information on PTW detection provided in the investigated user manuals, with current ADAS sometimes PTW stay undetected under certain circumstances.

6 Scientific Literature on Radar Limitations

6.1 Research Questions addressed

The following chapter will investigate existing scientific literature regarding the use of radar as a sensor in the automotive context. Radar sensors are generally used for many ADAS, including, but not limited to, Adaptive Cruise Control (ACC) and Emergency Braking Systems. It is expected that the general literature on automotive radar sensors will provide information regarding potential weaknesses and limitations. This information can be derived from the general working principle of radar sensors. Furthermore, it is expected that answers regarding the differences and similarities of PTW conspicuity compared to other road users can be found in the literature. Moreover, technical solutions might be derivable from the information given by the sources.

6.2 General Information on Radar Used in Vehicles

Radar sensor technology is widely used in driver assistance systems. Some important general information that is relevant to understanding the conspicuity of PTW, as well as the differences compared to other road users, such as cars, are described in the following.

In general, automotive radar sensors use a frequency between 76 and 77 GHz. A frequency between 77 and 81 GHz is also possible. Formerly also the frequency of 24-24.25 GHz was used for short-range applications. Due to European and US regulations, this ultra-wideband is phased out and no longer available. To detect an object, the signal strength needs to be above a certain threshold that can be determined by the so-called Signal to Noise ratio (SNR). This is used to filter out so-called background noise and only get returns from relevant objects. However, the correct SNR is crucial, and an appropriate SNR might vary from situation to situation. For instance, if the SNR is chosen too low, many unwanted clutter detections (from the surroundings) will occur. However, if the SNR is chosen too high, objects that trigger smaller reflections are filtered out even though they might be of interest. Such small objects can also be PTW (more can be found in Chapter Radar Cross Section).[18]

Radar sensors can measure the radial distance, azimuth angle, and relative velocity. Through this, they can determine the distance to an object in the longitudinal and lateral direction as well as its velocity. Some sensors also offer the capability to determine object class or orientation. The general working principle of radar relies on sending out power and receiving it back again if it is reflected by different objects.

[18] Winner H., Hakuli S., et Al., *"Handbuch Fahrerassistenz*", ATZ/MTZ Fachbuch, 2015

Radar sensors feature different specifications that include opening angle in the vertical and horizontal direction as well as range, which together contribute to the achievable field of view. Please note that the opening angle in the horizontal direction (azimuth) is usually much larger than the one the vertical direction (elevation). Radar sensors typically do not feature a great resolution in a vertical direction making it hard to determine the height of an object above the ground. Radar sensors are known to have quite an extensive range that can reach up to approx. 250 meters. However, it is important to keep in mind that the signal strength that is received by a radar sensor decreases with increasing distance as the same power must cover a larger angle segment with increasing distance.[18]

Automotive radar sensors for current applications should be capable of detecting multiple objects. Furthermore, they need to be capable of separating such objects into actual separate objects. Therefore, not only the accuracy of the measured range, azimuth, and velocity is important, but also the resolution. I.e., the resolution determines which difference in distance, azimuth, or velocity needs to be present to be able to separate two objects. Usually, distance and relative velocity are used for the separation of two objects. If the separation capability is low, it can occur that two objects at a similar distance with similar velocity cannot be separated into two objects.

In general, radar sensors are known to usually have low angular resolutions and accuracies. Therefore, the correct determination of an azimuth angle is challenging. Some radar sensors also determine the elevation angle, but the opening angle is usually quite small, and the resolution for this angle is not high. This can lead to difficulties in detecting stationary objects. Often radar sensors are said to not be able to detect stationary objects. However, this is incorrect. The actual problem with stationary objects is that many radar sensors are not capable of determining the height of an object. Therefore, sign gantries above the road can lead to detections and so-called false positives or ghost objects (detection of something that is not there). To prevent too many such false positives, the used algorithms of automotive radar sensors often delete stationary targets from the object list.[18]

Some advantages of radar sensors, such as their capability to detect objects in a wide range and their ability to directly measure velocity, were already mentioned above. Another advantage of radar technology is its ability to still work properly in any weather and environmental conditions. However, even though it is much less influenced than, e.g., LIDAR technology, heavy rain can still influence the detection capability of a radar sensor. It can e.g. cause false positives through the rain droplets or decrease the signal strength that reaches the radar sensor, which especially complicates the detection of smaller objects.

Further effects of radar sensors are known for so-called multipath effects. In the case of multipath, a sent ray does not reach the receiver through one straight reflection but is reflected off several objects before it is received again by the sensor. This can be advantageous in cases where the sensor is capable of detecting occluded objects (e.g., in the case of vertical reflections on the road surface). However, it can also lead to ghost objects (e.g., in cases where the ray is reflected off a guard rail). Furthermore, a signal of a weaker reflective target can be blocked by the reflection of a strong reflective target. Such objects are, e.g., trucks, but also guard rail posts.

6.3 Radar Cross Section (RCS)

The Radar Cross Section (RCS) can be used to measure the reflectiveness of an object. It is usually measured in square meters, and the reference is the reflectivity of a spherical reflector with an ideal conductive surface. Alternatively, the RCS can be converted into decibels, the so-called dBsm.[18]

6.3.1 General Information

The RCS can vary through the material and surface properties of an object. For instance, metallic objects have a large reflectivity for radar waves. Furthermore, the RCS is angle-dependent.

Table 4: Typical orders of magnitude for RCS [20]

Type	RCS	RCS in Decibels
Truck	1000 m^2	30 dBsm
Car	100 m^2	20 dBsm
PTW	10 m^2	10 dBsm
Pedestrian	1 m^2	0 dBsm

Table 4 shows rough magnitudes of RCSs for different object classes at a larger distance. Note that the exact RCS strongly depends on the shape and material but also viewpoint, direction and distance of the object. However, the table already shows that the RCS for PTWs, i.e., PTWs, is much lower than that for cars or trucks. This can lead to the inability to detect smaller objects. If the reflected signal strength is below the SNR, it will not be included in the target list. Furthermore, the afore-described effect of blocking or blinding can occur if objects with larger RCS, such as trucks, are in the proximity of smaller objects. As mentioned above, angle reflectors, such as guard rail posts and access ladders of trucks, show a significant reflection capability.

Geary et al. looked into RCS measurements.[19] In particular, it also provides measurements for VRUs. In general, the PTW shows a smaller RCS than the tested cars. However, the angle-dependent variations for PTWs are much less than for cars, which means that depending on the viewing angle, the RCS of a car can be reduced to the same order of magnitude as that of a PTW. This makes the classification of objects through their reflectivity nearly impossible.[18] Moreover, when viewed from the front and rear, the RCS of a bicycle and a PTW are rather similar.[19] A PTW usually shows its largest RCS from the side. Interestingly, at exactly 90° the bicycle has a larger RCS than the PTW. This might be due to the bicycle being flatter along the length compared to the PTW.[19]

6.3.2 Influence of PTW Design

Already knowing that the RCS of PTWs is much lower than that of cars and trucks, Silberling et al. performed RCS measurements for different types of PTWs and compared the results.[20] The tested PTWs were from the group of retro-standards (Honda CB1100), sport bike (Honda CBR600RR), scooter (Honda Metropolitan) and touring (Harley Davidson Ultra Limited). Measurements were taken from a fixed distance with varying angles and from a fixed angle with varying distances. The fixed distance measurements were taken with and without rider. Interestingly, one cannot find any significant difference in the RCS with and without a rider. In general, scooters showed the lowest RCS in most cases, but the general distribution of its RCS is comparable to the others. It shows the lowest RCS from the front, front oblique, side, and rear oblique. In the category rear, however, sport motorcycles showed the lowest RCS. Its RCS was also quite low for the category front oblique. The sport bike scoring lowest from the rear might be due to its aerodynamic shape and the different design of the rear fender. For the highest RCS concerning the front and front oblique, the scores of the category touring and standard relatively equal. In addition, side and rear oblique show the largest RCS for touring and standard with the sports bike being only slightly worse. From the rear, the touring PTW presents the highest RCS. Other general remarks were that all PTWs trigger most reflections in their geometric center, which is different from cars where reflections come from the edges (front, rear, side). Furthermore, the RCS varies greatly depending on which sensor is used.[20]

In summary, it can be concluded that smaller bikes also show a smaller RCS. Furthermore, interestingly the compact design of sport bikes can hinder to gain a large RCS. Moreover, most

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[19] Geary K., Colburn J. S., Bekaryan A., Zeng S., Litkouhi B. and Murad M., *"Automotive radar target characterization from 22 to 29 GHz and 76 to 81 GHz"*, 2013 IEEE Radar Conference (RadarCon13), 2013

[20] Silberling J.. et al., *"Development of a Surrogate Motorcycle Soft Target for Use in ADAS Testing"*, Dynamic Research, Inc., Torrance CA, USA, "2018 Safety Environment Future: Proceedings of the 12th International Motorcycle Conference."

reflections are triggered by the geometric center of the PTW, which should be kept in mind when calculating the distance to an object.

6.3.3 Validation of the PTW Target

As explained in chapter 2.2.3, a PTW target is used for testing and measurements of PTW conspicuity. Within the MUSE project, the company 4a systems developed the GMT to get a representative target for multiple different real PTWs including the motorcyclist in terms of dimensions and values of the most registered PTWs in Europe with a cylinder capacity lower than 500 ccm (ACEM 2014).

In this whitepaper, the conspicuity of PTW is evaluated using the GMT as a dummy for PTWs, so it needs to be validated how this PTW target represents real PTWs in various test scenarios. MUSE project deliverables D2.1 A2 and A3 explain the measurement results of the radar reflectivity of real PTWs compared to the GMT.

The radar cross-section of a motorcyclist depends on the observation angle and typically varies significantly. Theoretically, there is no RCS variation with the distance. However, due to the field of view of the radar sensor and the implemented free space loss compensation, the measured RCS varies significantly over distance and at near distances, the motorcyclists are not covered in their entire spatial dimensions. Therefore, in the following measurements, RCS is referred to as the measured RCS by radar sensor with its specific parameter set and does not correspond to the physical RCS. In addition, the RCS is also influenced by geometrical effects, i.e. multi path with constructive and destructive interferences.

To validate the GMT for this whitepaper, the measurements by a 77 GHz Sensor Bosch MRR-SGU are evaluated from three different perspectives. More information on the test cases is provided in MUSE Deliverable 2.1.

In the following, the two main cases of PTW observation in road traffic are examined. One the angle of 0° and the other of an angle of 90°. The additional analysis of 180° and 270° is not considered to be necessary, since the values do not change due to the more or less symmetrical structure of each reference vehicle and the GMT.

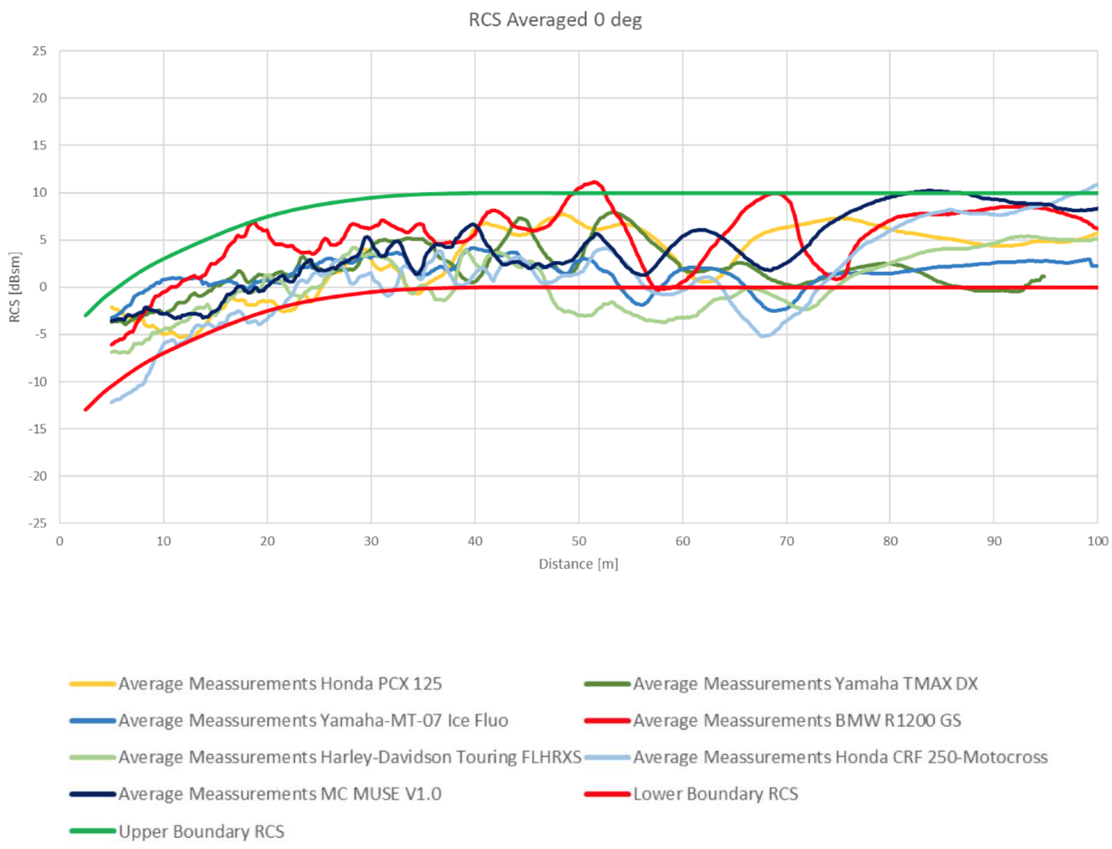

Figure 16: Example RCS of 4a GMT versus real PTWs – 0° [2]

Figure 18 describes the measurements in a fixed angle of 0 ° measured from the rear end. This scenario is representative for ACC or AEB scenarios, where passenger cars and PTWs are traveling in the same lane. Considering the measurement results at a fixed angle of 0°, c.f. 18, over a maximum distance of 100m, it becomes apparent that the RCS of the different PTWs behaves quite differently. Particularly at approx. 45-75m, large deflections can be seen. These even move below the lower boundary for some PTWs. These fluctuations are due to multipath reflections and are of an arbitrary character. The installation height of the sensor also contributes to this. The upper and lower boundaries were determined due to the fluctuation of the measurement result of the different PTWs. The average measurement of the GMT behaves at an angle of 0° like the real PTWs and provides a first approach for the representativity of the target.

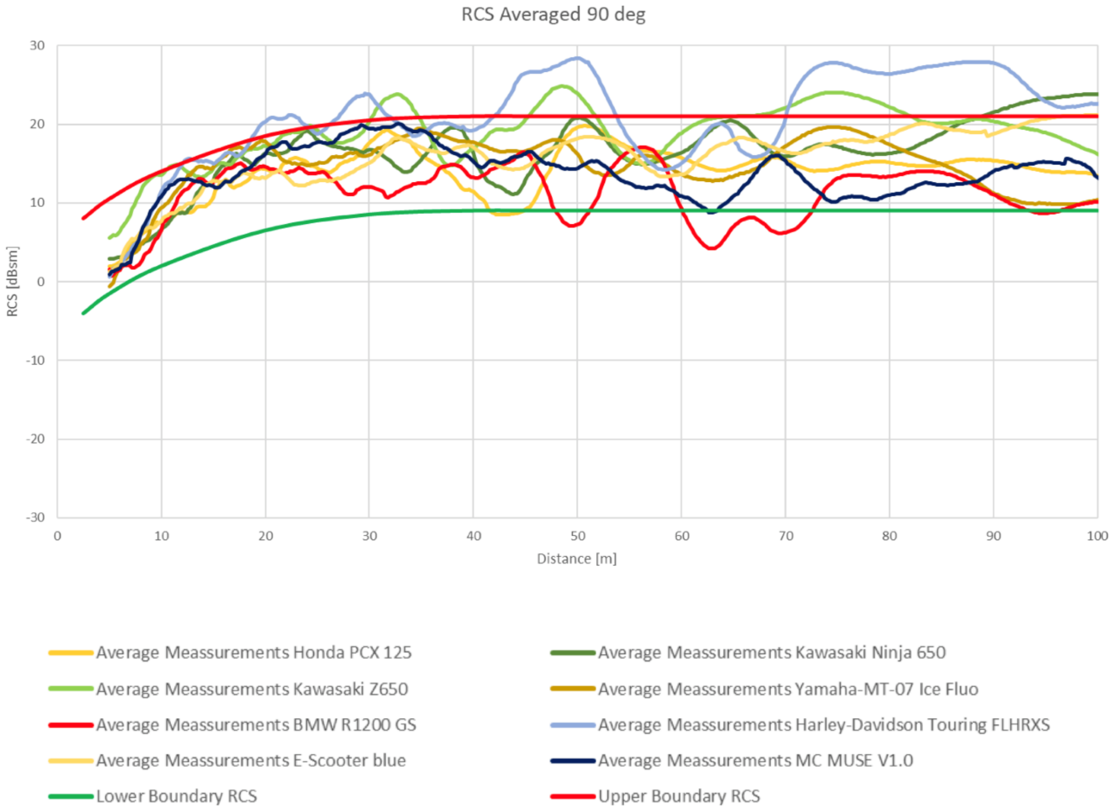

Figure 17: Example RCS of 4a GMT versus real PTWs – 90° [2]

Figure 19 describes the measurements at a fixed angle of 90 ° measured from the rear end. This scenario is representative of traffic scenarios, where the trajectories of passenger cars and PTWs cross each other. The average measurements at an angle of 90° behave slightly different compared to 0°. The range of the measured values and therefore also the upper and lower boundaries are much higher with 20dBsm and approx. 10 dBsm. This is mainly due to the better reflectivity of the side panels of the PTWs and the consequently higher RCS. Again, fluctuations which are due to multipaths and reflections occur in a distance range of about 40-70m. The average RCS of the GMT is again between the upper and lower boundary. Also, no significant deflections occur.

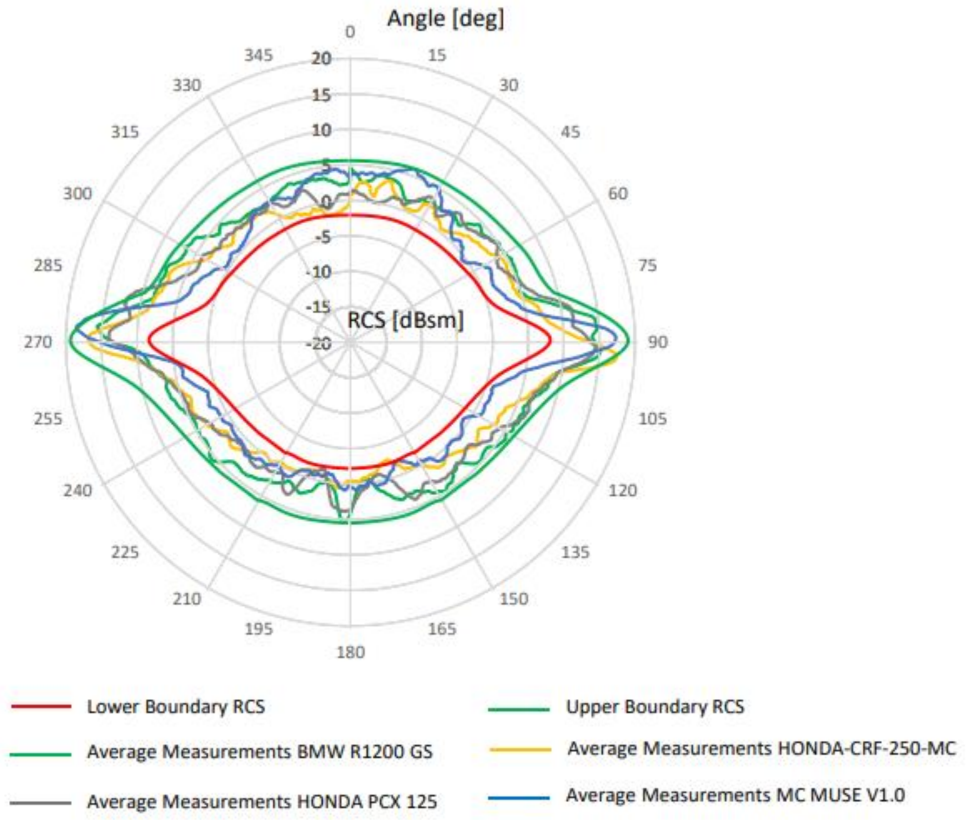

Figure 18: Examples of RCS of 4a GMT versus real PTWs - 360° [2]

Finally, the RCS is observed over 360°. The distance is now fixed at 40 m. The findings from Figures 18-19 are reflected in this case, because the RCS measurements reach their maximum at 90° and 270°. Especially when viewing from the front or back (0° or 180°), the RCS value of an object decreases dramatically. It can be seen that the initial assertion of the symmetries of the vehicles are not completely confirmed, since certain asymmetries are present. This is also reflected in the values of the RCS. However, the trend is very similar. Furthermore, it becomes clear that the side of the vehicles plays a decisive role in the RCS. For example, the BMW 1200 GS has a higher RCS at an angle of 0° and 180° than the Honda CRF 250 MC and the Honda PX125. This can be explained by the narrower design of the two Honda models and their lower reflectivity. The GMT is again in the mid-range. A relatively clear measurement of its RCS can be seen at 90° and 270°. This can probably be attributed to the smooth surface of the model, which does not occur in real PTWs due to various components such as the engine or body parts.

In general, the RCS increases when observing a PTW from 90° as in Figure 19, and decreases when looking from front or back, cf. Figure 18. If we have a closer look, large fluctuations arise for the RCS depending on considered distance as well as the PTW type. Figure 20 summarizes the two figures above at a certain fixed distance of 40m and moreover covers the full 360° range view of all four PTWs.

The evaluation shows that the 4a RCS measurements are also in the addressed range of real PTWs which ensured comparability. Therefore, the GMT is validated in the most perspectives as a representative target for tests on the efficiency of ADAS detecting PTW.

6.3.4 Use of Different Frequencies

As mentioned in the general remarks on radar sensors, they often have difficulties in angular resolution and accuracy. This is expected to improve when using higher frequencies. Therefore, Köhler et. al. performed measurements for sensors using frequencies beyond 100 GHz. The study aimed to find out whether this would have a positive effect on attenuation and RCSs. The measured RCS for PTWs stayed comparable to that measured with a 77 GHz sensor. However, the target dimensions can be better estimated through the reflection points with sensors using a higher frequency. This can lead to better identification of the PTW dimension through the RCS and helping to increase conspicuity.[21]

6.4 Spreading in Doppler Signature / “Micro Doppler Effects”

An interesting effect in the velocity measurements can be seen when detecting humans with radar sensors. This effect is called spreading in Doppler signature[19] or “Micro Doppler Effect” depending on the considered reference.[22] In general, the effect occurs since the arms and legs of a walking pedestrian move individually while walking and trigger multiple detections with different Doppler velocities. This effect was seen in real test drives and helped to distinguish between cars and other obstacles and pedestrians[22]. Geary et. al. saw this effect not only for pedestrians but also for bicycles and PTWs with a rider on top. Even small movements led to the impact that could help to better identify VRUs and separate them from other smaller obstacles or clutter.[19]

6.5 Key Takeaways

The analyzed sources clearly show answers to the research questions b), c) and d). Namely regarding the limitations of current sensors and the differences and similarities of the conspicuity of PTWs compared to other road users. The main difficulty radar sensors have is caused by the low RCS of VRUs including PTWs. This can, in various ways, cause a PTW remaining undetected. For instance, a low RCS can lead to not being detected in the first place, but also other unfortunate combinations can occur such as an increased attenuation during rain. This can cause an even stronger decrease in the received signal of PTWs below the SNR

[21] Köhler, M. et. Al*., ”Feasibility of automotive radar at frequencies beyond 100 GHz”*, International Journal of Microwave and Wireless Technologies, 2013

[22] Dickmann, J., ” Making *Bertha See Even More: Radar Contribution*”, IEEE Access, 2015

so that objects will not be detected. Besides, occlusion can occur if an object with a large RCS is within the proximity of an object with a low RCS.

Furthermore, answers to research question for regarding technologies to improve PTW conspicuity can indirectly be derived. Since it was seen that a low RCS is the main issue, it seems reasonable to investigate how to increase the RCS for PTW. The analysis of different PTW has shown that already the design choice makes a difference, even though it cannot increase the RCS to the same order of magnitude as seen in cars. The development of radar systems for the detection of PTW should consequently improve in the future in order to achieve better conspicuity. Furthermore, it was observed that an increase in frequency would not help to improve the RCS. However, it might help in the classification of the different objects.

7 Methods to Improve PTW Conspicuity

7.1 Research Questions addressed

Being recognised by other drivers has always been the first step towards PTW riders remaining safe in traffic, but as the world’s car manufacturers race to develop semi-autonomous vehicles, riders are starting to face a new challenge: Being noticed by the electronic devices of modern vehicles rather than the biological eyes of their drivers.

The Connected PTW Consortium evaluated different methods that allow PTWs to be noticed by cars and their drivers. Following, this chapter provides methods to improve PTW conspicuity.

Mainly two technological approaches to improve PTW conspicuity are proposed and discussed: Radar Technology and Cooperative Intelligent Transport Systems (C-ITS).

7.2 Radar Technology

7.2.1 Improve Radio Reflectivity

Due to the smaller size, the slim shape, and the large plastic part, PTWs have less reflection on radar sensors than cars and trucks. This problem also existed in the field of shipping, where smaller boats were detected very poorly by other ships. There is a method to increase the visibility of smaller ships that is successfully used in the nautical field: small corner radar reflectors at the ends of protruding objects. Corner radar reflectors are radar reflectors, which are positioned at an angle of 90 degrees to each other and can therefore return the radar waves directly to their point of origin.

By putting corner radar reflectors together, a spherical array of three-sided open boxes will be created.[23]

This method can also be used on PTWs to enhance radar reflection and increase visibility.

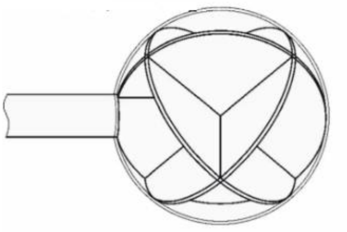

Figure 19: Spherical Array of Corner Radar Reflectors [25]

Suzuki and BMW, both CMC members, published patent applications on the use of corner radar reflectors on bikes to increase the radar reflectivity of PTWs, whereby the mounting positions and the reflectors differ.

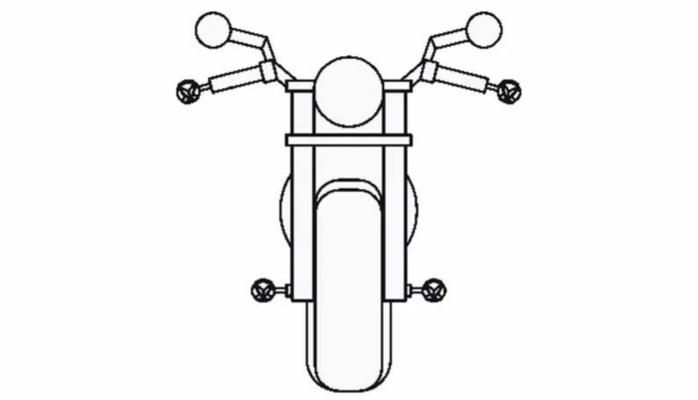

Figure 20: Mounting Positions of Radar Reflectors [26]

Possible positionings on PTWs are at the end of the handlebars, axles, mirrors or near the indicators and the front mudguard. By mounting them on the ends of the bars and the bike's axles front and rear, there's no angle at which a radar can be pointed at a bike without hitting at least one of the reflectors, bouncing a strong signal back to the radar sensor and improving the conspicuity towards sensor based ADAS. [24]

[23] Wikipedia, "*Corner reflector*".
(https://en.wikipedia.org/wiki/Corner_reflector, accessed on 02.05.2022)

[24] Purvis Ben, „*BMW Develops Radar Reflectors",* Cycle World, 22.03.2021

7.2.2 Improve Radar Detection

The use of different frequencies was already shortly discussed in chapter 6.3.4. Further improvements are to be expected with the use of so-called 4D imaging radar technology. Those radar sensors can detect distance, azimuth, elevation, and velocity with more significant accuracy and resolution than today's sensors.[25] [26] Furthermore, they are expected to show a lower latency.[25]

Other technological advances are the use of multiple input multiple output systems with multiple antennas (MIMO), digital beamforming for higher angular resolution and the use of so-called RadCom (Radio Communication) systems.[27] [28] In such systems, the radar sensors can also be used for communication, which could increase the conspicuity of PTWs. Moreover, improved motion models could be helpful for the detection of objects that show difficult tracking and prediction tasks. Such objects include pedestrians, but also PTWs since they move quite differently than cars.[29]

Finally, the use of Artificial Intelligence (AI) is of great interest in order to improve object classification by radar sensors.[30]

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[25] Analog Devices, *"From ADAS to Driver Replacement—Is Actual Radar Performance Good Enough?",* (https://www.analog.com/en/thought-leadership/from-adas-to-driver-replacement.html#, accessed 13.04.2022)

[26] *Arbe, arbe future radar*, (https://www.sec.gov/Archives/edgar/data/1816696/000121390021016440/ea137987ex99-1_industrial.htm, accessed 13.04.2022)

[27] Wiesbeck W. and Sit L., "*Radar 2020: The future of radar systems,"* 2014 International Radar Conference, 2014

[28] Wiesbeck, Werner, *"Systemkonzepte für das Radar der Zukunft"*, VDE Dialog, 4/2020

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7.3 C - ITS Technology

Based on real traffic accidents from GIDAS (German In-Depth Accident Study), a study to evaluate the potential of future Cooperative Intelligent Transport Systems (C-ITS) for PTWs was made by CMC;[31] these advanced safety systems could tackle the challenge of increasing the safety level of PTWs by communicating vehicle positions and warn drivers of an approaching PTW. In a technology open way, all current possibilities are considered, that allow road vehicles to communicate with other vehicles, traffic signals, roadside infrastructure, and other road users (V2X Communication). C-ITS can be approached by WLAN communication (ETSI ITS G5) or cellular technology (LTE C-V2X or 5G NR-V2X) according to the standardizing organization 3GPP [32].

The cooperative data exchange between the road users and with the infrastructure works already where cooperative users are not in a line-of-sight and radar might not detect the other vehicle. By reducing the distance between cooperative users, the quality of the communication improves.[33]

So far, C-ITS specifications for cars did not sufficiently take PTW specific safety factors into consideration, and as a result, PTW rider safety will not fully benefit from C-ITS systems. There are some challenges to the adaptation of these specifications to PTWs, like their different shape with less space for board equipment and their more agile driving dynamics. Wireless communication between vehicles and the infrastructure can help to detect dangerous situations and approaching PTWs earlier than the human eye or radar sensors in cars can. V2X allows warning of drivers about many scenarios where there may be imminent danger, especially in Non-line-of-sight (NLOS) situations. Many warning systems based on V2X communication are under development by the car industry. However, for PTW-specific situations, they should be adapted, or even newly developed.[34]

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7.4 Key Takeaways

As a PTW rider, being seen by other road users is essential for safe traveling in public traffic. Therefore, there are different methods provided to increase PTW conspicuity and improve rider safety through rider gear and technology. Whilst high-visibility riding gear can help car drivers to recognise a motorcyclist, an increased radio reflectivity or communication between PTW and other road users could improve the conspicuity for technical assistance systems in cars. Further future advances in radar-based on-board sensor technology could also help to increase the conspicuity of VRUs. A better angular resolution can help to distinguish between two objects that are located close together and improved motion models could support the tracking of PTWs. The current advances using AI could be beneficial as well to improve object classification. Finally, an introduction of RadCom systems could be advantageous for the detection of PTWs. In situations where PTWs and other road users are not in the line-of-sight, innovative C-ITS technologies (i.e., V2X) could warn drivers of an approaching PTW or passenger car. This assistance could prevent hazardous situations, avoid accidents and in consequence improve PTW safety.

8 Conclusion

The aim of this white paper is to evaluate current research, academic papers technical reports and studies dealing with the conspicuity and the detection of Powered Two Wheelers (PTWs) as well as the evaluation of methods to improve the conspicuity of PTWs and other PTWs. Therefore, the conspicuity of PTWs was examined from the perspective of user protection, the legislation, and a manufacturer's point of view in user manuals. Moreover, studies with PTWs as well as scientific literature concerning the conspicuity of PTWs, and existing limitations were analyzed. Summarising the key takeaways of the previous chapters the necessity to have a special focus on PTW detection was pointed out. Under certain circumstances, the detection of PTWs is challenging for Advanced Driving Assistance Systems (ADAS), due to the different way of motion, the slim shape and as a result the smaller radar reflectivity of PTWs compared to cars.

Following the EU definition, PTW riders are considered as VRUs. The protection by other road users, mainly cars, is a major factor to decrease the number of collision accidents. CMC accident studies confirm that EURO NCAP PTW test scenarios consider the collision accident types which have the highest potential to improve safety. Therefore, the use case scenario roadmap is suitable for an evaluation of the efficiency of passenger car ADAS on PTW detection.

A major goal from CMC is to enhance PTW safety and one of the most effective ways is to improve conspicuity of PTWs by automotive systems. Therefore, CMC strongly supports the approach that passenger cars ADAS recognise PTWs qualitatively equivalent to cars.

Further studies should analyse the influence of PTW-specific characteristics on the performance of passenger car ADAS. Hereby, the evaluation if safety relevant ADAS in passenger cars are triggered reliably by PTWs, should be focused upon.

Abbreviations

5GAA	5G Automotive Association
ACEM	European Association of PTW Manufacturers
ADAS	Advanced Driver Assistance Systems
ACC	Automatic Cruise Control
AEB	Automatic Emergency Braking
CAM	Cooperative Awareness Message
CMC	Connected PTW Consortium
C-ITS	Cooperative Intelligent Transport Systems
ETSI	European Telecommunications Standards Institute
EU	European Union
GIDAS	German In-Depth Accident Study
GMT	Global Motorcyclist Target
HMI	Human-Machine Interface
LSS	Lane Support System
OEM	Original Equipment Manufacturer
PTW	Powered Two Wheeler
RadCom	Radio Communication
RCS	Radio Cross Section
RSU	Road Side Unit
R&D	Research and Development
V2X	Vehicle-to-Everything Communication
V2I	Vehicle-to-Infrastructure
VRU	Vulnerable Road Users
VUT	Vehicle under Test

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Tables

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