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MOTORCYCLE RIDER REACTION TIMES AS RESPONSE TO VISUAL WARNINGS

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Cooperative Intelligent Transport Systems (C-ITS) offer the chance to increase motorcyclists' safety by delivering information from other road users and infrastructure that go beyond the capabilities of onboard sensors in terms of an increased spatial and temporal forecast range. Yet, in order to ensure a safety benefit for non-automatically intervening C-ITS applications, suitable warnings have to be issued to the rider to allow for an appropriate reaction. Furthermore, there is little knowledge about rider reactions in general, which is e.g., necessary to parametrize rider behaviour models in simulated environments.

Therefore, the Connected Motorcycle Consortium (CMC) investigated riders' reaction times towards a visual advisory warning in unexpectedly occurring scenarios on urban and rural roads. A conservative warning design was chosen which avoids an overestimation of riders' performance and therefore delivers information that include riders' reactions under non optimum conditions.

Two scenarios 1) with a high accident relevance and 2) in a typical motorcycle riding environment were under investigation: an urban crossing scenario with a violation of the rider's right of way and an obscured critical situation, such as a broken-down vehicle behind a right-hand bend. The test scenarios were embedded in a permuted order in a sequence of uncritical situations that visually resemble the critical scenarios to prevent riders from coming into an unnaturally overcautious state. The reactions of $N = 24$ motorcycle riders e.g., based on gaze behaviour, throttle off and brake onset towards the warning were investigated on the DESMORI dynamic motorcycle riding simulator at WIVW.

Even with certain limitations regarding generalizability, conclusions can be drawn for PTW assistance system design and a comparability to passenger car driver reactions may provide interesting insights. Further, any other kind of simulation which involves estimations regarding motorcyclists' reactions towards a warning, requires a rider behaviour model. The gained information might also be helpful to optimize these models and allow a more precise assessment of the effectiveness of newly developed assistance systems by means of simulation.

REAKTIONSZEITEN AUF VISUELLE WARNUNGEN VON MOTORRADFAHRERN

Cooperative Intelligent Transport Systems (C-ITS) ermöglichen es, die Sicherheit von Motorradfahrern über die Bereitstellung von Informationen anderer Verkehrsteilnehmer und der Infrastruktur zu erhöhen. Diese Informationen gehen über die räumliche und zeitliche Vorhersagegüte fahrzeugseitiger Sensoren hinaus. Um jedoch einen Sicherheitsvorteil für Assistenzsysteme zu erzielen, die ein aktives Eingreifen des Fahrers erfordern, müssen angemessene Warnungen an den Fahrer ausgegeben werden. Zudem ist bislang generell wenig über die Reaktionen Motorradfahrender bekannt, was bspw. für die Parametrierung von Fahrerverhaltensmodellen, die im Kontext der Simulation zum Einsatz kommen, notwendig ist.

Aus diesem Grund untersuchte das Connected Motorcycle Consortium (CMC) die Reaktionszeiten von Motorradfahrern auf eine visuelle Kollisionswarnung in unerwartet auftretenden Szenarien auf innerstädtischen und ländlichen Straßen. Für die Studie wurde ein sog. konservatives Warnungsdesign gewählt, welches eine Überschätzung der Fahrerleistung vermeiden und Informationen zum Fahrerverhalten unter nicht optimalen Warnbedingungen bieten soll.

Es wurden zwei Szenarien 1) mit einer hohen Unfallrelevanz und 2) in einer typischen Motorradfahrumgebung untersucht: ein städtisches Kreuzungsszenario, in dem die Vorfahrt des Motorradfahrers durch einen Pkw-Fahrer genommen wird und eine verdeckte kritische Situation, in Form eines liegen gebliebenen Fahrzeugs nach einer Rechtskurve mit Sichtverdeckung auf einer Landstraße. Die Untersuchungsszenarien wurden in permutierter Reihenfolge in eine Sequenz aus unkritischen Szenarien eingefügt, die den kritischen Situationen optisch gleichen, um zu verhindern, dass die Fahrer in einen unnatürlich übervorsichtigen Zustand geraten. Die Reaktionen von $N = 24$ Motorradfahrern wurden basierend auf Verhaltensmarkern wie z.B. dem Blickverhalten, Schließen des Gasdrehgriffs und Beginn der Bremsung auf eine generische Warnung hin untersucht. Die Studie wurde auf dem dynamischen DESMORI Motorradfahrsimulator des WIVW durchgeführt.

Obgleich aufgrund der simulierten Fahrumgebung gewisse Einschränkungen bezüglich der Generalisierbarkeit vorliegen, können Schlussfolgerungen hinsichtlich des adäquaten Motorrad-Warnungsdesigns gezogen werden. Ebenso zeigen die Ergebnisse ob und inwiefern die häufiger untersuchten Reaktionszeiten von Pkw-Fahrenden vergleichbar sind. Darüber hinaus können die Erkenntnisse für jegliche Simulation genutzt werden, die ein Verhaltensmodell von Motorradfahrern benötigt. Durch Optimierung dieser Verhaltensmodelle werden präzisere Abschätzungen der Effektivität neuentwickelter Fahrerassistenzsysteme in der Simulation möglich.

1 Background & Motivation

Technical systems, such as anti-lock braking (ABS) control units, can process data and operate within a few milliseconds. Yet, to stay with the ABS example, these very fast responses can only provide a benefit if the rider is actually braking. More precisely, if the rider is interpreting a situation or a warning correctly and reacts accordingly. So far, there is little knowledge about how long a rider reaction towards e.g., a warning takes. Additionally, the questions are raised whether reactions from the passenger car domain can be applied to PTW research and how a PTW rider behaviour model should be parametrized to represent realistic rider behaviour? This data is missing for PTW riders. Consequently, this user study conducted on a dynamic motorcycle riding simulator provides empirical data on PTW rider reaction times towards visual notifications. It helps to understand whether and how well the investigated purely visual rider notification is suitable to reduce critical events. It provides information on the relation of PTW riders' reaction times to passenger car drivers' reaction times in a comparable simulated setup. Further, it provides a reference reaction time for OEMs to achieve with their own HMI warning concepts. This knowledge bridges the gap between results from the accidentology site to the use case and test case specific strategies, which aim to the decision on how an application's display/ alert principle should be designed (e.g., advisory notification, crash warning, active intervention).

It is very important to mention that this participant study on a motorcycle simulator provides first empirical evidence for point estimates and spread of reaction times towards a visual C-ITS warning. Nevertheless, the distribution of reaction times towards a visual warning on a real motorcycle in real traffic etc. might vary significantly as there is a huge number of factors influencing these reactions (e.g., type of motorcycle and its ergonomics, dashboard downward angle, type of warning addressing different sensory channels of the rider, rider skills and workload resulting from the scenario, behaviour of surrounding traffic …). As a first step, it is simply not feasible to vary all these potentially relevant influencing factors in a rather controlled way and in a naturalistic field test to get results on PTW rider reaction times.

The chosen study design follows a so-called conservative approach. This means that the rider notification, which is presumably one of the major impact factors on rider reaction times, is designed in a minimalistic and easy-to-be-implemented way. It consists of a generic warning icon without any attention capturing effects, such as flashing, and comes without any warning tone. This type of notification is assumed to be quite easily implemented on PTWs with state-of-the-art technology (i.e., TFT dashboard). Consequently, the study shall provide an estimate for the upper boundary of reaction times (i.e., long reactions), which must be assumed under non-ideal warning conditions (e.g., no additional tone etc.).

The results of this study can be used in the following ways:

1. Based on the temporal evolvement of different accident scenarios, the results help to better estimate for which C-ITS applications running on a PTW, a visual warning could be appropriate.
2. Any OEM's individual HMI solution, i.e., rider notification concept, should result in faster reaction times and less missed warnings in this test setup than the conservative rider notification assessed in this study.
3. The distribution of rider reaction times can clarify to which extend results from passenger car research are applicable to the PTW domain and serve as an input to parametrize rider behaviour models in traffic simulations necessary for the effectiveness estimation of (C-ITS) safety applications.

2 Methods

2.1 Motorcycle simulator description

The DESMORI dynamic motorcycle riding simulator has been used for the participant study (see Figure 1). It is equipped with a BMW F 800S as mockup, mounted on a six degrees of freedom hydraulic Stewart platform. The mockup enables the rider to interact with fully realistic controls, such as usual handlebar, brake lever / pedal, clutch, gear selector, etc. that he/ she is used to. The manual gear shift uses a sequential six-speed gearbox. An electrical actuator produces a steering torque at the handlebar up to 80 Nm. The rider steers the motorcycle through a combination of steering torque and induced roll torque by shifting his/ her weight. The cylindrical screen with a diameter of 4.5 m and 2.8 m of height enables 220° horizontal field of view. The two rear-mirrors are realized by 7-inch TFT-displays while the dashboard is displayed on a 10-inch TFT-touchscreen and an average dashboard downward angle of 33° measured with the riders of this study's panel. Sound is provided via body shakers, which are attached to the riders' individual helmets. Moreover, a shaker that is installed below the seat delivers vibrations from the engine and high frequent road roughness. A rope-towing mechanism simulates longitudinal forces such as wind drag to the rider torso. A camera is mounted right above the dashboard pointing towards the rider's head, which is used for head tracking and gaze behaviour analyses.

Figure 1: DESMORI dynamic motorcycle riding simulator at WIVW.

2.2 Test course

The test course had a total length of approx. 37 km. It consisted of different modules on rural and urban roads. The order of modules was permuted in four versions to avoid sequence effects. As can be seen in Figure 2, there was one urban and one rural test scenario, which were experienced twice per participant (the geometry and resulting trajectories etc. were identical, while the virtual environment was different to avoid any kind of expectations). Both test scenarios had in common that the conflict partner was obscured and therefore could not be seen by the rider in the moment when the warning was emitted. Additionally, there was a rural and an urban baseline scenario without warning but elsewise comparable conditions. The urban test scenario was motivated from the FT Accidentology results. It represents a so-called cross traffic scenario (accident type 302 in the GIDAS data base). The PTW was approaching a crossing and had the right of way. A passenger car that was obligated to wait came from the right-hand side. Though, the passenger car entered the crossing as the simulated driver did not see the PTW. The view was obstructed by buildings close to the road. The passenger car came to a stop covering approx. 1/3 of the PTW's lane. In the rural scenario, the obstacle was a construction site or a broken-down vehicle respectively. These obstacles could not be seen due to trees close to the road and a right-hand bend with a slight downhill section afterwards.

Figure 2: Urban (left) and rural (right) test scenario.

2.3 Study procedure

Figure 3 illustrates the study procedure. All participants were welcomed and received an informed consent document providing all necessary information related to the study. Following the study instruction, a rating on the general attitude towards C-ITS applications on PTWs was collected. Two short rides in a rural and an urban environment on the simulator followed with the main aim of familiarizing with the virtual vehicle control again. Following the successful completion of these rides, the participants received specific instructions for the test ride. Besides trip length, traffic regulations etc., it contained information on the C-ITS application. The working principle of Vehicle-to-X (V2X) communication was explained as well as the type of rider notification. A broken-down vehicle warning as well as a green light optimised speed advisory (GLOSA) as comfort function were named as exemplary use cases. A rider notification for GLOSA was shown on the info sheet in order to divert attention away from potentially upcoming critical situations.

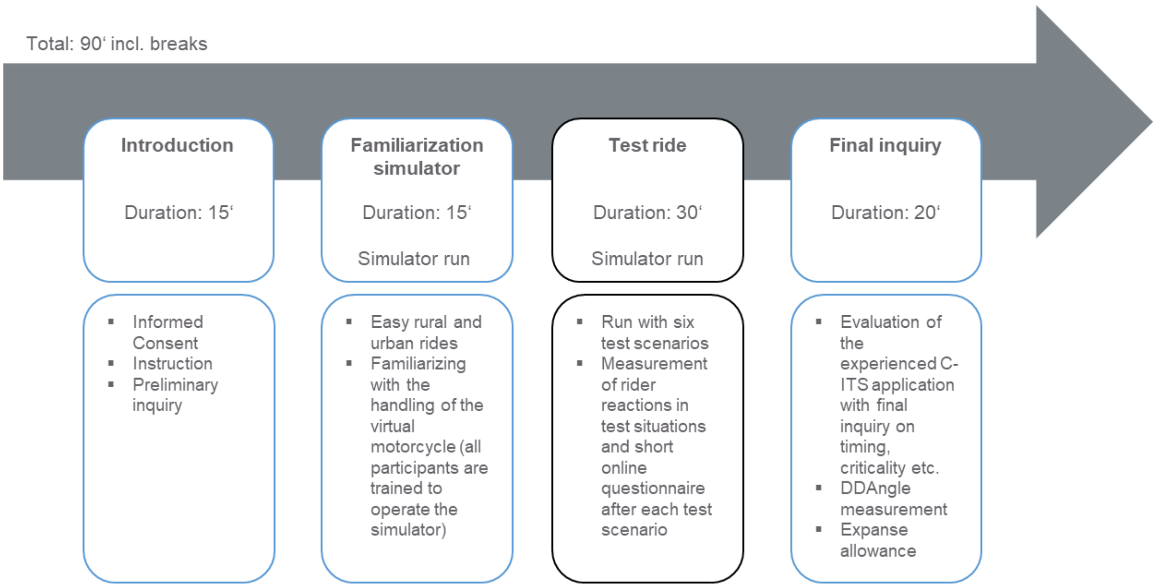

Figure 3: Schematic study procedure.

After each test scenario the riders answered two questions while riding. At the end of the appointment, a final inquiry was conducted and riders received an expanse allowance. In order to facilitate the interpretation of the data, every participant mounted the mockup again and assessed whether he/ she could recognize the dashboard in the peripheral field of view. Additionally, the dashboard downward angle (DDAngle) was measured as illustrated in Figure 4.

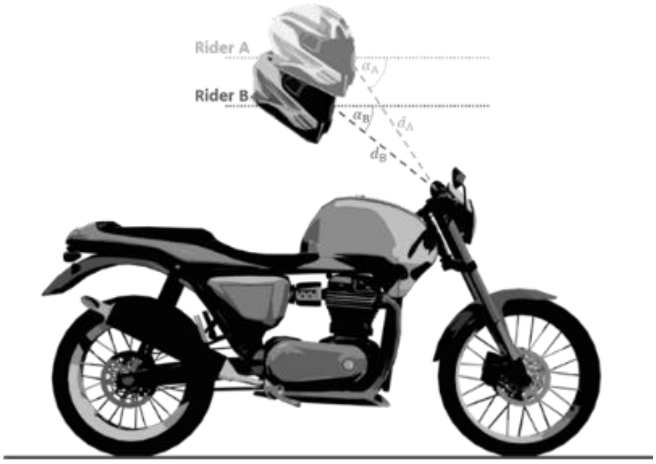

Figure 4: Schematic representation of different dashboard downward angles as a function of different rider heights.

2.4 Rider notification

The rider notification provides a purely visual warning to the rider, which is shown on the upper edge of the dashboard (see Figure 5). The simulated dashboard has a size of 7-inch with a resolution of 1920 x 1080 and it is mounted at an average dashboard downward angle of 33°.

The warning was designed as a non-specific warning with a red rectangle at a size of 16 mm * 27 mm. This decision was taken to investigate an OEM-independent generic warning. Further, it is a result of the conservative approach, which means that a minimum notification would be subject to investigation. The notification was triggered TTA = 3 s prior to when the obstacle became visible. The warning was then displayed for three seconds and disappeared automatically.

Figure 5: Rider notification (red rectangle) in the dashboard.

2.5 Measures and statistical analysis

Three different types of reactions were analysed (Figure 6).

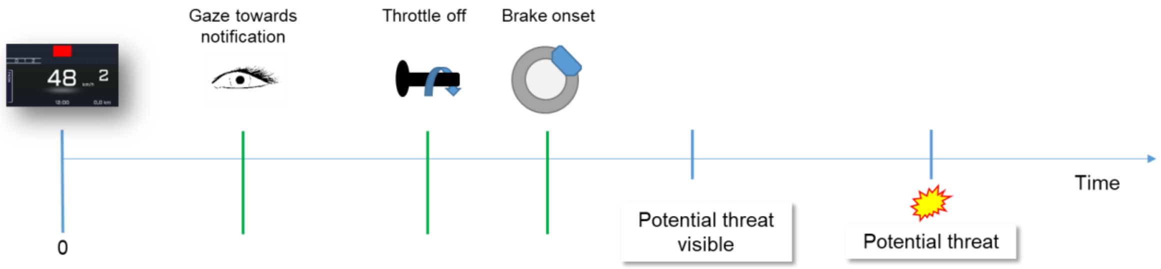

Figure 6: Schematic representation of different possibilities to calculate reaction times.

The starting time t_0 for any calculation is always the issuing of the visual warning in the dashboard (warning onset). The following three types of reactions are analysed:

1. *Warning onset until gaze towards notification.* The gaze behaviour, which distinguishes between 'gaze towards dashboard' and 'gaze not towards dashboard' is retrieved from the video data via manual video annotation. It is assumed that a gaze towards the dashboard while the warning is displayed goes along with the recognition of the warning, which is one of the major variables of interest.
2. *Warning onset until throttle off.* This parameter measures the time between warning onset and the release of the throttle twist grip as the potentially first and intuitive reaction to reduce the speed. A throttle twist grip release is defined as complete release to the neutral throttle position.
3. *Warning onset until brake onset.* This parameter measures the time between warning onset and the start of mechanical braking (either front or rear brake or both) as a rider reaction for significant speed reduction. Brake onset is defined as an operation of any brake lever:

Depending on the evolution of each specific test scenario, throttle off and brake onset must not necessarily occur, if a rider judges the situation as sufficiently controllable and safe. If there is no gaze towards the dashboard, the situation is counted as a missed warning. Consequently, no type of reaction towards a warning can be calculated in this case. Any rider response later than 300 ms after warning onset was regarded as response to the warning instead of a regular control gaze towards the dashboard.

In addition to the vehicle dynamics data, subjective measures were gathered. After every test situation the riders were asked whether the C-ITS application emitted a warning. If the answer was positive, the riders were asked what their reaction was. This information helps to interpret the riding data. For instance, a rider may reply that he recognised the warning but decided not to brake, because there was enough space on his lane to pass the potential conflict situation. The second question targeted the perceived criticality of the experienced situation. A final inquiry completed the appointment.

Video annotation was done with SILAB VideoAnalysis®. Data has been pre-processed with MatLab® and further analysed using *Statistica*® and *SPSS*®. Descriptive data, such as means, distributions etc. show raw data if not elsewise stated. A base 10-logarithm was calculated for inferential statistics of the reaction times to account for skewness and non-normal distribution of the raw data.

2.6 Participants panel

A total of $N = 24$ riders participated in the study, while $n = 3$ were female. The panel covers a wide spread of different ages and levels of riding experience as can be seen in Table 1. The study has been approved by WIVW's group in charge for ethical assessment. The strict ethical guideline as defined in the standard operating procedures based on the Guidelines for Safeguarding Good Research Practice of the German Research Foundation (DFG) as well as the Code of Professional Ethics of the German Association of Psychologists (bdp) and the German Psychological Society (DGPs) has been followed. All participants were recruited from the WIVW motorcycle rider panel, which consists of non-professional riders that had previously been trained to ride the simulator safely.

Table 1: Panel description (N = 24 with n = 3 female riders).

	Mean	***Standard deviation***	***Minimum***	***Maximum***
Age in years	36	12	20	60
Motorcycle mileage covered during the last 12 months in km	3 854	3 232	500	12,000
Motorcycle mileage during lifetime in km	78,500	79,900	2 000	300,000

3 Results

The analysed segments start with the warning onset and stop when the rider has passed the potentially critical situation.

Figure 7 shows the gaze reaction time data. First of all, in both, warning and baseline scenarios, riders' show (control) gazes towards the dashboard. In the baseline condition, more regular control gazes towards the dashboard can be observed in the urban area as compared to the rural setting. The number of riders with at least one gaze towards the dashboard increases with a warning being presented (Rural: with a warning 56% (27/ 48) instead of 9% (2/ 22) without warning; Urban: with a warning 94% (45/ 48) instead of 63% (15/ 24) without warning). Further, it is recognizable that there is a certain spread of measured reaction times between riders and test scenarios.

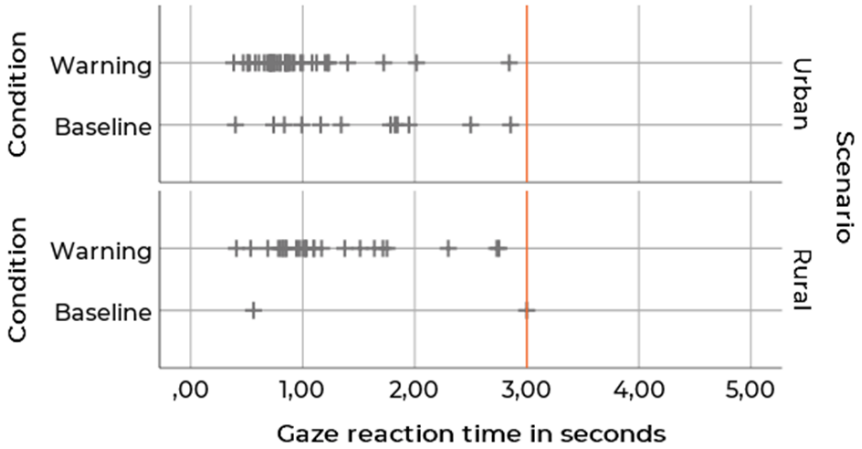

Figure 7: Riders' gaze reaction time after the warning has been emitted for rural and urban scenarios in warning and baseline condition. + indicates a single measurement, the orange vertical line indicates the point in time when the obstacle becomes visible and the warning disappears.

In comparison to the baseline condition, the riders' show earlier gazes towards the dashboard in the warning condition ($F(1,11) = 6.89$, $p = .024$, $\eta^2_{part} = .385$). Within the warning condition, an average gaze reaction time of approx. 1 sec is observed, with faster reactions in the urban scenario on average.

Table 2: Descriptive statistics regarding gaze behaviour as response to the warning. All values are given in seconds.

Condition	**Scenario**	***N***	***Mean***	***Mdn***	***Min***	***Max***	***SD***
Baseline	Urban	12	1.52	1.56	0.40	2.86	0.74
	Rural	2	1.78	1.78	0.56	3.00	1.73
Warning	Urban	42	0.91	0.80	0.38	2.84	0.44
	Rural	26	1.22	1.02	0.41	2.75	0.61

Table 2 contains detailed descriptive statistics on the gaze behaviour following a visual warning. In the baseline condition, throttle off or brake responses cannot be observed within the hypothetical warning period, while a majority of the riders in the warning condition shows a throttle off or even brake reaction before the obstacle becomes visible (Figure 8).

Analysing the throttle off response, a higher number of reactions can be seen in the urban scenarios as compared to the rural scenarios (n_{Urban} = 34/ 48; n_{Rural} = 21/ 48). For the braking manoeuvres the number of reactions is equally distributed (n_{Urban} = 26/ 48; n_{Rural} = 26/ 48). Yet, with the major difference that all urban brake reactions occur as response to the warning within the three seconds warning period, while more than half of the brake reactions in the rural scenario are observed when the potential threat is already visible.

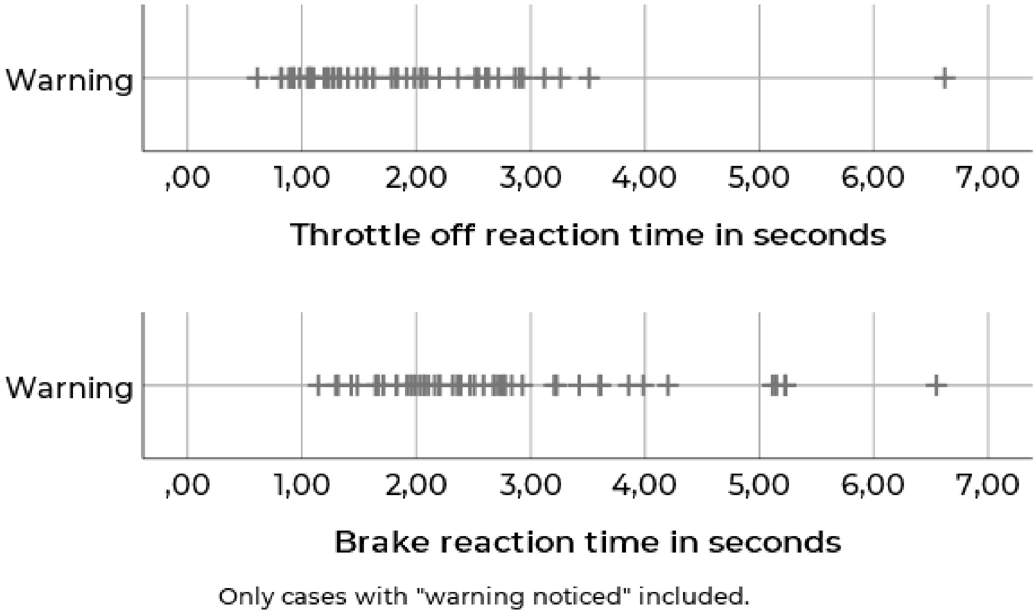

Figure 8: Riders' throttle off and brake reaction times after the warning has been emitted for rural and urban scenarios.

Additionally, riders react earlier in the urban scenarios as compared to the rural scenarios within the warning condition (throttle off: Mdn_{Urban} = 1.27 sec; Mdn_{Rural} = 2.13 sec; Brake onset: Mdn_{Urban} = 2.13 sec; Mdn_{Rural} = 3.51 sec). The overall median value for the throttle off reaction time is *Mdn* = 1.51 sec and *Mdn* = 2.49 sec for the brake reactions. Detailed statistics regarding both types of reaction times can be found in Table 3Table 2.

Table 3: Descriptive statistics regarding throttle off and brake onset reaction times as response to the warning. All values are given in seconds.

Parameter	***N***	***Mean***	***Mdn***	***Min***	***Max***	***SD***
Throttle off	55	1.79	1.51	0.61	6.62	1.00
Brake onset	52	2.79	2.49	1.14	6.55	1.20

Figure 9 provides a summary of the different reaction times as function of the scenario. The course of actions starting with a gaze towards the dashboard followed by a throttle off and then brake response can be seen. The urban scenario, which is more time critical provokes more homogeneous reactions within the warning period, while the reaction times in the rural scenario show a larger spread.

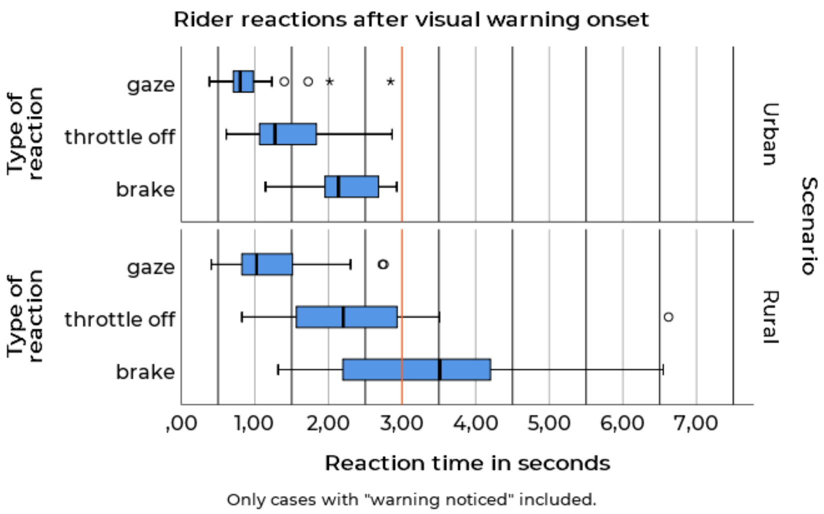

Figure 9: Summarizing rider reaction time boxplot containing data from participants who reported to have seen the warning. The plot shows rider reaction times for gaze, throttle and brake reactions separately for urban and rural scenarios. The orange vertical line indicates the point in time when the obstacle becomes visible and the warning disappears. Black vertical lines in the boxes mark the median value, while the box gives the interquartile range.

4 Discussion

The present paper described a dynamic motorcycle simulator study, which investigated motorcycle riders' reaction times towards visual warnings. A 'conservative' rider notification in terms of a red rectangle in the dashboard without any auditory component has been subject to investigation. Two scenario types were included: a cross traffic scenario in an urban environment and a broken-down vehicle/ road works scenario on a rural road. Both scenario types were experienced twice with a warning and once without a warning by every participant. To prevent expectancy effects, dummy scenarios were included that resembled the test scenarios in terms of road geometry, view obstruction etc., but did not include any potentially critical situation. This scenario design worked well as the participants could not identify the scripted critical scenarios while approaching. This means that no expectancy effects occurred, such as unnaturally cautious behaviour while approaching the test scenarios.

The first reaction time of interest, was the time between warning onset and gaze directed towards the dashboard. Even in the baseline condition, riders' have shown control gazes towards the dashboard during the hypothetical warning period. Yet, in the warning condition the number of gazes towards the dashboard was clearly increased. This has a high face validity as riders seem to control their speed more often in the city as compared to the approach phase of a rural curve. Additionally, the riders directed their gaze earlier towards the dashboard, which indicates that the warning was salient enough to catch the riders' attention. Yet, 16 out of 96 warnings were missed, which primarily occurred in the rural scenarios. This might be a result of different gaze behaviour for rural and urban scenarios. The latter providing a more vivid environment and potentially a higher perceived need to control the velocity on a more regular basis. In summary, the purely visual warning could be notified by a majority of riders, given an average dashboard downward angle of 33°. Yet, an improved rider notification design (e.g., warning tone, visual signals closer to the natural line of sight etc.) should increase the acceptance of an application and should have the potential to create less missed warnings and potentially shorten reaction times further.

In the baseline condition no throttle off or brake reactions were observed in the hypothetical warning period. This means that the throttle off and brake reactions observed in the warning condition were really a response to the warning and not the scenario itself. It is important to mention that the participants did not stay passive in potentially critical situations. When the obstacle became visible the majority showed an avoidance manoeuvre in terms of swerving as – especially in the urban scenario – braking did not seem to be a promising avoidance manoeuvre anymore. Yet, these reactions occurred when the potential threat became visible and were therefore not subject to investigation in this study. The difference between the rural and urban scenarios which was already found for riders' gaze reaction times was also found for throttle off and brake reactions. Thus, the road type seems clearly to make a difference. The underlying reason for the different reaction times might be the scenario itself (e.g., the urban crossing scenario requires a faster reaction than the rural broken-down vehicle warning from the point in time when the critical situation becomes visible.) or psychological effects such as imposed rider workload (e.g., higher level of awareness in the urban setting with more action in the periphery) as a result of the scenario.

The collected data set seems to show differences to data sets on driver reaction times in the passenger car domain. For instance, guidelines such as the ISO 15623 2013 (E) suggest minimal driver reaction times of 0.4 sec and maximal reaction times of 1.5 sec or SAE J2400 names 1.18 sec before starting a response to a Forward Collision Warning. Passenger car simulator study results, for instance, Winkler et al., 2015 measured 0.86 sec on average as brake reaction time with a purely visual generic warning in a HUD in a time-critical crossing scenario with a pedestrian. Bella and Silvestri, 2017 investigated a cross traffic scenario in a driving simulator with a purely visual warning in the dashboard triggered approx. with a TTC = 4 sec. Their average reaction, defined as time between warning onset and the moment when the driver starts to decrease the speed, is 0.94 sec. For the crossing scenario in this study as fairest comparison, the mean throttle response was 1.47 sec and 2.18 sec for braking. Completely missed warnings were not really an issue in the cited passenger car research.

Obviously, simulator studies go along with certain limitations starting from some missing environmental factors (e.g., sun glare) to the focus on relative or scenario-dependent validity, which should avoid the expectancy of a one-to-one match to results gained in a field study. Yet, the chosen simulator study has clear advantages, which made it efficient and appropriate to follow this approach. First of all, there is almost no information on PTW rider reaction times available and this study should be a first step towards empirical evidence in this domain. The advantages such as a fully controlled environment in terms of behaviour of other traffic participants, repeatable critical scenarios or convenient and precise measurement of all necessary data etc. dominate. Further, besides ethical and safety constraints in investigating rider reaction times in potentially critical scenarios in a field test, the results would not have been generalizable either. Simply because, one specific PTW with its given ergonomics, dashboard downward angle etc. would have been investigated and the results gained with another PTW (e.g., touring vs. chopper) could have been completely different.

5 Conclusion

The results of the presented user-centred simulator study successfully provide a first estimation of motorcycle rider reaction times to a generic purely visual warning. These reaction times can be seen as a benchmark for future visual warning designs. Thus, it is an opportunity for OEMs or TIER1-suppliers to compare the reactions triggered by their rider notification solutions in a comparable setup to the generic warning design in order to assess their efficacy. Therefore, new warning designs should ideally result in lower or at least equal rider reaction times and less missed warnings as compared to the given conservative rider notification. Besides the already acceptable salience of the investigated warning, potentials of improvement were identified, which should be taken into account for further developments.

Secondly, even if it is rather impossible to identify absolutely comparable studies from the passenger car domain, the empirical evidence suggests a need for PTW-specific reaction time analysis as more missed warnings were observed and reaction time distributions differ.

Thirdly, the distributions of rider reaction times can serve as important input to the tuning of rider behaviour models, which are required to create effectiveness estimations for (C-ITS) safety applications by means of traffic simulation.

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Providing the PTW rider safer riding – cooperative collision warning

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Abstract
This paper concentrates on one specific research topic (among several investigated) to increase safety of PTW rides engaged with modern cars and Connected (semi)Automated Vehicles (CAV). Based on recent industry and user initiatives, it is safe to propose that PTW riding makes an important contribution to our quality of life. Smartly integrated in the transport system, along with public and other private means of transport, PTWs make it possible something that we usually take for granted: sustainable and easy urban neighbourhood mobility. So, we should address how to have the PTW users to survive in traffic with present ADAS-equipped cars and future CAVs. It starts with improving PTW conspiquity on the sensors of current and future CAVs' ADAS systems and reaches on equipped PTWs in circulation cooperating in from Cooperative Collision Warning (CoCW) until Cooperative Safe Overtake Assist (C-SOA). Scenarios and results will be discussed.

Keywords:
Powered two-wheelers (PTW), Connected automated vehicles (CAV), enhanced safety, cooperative warnings, manoeuvre coordination

1 Setting the scene

In addition to researchers, European PTW Industry is progressing in making motorcycling safer through connectivity and cooperation. The transition to more connected automated vehicles (e.g., cars, trucks) in circulation is likely to increase in near future, but it will take several decades before *majority of cars in circulation* will be self-steering autonomous ones (i.e., SAE Level 4/5). On the other hand, PTWs drag significantly behind advanced rider assist systems (ARAS) development. There are only few PTW makes and models in circulation that have any ARAS installed. It is more than likely that this will take up to half a century before sufficient number of motorcycles in circulation will be replaced with *new connected and cooperative motorcycles* that are fitted with features supporting communication, connectivity and cooperation with other vehicles *and* that are equipped with ARAS and/or environment perception systems that may assist riders in their riding tasks or even take over some parts of the motorcycle riding. It is not evident that motorcycling as we know it, still exists that point in time.

In recent research, VTT research team has concluded based on several tests in various research projects that there is still a huge gap to be covered in how well the environment perception systems (sensors and software) of modern cars' ADAS will manage to collaborate with the approaching and/or preceding non-equipped PTW. The outcome of the test events has been that the state-of-the-art sensor systems of modern cars including radars, LiDARs (Light detection and ranging, also known as laser scanner) and cameras were not fully able to *early enough* and *dependably enough* to detect and identify the "event ahead" as a motorcycle. It is a fair assumption that at current state of development of commercial and state-of-the-art sensor systems, PTWs and motorcyclists are just like "flying empty plastic bags" for the sensors on-board cars in circulation.

Within the transport system, PTWs take up less space in traffic. Due to their narrow shape, one traffic lane can easily fit two PTWs, ridden in a zipper-like fashion or single PTWs running on either side of the centre line of a lane; disadvantage being that *none of these* would be in the main visibility area of cars' sensors. PTW frontal and rear "faces" contain mostly plastics (i.e., fenders, windshields, fairings), rubber (i.e., tires) and other non-metallic materials thus causing problems for the radars of cars and CAVs to detect the PTW.

2 Reasoning based on current developments to promote PTW inclusion in CCAM

2.1 Accidentology: PTW riders suffer from accidents caused by other vehicles

The PTW accidents can be divided into two major categories, namely '*collision accidents*' involving at least one other vehicle than PTW, and '*riding accidents*' where only PTW is involved. The most common *collision accident* types including other vehicle and PTW are (other vehicle as faulty party unless otherwise stated) crossing traffic (18%), longitudinal traffic (13%), lane change (8%), left turn (6%), longitudinal traffic (5%), lane change (PTW as faulty party, 5%), and other vehicle U-turn (4%) as reported based on the German GIDAS database. These accidents would be addressed using cooperative ITS and environment perception systems, including in-vehicle systems and connectivity between the vehicles (PTW, other vehicles) and vehicles and infrastructure. In addition, there are three major types of single vehicle PTW *riding accidents*, namely derail in left curve (11%), right turn (10%), and straight road (7%). These accidents are likely to be avoided by stand-alone individual ARAS.

The majority of accidents involving PTW and other vehicle are caused by other vehicle drivers (50-70 %), the majority of collision 'partners' are cars (60-90 %), and the most commonly the collisions take place in intersections when cars are crossing and/or turning (15-30 %) as reported by CMC, see figure below. There is an immediate request to make PTWs more visible (digital consipicuity), improve the performance of in-vehicle ADAS systems (sensors and software), enhance car driver and PTW rider warning strategies, and/or to equip PTWs with equivalent environment perception and cooperative safety and vehicle detection systems. PTW industry has identified several possible C-ITS applications and services that would benefit riders and increase their safety in traffic based on comparison with

German GIDAS accident datasets weighting toward the German traffic accident statistics.

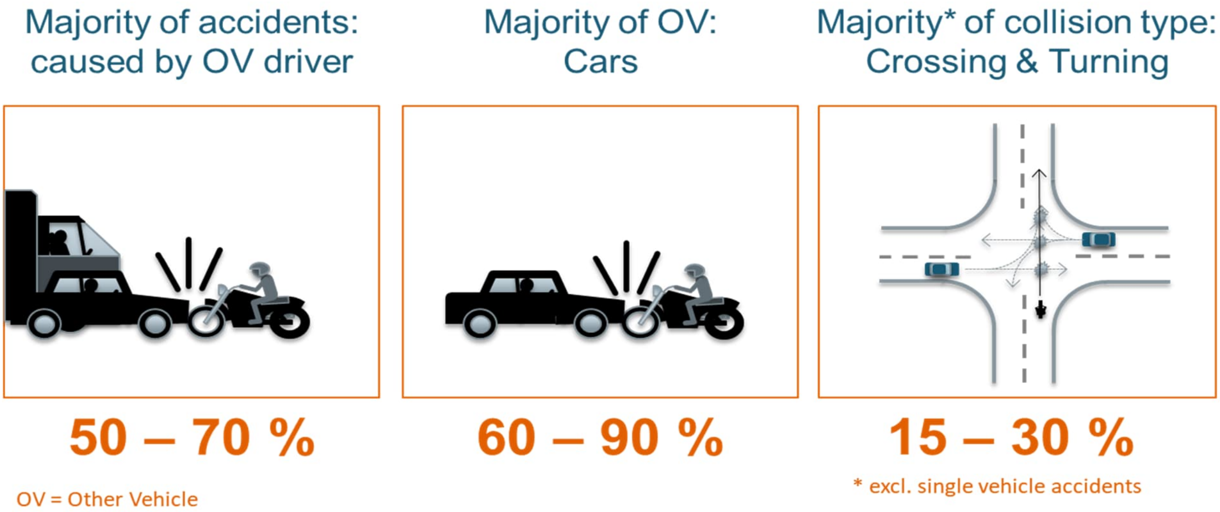

Figure - PTW Accidents – Perception Failures ©CMC, VTT

2.2 Connectivity: PTWs are part of overall transport system — shall be able to connect with other vehicles

It is only question about timing, when the general development of intelligent transport will lead to majority of motorized vehicles in traffic to be connected to information networks, capable to scan their imminent proximity for objects, and being able to communicate with background systems and/or other vehicles. PTW users must have equal access to connected traffic services and data as equal road users. New car models are equipped with devices to facilitate automatic emergency call, eCall service, and very few also with ITS-G5 5.9 GHz communication. Slow penetration of ITS-G5 may be caused by their emergence to cover most road networks including the lower category roads will “never happen”. Mobile cellular networks, on the other hand, cover around 95% of population and road networks already. While circuit-switched networks (2G, 3G) will be gradually replaced by 4G/LTE/5G networks, to continuum in Europe is ensured.

2.3 Advanced rider assist systems: PTW industry are slowly deploying ARAS

PTW industry would be able to develop Advanced Rider Assistance Systems (ARAS) that enable significant improvements in PTW riding and rider safety. These systems shall feature new capabilities such as adaptive cruise control (ACC), automatic emergency braking (AEB), lane departure warnings (LDW), and other alerts and assists to augment the rider’s capabilities and assist them.

For PTWs, the future would be to develop a ‘*vehicle that is not to cause a crash*’. This would be well in line with the industry and rider lobbyists’ positions of a future riding on PTWs. The approach is to improve ARAS to monitor and augment the vehicle operator’s capabilities and making the roads safer without removing the human from the operator’s seat of PTW. New systems combinations like embedded environment perception (see below) extended with further information provided to enhance vehicle operator awareness via connected V2X vehicle (see below) services are emerging to address the evermore multiple, complex, sudden and unanticipated traffic situations. The ADAS solutions that have been designed for cars do not work on PTWs as such; instead, tailor-made ARAS are *a must*.

PTW industry has only recently (2020) published their first set of 19 connected motorcycle *use case definitions and technical descriptions* (also referred as *application specifications*). There are two common nominators inherited in all of these: firstly, they require *V2X communications* to be in place in majority of other vehicles and infrastructure (RSU) to benefit a rider whose *own PTW shall be equipped with required hardware and software*; secondly, they consist *no major actuator initiation on the PTW*, but mere warning strategies for the rider. This is in line with the rider community inspirations at large.

2.4 Environment perception: PTWs lack boost for new tech-based innovations for ARAS

A most recent automotive-quality *environment perception sensors* together *with V2X communication* technologies allow the vehicles to “see” beyond its operator’s line of sight, a crucial capability for connected automated driving. Because no single sensor can meet all the requirements for automated vehicles, complex sensor suites, such as LiDAR, along with radar and cameras, will be most effective to drive deployment of automated cars and trucks. The higher the resolution of LiDARs, the more accurate their ability to detect objects, other vehicles and persons under different lighting and weather conditions, translating into safer driving.

Sensors have specific operating capabilities that make them suitable for specific functions. *Long-range radar* is used for a.o. adaptive cruise control, while *short/medium-range radar* for rear collision warning and cross-traffic alert as well as detecting distance and speed. *LiDAR* can create highly accurate 3D renderings (point clouds) of the vehicle’s surroundings for instance for emergency braking, pedestrian detection and collision avoidance. *Cameras* are convenient for texts, numbers, fonts, traffic sign recognition, object classification, lane departure warning, park assist and view around the vehicle, and *ultrasound sensors* for park assist. Some of these functions and technologies would be well appreciated by concerned motorcyclists. Regarding PTWs, the automated riding is *not the target* for motorcyclists nor for the industry. Instead, for PTWs the environment perception can and would be convenient for advanced rider assist and safety solutions as well as for PTW visibility.

2.5 Vehicle-to-Everything connectivity: PTW users will benefit from V2X

The in-vehicle stand-alone systems cannot detect objects outside of their line of sight. Vehicle-to-everything (V2X) technology could solve this issue by enabling vehicles to communicate with connected devices on other vehicles, pedestrians, cyclists and roadway infrastructure. If the devices are connected to the same network, V2X allows cars to interpret the movement of objects outside of its own field of vision as well, providing an additional layer of safety. V2X in general, independently from the underlying technologies, enables a wide range of information exchange and connected cooperative applications and services.

New technologies aimed at improving the efficiency, safety and environmental performance of road transport are playing a significant role in achieving the European goals in this area. One emerging field is that of cooperative intelligent transport systems (C-ITS), which enable ITS users to cooperate with each other and the surrounding road infrastructure by exchanging secured and trusted messages. In road transport, C-ITS typically involves vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and/or infrastructure-to-infrastructure (I2I) communication, and communication between vehicles and equipped pedestrians or cyclists (included in V2X). It is worth noting that motorcycles or other PTWs have not specifically been mentioned in this context.

Cellular V2X (C-V2X) is an extension of cellular standards and an important factor in next-generation wireless technology for safety- and time-critical and automated driving solutions. C-V2X has 2 modes: C-V2X Network, using traditional IP-based network communications, and C-V2X Direct In general, C-V2X Direct directly connects vehicles to everything. Collectively, these communications will redefine intelligent transport by providing real-time, highly reliable, and accessible information flows to benefit vehicle operators and their vehicles. Using direct communication mode, C-V2X Direct is designed to help expand the role of mobile technology for road safety applications by facilitating the ability of vehicles' direct communication using the 5.9 GHz band without the involvement of a cellular network or cellular network subscription or fixed wireless network.

Complementary to other ADAS sensors, like cameras, radars, and LiDAR, C-V2X technology is designed to support 360-degree non-line-of-sight (NLOS) awareness and is designed to extend a vehicle's ability to "*see, hear, and understand*" the environment down the road, at blind curves, intersections, or in adverse weather conditions. The technology also supports advanced vehicle communication capabilities for improved traffic efficiencies, like real-time map updates and event notifications relayed using cellular network and Mobile Edge Computing (MEC) infrastructure.

3 VTT's Connected Motorcycle Research platform

3.1 Research platform

The Connected Motorcycle (CoMC) as a research platform serves multiple research initiatives in the area of Connected Cooperative Automated Driving (CCAD). The CoMC platform has been used in several European and national research projects together with relevant interested industries. The role of the CoMC is to bring in the PTWs into the CCAD domain; not just as a "dumb Other Vehicle", but active connected vehicle that communicates actively with other equipped vehicles and infrastructure. In order to facilitate active involvement in CCAD domain, there are two main domains integrated in the platform, namely *environment perception* and *connectivity*. In addition, the VTT's CoMC platform architecture is based on various connected functional management modules e.g., positioning, environment perception, data, applications, communication and human-machine interface modules.

Environment perception management module on CoMC contains a.o., GPS for lane-level position accuracy, 6DoF Gyroscope or Inertial measurement unit, radar and LiDAR, thermal and 3D imaging, riding manoeuvre data capture, data network monitoring and data logger and storage.

Connectivity management module of CoMC contains a.o., C-ITS application module, C-V2X Direct communication, ITS V2X stack, Cellular 4G/LTE/5G_NSA/5G_SA) and ITS-G5 communication units.

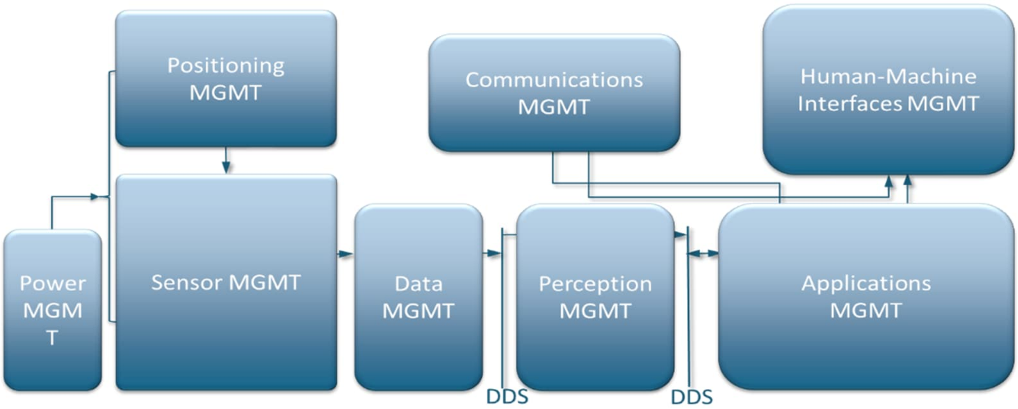

Figure – Functional Architecture of VTT CoMC platform for Connected Automated Mobility

3.2 Equipped PTW for connectivity and cooperation

VTT research motorcycle is based on KTM 1290 Super Adventure R due to its unique set of functions and characteristics available for research purposes. VTT has tested other more sophisticated tools for added conspiquity. For active digital visibility, the motorcycle is fitted with V2X communication system to transfer positions, speeds and riding/driving directions (i.e., trajectory and manoeuvring) between other connected vehicles. The hardware configuration is more or less similar to that of cars.

Figure – Environment perception and V2X Platform on JARNO research vehicle ©VTT

V2X makes it possible for motorcycle to connect and communicate with other connected vehicles. Jarno research motorcycle hosts 4G LTE and G5 radio modems for connectivity using standard (or under specification) C-ITS messages. Over mobile connectivity, Jarno can make its position, direction, heading and speed (trajectory) known to other vehicles. In return, Jarno can receive similar information from other vehicles. Thus, it is actively making its presence known (enhance the digital visibility) to other vehicles, increasing the rider safety related to almost all accident types except vehicle tumbling off the road (derailing).

Solution that is even more sophisticated would be an *on-board environment perception solution* installed and fine-tuned for motorcycle. Jarno research motorcycle hosts a large variety of sensors for environment perception, i.e., to detect objects and their characteristics in its surroundings and to identify the size, nature and quality of the object, e.g., human, bicycle, car, truck, traffic sign, light post, rolling ball. For this purpose, long and short-range radars are used, LiDARs, cameras and sensor data fusion on-board. Using this equipment, it is possible to prepare the rider for unexpected traffic situation and road condition including friction.

Figure – JARNO - The Connected Motorcycle Platform of VTT. Front: LiDAR and radar (left); Rear LTE-4G/G5 comms antennas, IMU, GNSS (right) ©VTT

3.3 PTW Cooperative Collision Avoidance and Safe Overtake Assist

Currently, there are the following PTW C-ITS services for research available: ITS G5 and Cellular 4G-LTE, while the full target is on C-V2X Direct communication between PTWs and other vehicles. Current commercial 5G networks are 5G-NSA (Not Stand Alone) that have been implemented using underlaying 4G LTE network hardware. The basic and enhanced safety applications and connected services have been implemented using 5GAA Rel14 hardware (NSA).

During the CCAD testing periods the target is to look into the future. In that sense, only connected motorcycle and connected cooperative automated vehicles are used. In the various 5G and connected driving integration projects several V2X messages have been used. Also, some basic applications have been implemented e.g., *Motorcycle Approaching Warning MAW* (for CCAV), *Left Turn Assist/Warning LTA* (with CCAV), *Collision Warning* (with CCAV), *Collision Avoidance* (with CCAV), *Cooperative Collision Avoidance* (CoCA) and reaching up to *Connected Safe Overtake Assist* (C-SOA). The **Connected Safe Overtake presents the very top in Cooperative Collision Avoidance development**.

For the development, various test tracks have been used, namely VTT Tampere MotoSpace, 5G-SAFE+ site in Sodankylä Airport and 5G-MOBIX site in Helmond (NL).

Figure – VTT MotoSpace test track (above) and Sodankylä Airport (right)

3.4 Issues with PTW conspiquity

Motorcycles suffer largely from the same issues as their lighter PTW cousins. When *mopeds* and *electric scooters* remain currently undetected and non-identified for most ADAS sensors in near future. For semi-automated vehicles (SAE Level 2) these light PTWs are moving hazards unless PTWs' conspiquity shall be enhanced or digitally enabled. Modern motorcycles' metallic parts are mainly in the internal combustion engine (ICE), front fork, main frame, and rear subframe, shock absorbers and swing arm — all visible mainly only from side view. *From frontal view*, visible are only front tire, (plastic) fender, plastic (semi/full) fairings (when equipped), head lamp, windshield and the rider's (plastic/fibre) helmet and (textile/leather covered) arms and hands. *From behind*, there are only rear tire, plastic rear fender, register plate, (artificial leather) seat, (plastic/fibre) helmet and the rider's (textile/leather covered) back. None of these provide any meaningful radar reflections for detection and identification.

3.5 Simple but efficient – radar reflectors

For motorcycles — due to their higher price point than other L type vehicles — there are more possibilities to enhance their digital visibility. There are the same passive tools to add radar visibility, namely *radar reflectors*. Below is a photograph showing the radar reflectors installed in the Jarno research motorcycle. Figure below shows a short-range radar for in-vehicle environment perception and on its both sides there are the reflectors (shape of a pyramid triangle) for other vehicles' radars.

Figure - The radar (in centre) and radar reflectors on Connected Motorcycle JARNO ©VTT.

Radar reflectors may be the most convenient way to enhance light PTW conspiquity in the ADAS toolbox. They are most obvious, suitable and affordable. It would be rather affordable to design and imbed reflectors in the frontal silhouette of PTW. Below there are two figures showing what in this case are the differences in radar measurement results without and with radar reflectors. The target is a large adventure motorcycle, Jarno. On the left figure, the radar cross-section remains just above 10 (for this purpose a scaled number) in distances between 32 - 40 meters in front of the car; when the distance becomes shorter, the cross-section measurement becomes fully unpredictable and unreliable to make any object detection conclusions. On the right figure, the cross-section stays well above 15 and then the drop in reliability is eminent. These numbers *allow ADAS and CAVs a clear detection opportunity and enable identification of the object as a PTW*.

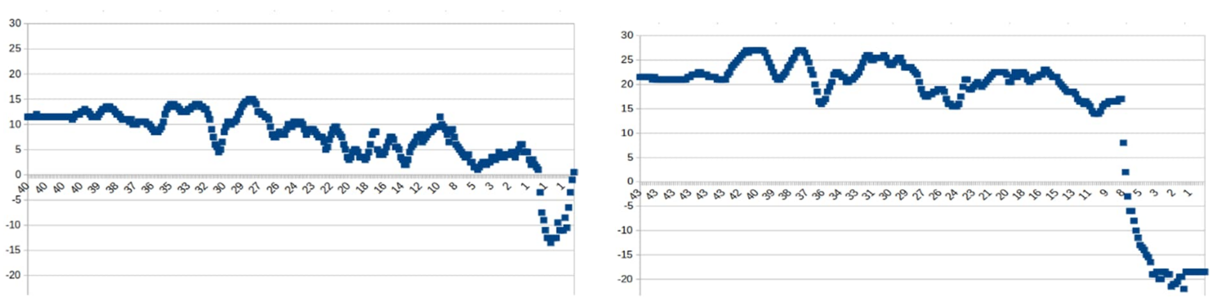

Figure - Radar Cross-Sections on motorcycle: without (left) and with radar reflectors (right) ©VTT

4 Case study scenario for Cooperative Safe Overtake Assist

4.1 CAV detect pedestrian and PTW and intends automated passing of pedestrian

The main objective of 5G-SAFE+ Use Case 3 was to assess the capabilities of 5G networks to provide safety critical information with low latency. The Use Case combined the detection of VRUs using multiple techniques (from infrastructure and through equipped VRUs), exchange of VRU information through CPMs, automated safe overtaking of the pedestrian and collision avoidance with the approaching PTW. These scenarios have been implemented in 5G-Safe-Plus (Celtic Next) and 5G-Mobix (Horizon 2020). The use of MEC (Mobile Edge Computing) allows to shorten the communication path and guarantee low latency.

The following V2X messages used in this case are:

- CAM Cooperative Awareness Message
- CPM Cooperative Perception Message
- DENM Decentralised Environment Notification Message
- MCM Manoeuvre Coordination Message

The instances of the pilots were:

- Use case 1: Communication exchange of the VRU detected by different methods to other road users. The pedestrian can be detected in two ways:
  a) detection of a objects on the road by infrastructure. A combination of LiDAR and camera is used to both classify and locate the object.
  b) detection of a pedestrian, from status message transmitted by the pedestrian's smartphone
- Use case 2: Exchange of the VRU data through CPM,
  a) integration of CPM response within the automated vehicle
  b) integration of CPM in situational awareness products in the connected vehicle
- ***Use case 3: Automated passing of the VRU*** (*UC 3 addressed in this paper*),
  a) assessment of the VRU behaviour (walking along road or crossing road)
  b) reaction of the vehicle based on assessment of VRU movement
  c) *exchange of information with PTW using MCM*

4.2 PTW Cooperative Safe Overtake Assist (C-SOA)

There were two scenarios of the Use Case 3:

- UC 3.1: CAV + CV: exchanging CPM and CAM messages
- ***UC 3.2: CAV + PTW, exchanging MCM messages*** (*UC3.2 is addressed in this paper)*

In this paper, focus is on UC3.2 and its variance where pedestrian possesses a smart phone with C-ITS connectivity application. **The overall scenario** for UC3.2 where there are PTW, CAV, CV and VRU (pedestrian) involved can be described following.

A pedestrian (VRU) is walking on the road. The pedestrian is detected by the detection unit (camera + LiDAR), and a CPM is sent over the mobile network. Connected Automated Vehicle (CAV) and Connected Vehicle (CV) are driving to west and approaching VRU from the opposite direction. PTW drives to east from the opposite direction to CAV and CV. CAV publishes its intention to pass the VRU. Then the applications (on-board ECU or in MEC) detect that *CAV is on a conflicting trajectory* with PTW trajectory. PTW is publishing continuously its trajectory using MCM to negotiate passing. CAV exchange CPM with CV behind.

Even if this scenario may sound quite straight forward there are several potential issues buried. First, the accuracy of CPM message may be insufficient, due to the delay in the communications, and the accuracy of relative position and object detection from the detection unit. Second, CAV must brake autonomously when PTW does not pass pedestrian on time for CAV to pass VRU safely. Third, CV cannot perform same automated manoeuvring as CAV. Forth, as an alternative or back-up solution is that the VRU will send its own status. The overall scenario (time=t0) is depicted below.

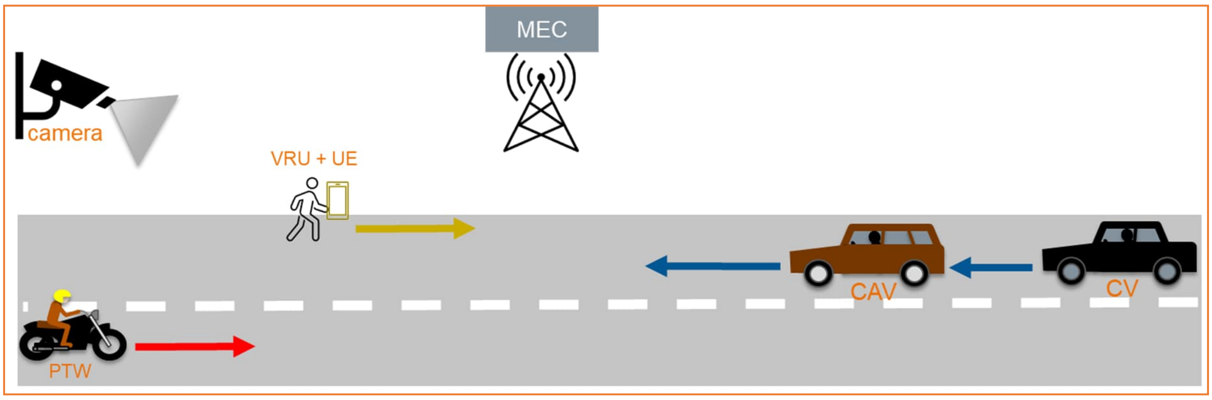

Figure – Connected Safe Overtake Assist (C-SOA) - Overall scenario, t=0 ©VTT

The Storyboard for UC3.2-1a is split in four based on their timeline (t1 – t4), see figures on the following pages.

Time t1:

The following events take place at **time t1 – CAV detect VRU and oncoming PTW** (ref to figure below):

1a: Detection unit app transmits position – sends CPM

2: CPM Messages are routed through the MEC on 5G test network and received by CAV, CV and PTW

3: PTW publish its trajectory

4: The detection data coming from different sources is fused in the vehicle or in the MEC

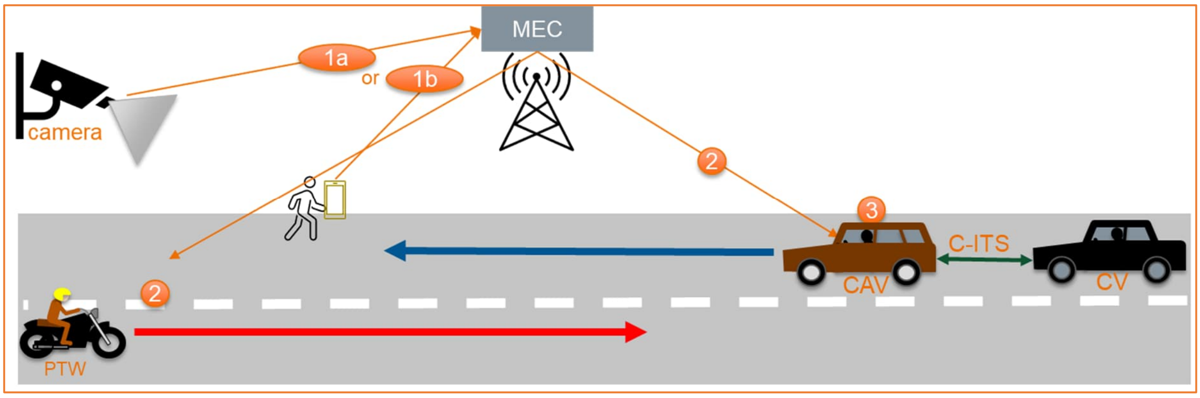

Figure – Time t1: C-SOA scenario - Detection of VRU & oncoming PTW

Time t2:

The following events take place at **time t2 – CAV's desired trajectory changed** (ref to figure below):

1: CAV intent to pass VRU

2: CAV detects potential collision with pedestrian

3: CAV calculates both safe trajectory (i.e., to stop) and desired trajectory (i.e., to avoid pedestrian), and publishes MCM

4: PTW receives MCM and thus is warned of VRU presence and CAV desired trajectory

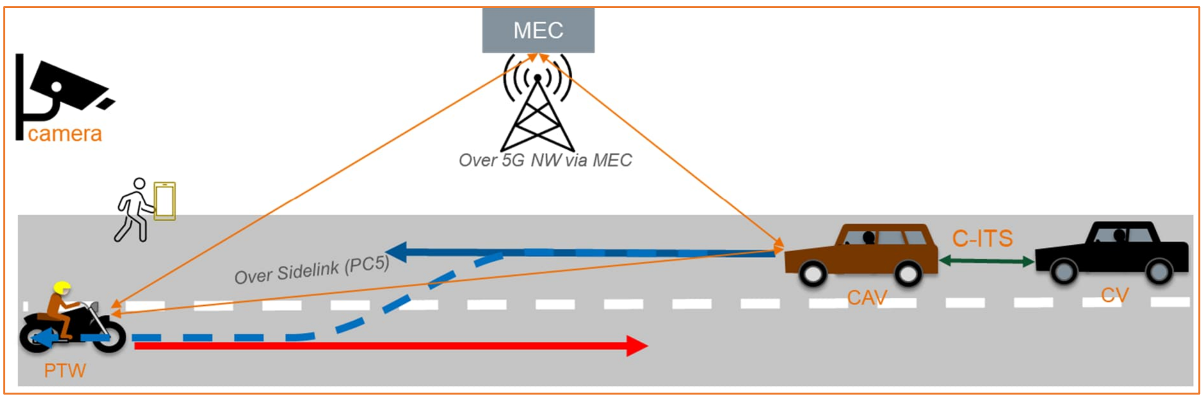

Figure – Time t2: C-SOA scenario - CAV's desired trajectory changed

Time t3:

The following events take place at **time t3 – PTW continues on safe trajectory** (ref to figure below)**:**

1: PTW continues on its trajectory

2: CAV (and CV) moves according to the (safe) calculated trajectory and brakes before the VRU allowing PTW safe riding

3: When PTW has passed (detected from MCM messages published by PTW), the CAV overtakes the VRU

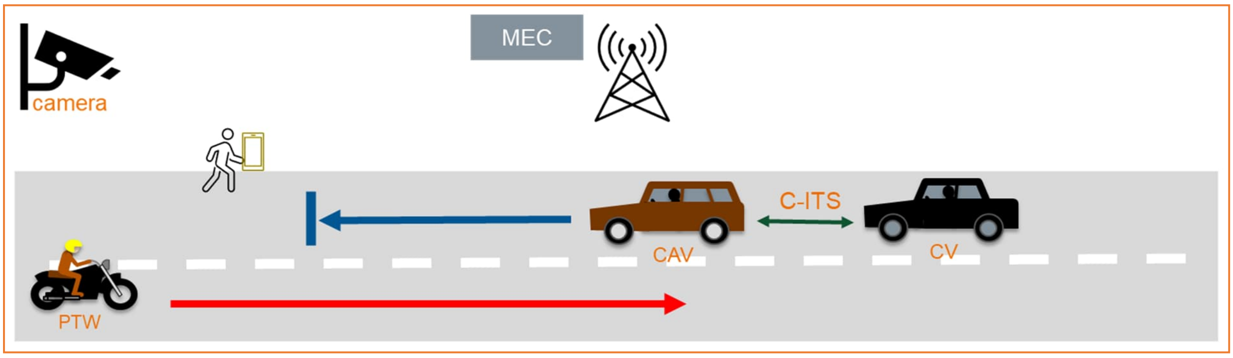

Figure – Time t3: C-SOA scenario - PTW continues on safe trajectory

Time t4:

The following events take place at **time t4 – All actors on safe trajectory** (ref to figure below)**:**

1: PTW continues on its safe trajectory

2: CAV (and CV) continue on their safe calculated trajectory

3: PTW passed VRU on its planned safe trajectory

4: CAV overtakes the VRU and returns to its trajectory when PTW publish MCM locating itself past VRU and CAV (detected by CAV from MCM messages published by PTW)

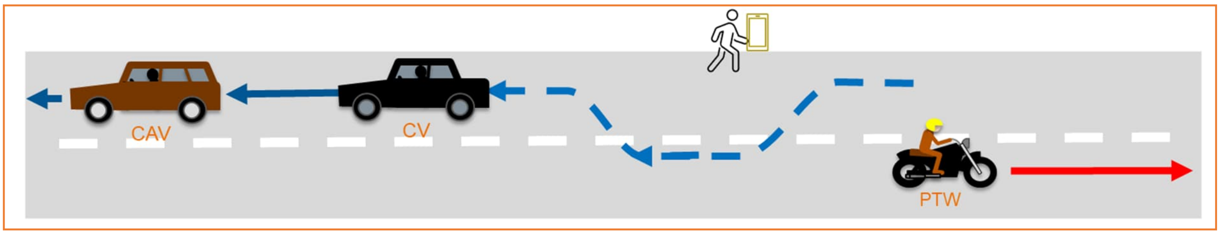

Figure – Time t4: C-SOA scenario - All actors on safe trajectory

4.3 Validation test procedure

The validation tests at the beginning used wireless ITS G5 channel, and then proceeded to Cellular 5G and C-V2X. Since the 5G network was 5G-NSA (not standalone), LTE-V2X was used for Basic and Enhanced Safety with C-V2X using Rel14 hardware (NSA). The next phase using Direct V2V (a.k.a.

PC5) (between Ego & Other Vehicle) takes place when 5GAA Rel15 Stand Alone 5G network hardware will become available. This concept is the steppingstone for *Manoeuvre Coordination Service* (MCS) to reach *Cooperative Collision Avoidance* (CoCA) and *Cooperative Safe Overtaking Assist* (C-SOA) between PTW and (semi-)automated car development and realization in the framework of Connected Cooperative Automated Driving (CCAD).

The sequence diagram for above described UC3.2 is depicted in the figure below.

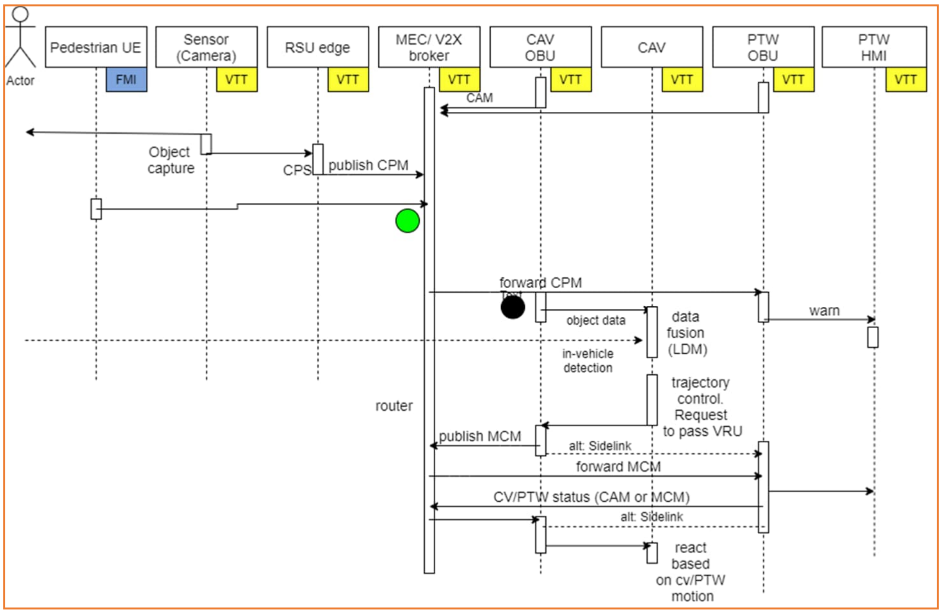

Figure – Example of sequence diagram for **UC3.2 case** with CAV and PTW Connected Vehicle ©VTT

The figure above presents the information flows related to the UC3.2. During the tests of the **UC3.2** where the VRU UE sends CAM the following data flows were evaluated. At link layer, the traffic from the V2X broker to the vehicle UE is monitored, corresponding to data flows 1-3 described above.

1. CPM data transmission from the VTT detection unit to the automated vehicle. The size of the message is 56 bytes, transmitted every 100 ms. Multiple detections result in multiple messages.
2. MCM data from the motorcycle to the automated vehicle. The size of the message is about 5 kByte, transmitted every 200 ms.
3. Test message RTT (Round-trip-time) data from the application to the MQTT broker for the automated vehicle. The test message is a very short message transmitted every 100 ms from the application on the OBU to the MQTT broker and back to the OBU application.
4. Test message: RTT data from the application to the MQTT broker for the motorcycle.

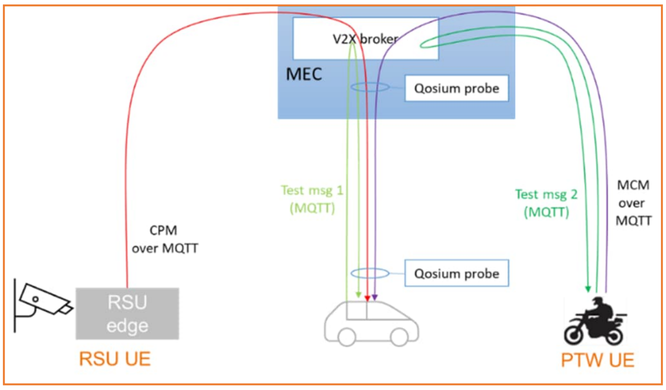

Figure - Information flows measured in UC3.2 ©VTT

A screenshot of the test event video (below) shows the CAV and following CV stopped in front of the detected VRU (here: pedestrian with UE sending CAM) and allowing the approaching PTW to proceed without any danger and delay while the CAV and CV wait and continue after the PTW has passed the case event.

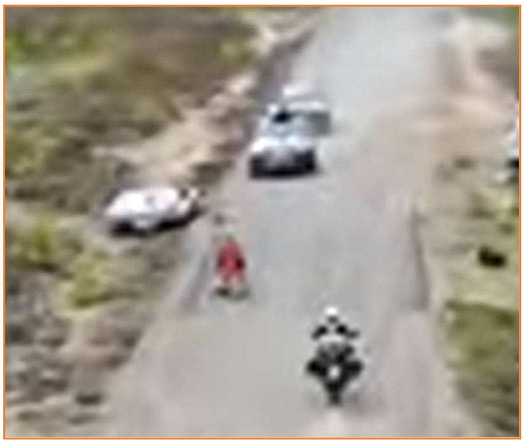

Figure - CAV and CV (behind) stopped in front of the Pedestrian Dummy

to allow PTW to pass the Dummy, video screen shot ©VTT

At the application level, through software which is directly integrated in the application software in the OBUs. The following measurement data is collected:

- Message flows. For each V2X message (CPM and MCM) the following data is logged: transmission or receipt time, timestamp from the V2X message payload, message size
- GNSS data: position (longitude, latitude), heading and speed
- Vehicle dynamics data: speed, acceleration, yaw rate
- Event data: collision detected or not, vehicle manoeuvre activated or not.

The results for three data flows, are shown here: the **MCM transmitted by the PTW and received by the CAV**. Five test scenarios were measured, with identical data flows in total 34 test runs of about 30 seconds. The first day there were some issues with the 5G test network, and the results are slightly larger than for the second day, see Table and Figure below.

Table - Aggregated latency of MCM for UC3 ©VTT.

E2E MCM (ms)	Overall UC3	First day (1a,2a,2c)	Second day (1b,2b,2d)
average	77.25	89.5	60.9
median	64	84	49
95% percentile	164	171	150

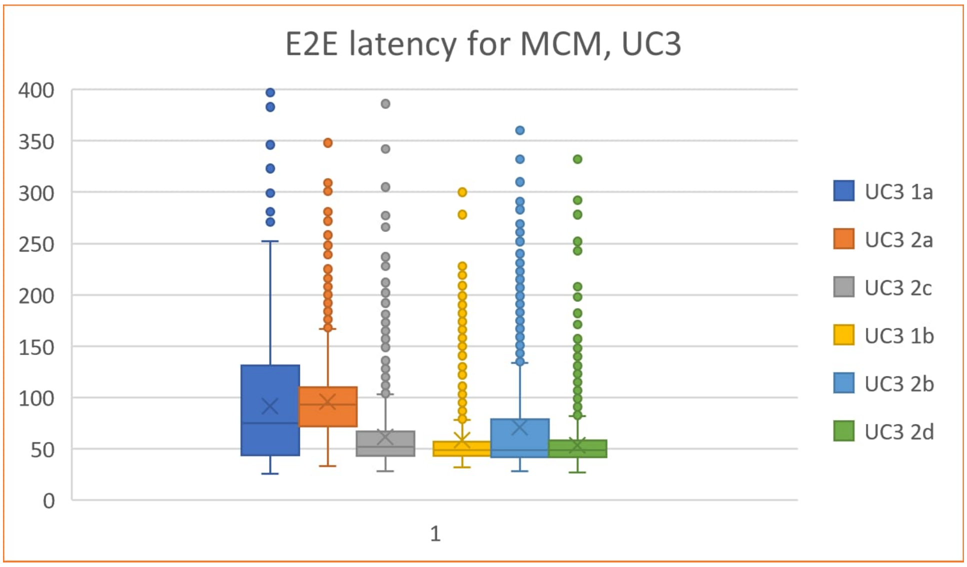

Figure - Box plots of the CPM latency for the test scenario in UC3 ©VTT.

In addition to the MCM, for both the CAV and the PTW the RTT round-trip-time of an MQTT message with empty payload was measured, see Table and Figure below.

Table – Round-trip-timing of MQTT test message for both CAV and PTW

RTT (ms)	Test message 1 (CAV)	Test message 2 (PTW)
average	40.9	47.7
median	31	37
95% percentile	86	105

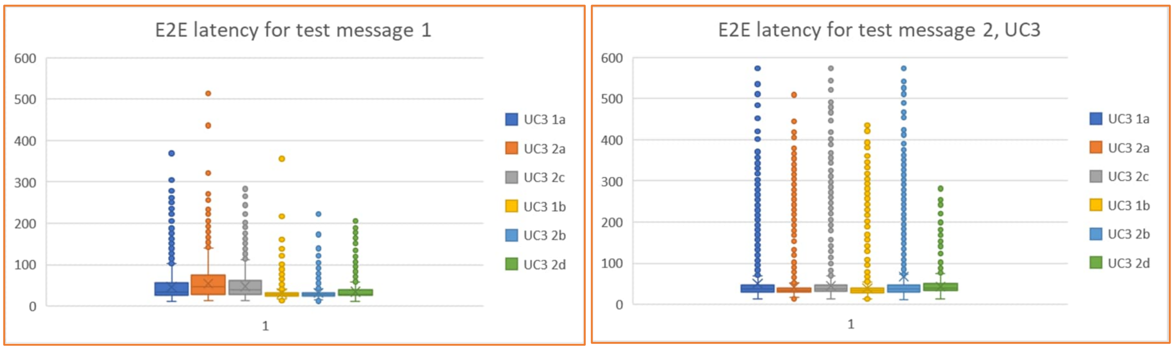

Figure - Box plots of the RTT of MQTT Test Message 1 of CAV and Test message 2 of PTW in UC3 ©VTT.

5 Discussion of the results

The results above show the first tests which were made on the scenarios in June 2022 in Sodankylä. During these tests different issues were identified with both the network, and the hardware used in the tests. Tests performed after the tests in Sodankylä in a similar 5G test network showed that much lower latencies can be obtained. The final tests for UC3 will be conducted in December 2022 in Sodankylä test track – together with the UC1.1 and UC2 pilots - and in March 2023 in Tampere. All the components and systems of the pilot will be physically present in Sodankylä test site. The target is to conduct pilot system demonstrations successfully, including a public demonstration event.

6 Conclusions

For PTW actors at large, it is compulsory to target actively to enhance the (basic) digital conspiquity of all PTWs. For the first step and especially for a lower (price point) category PTWs, one of the suggested measures is to develop radar-reflector-type parts in front and rear of the vehicle. With modern PTW design principles this should be quite feasible to implement.

PTW industry is actively participating in the international cooperation to prepare for the future of connected vehicles. However, it may not be cost-effective to work with a technology that would not serve the interests of motorcyclists in long run. This would be investing twice to achieve the very same functionality even if ITS-G5 is coming to markets in some car makes and models sooner than 5G connectivity.

By the time the maturity of connected vehicles in circulation would be sufficient to justify PTWs to be connected in vast numbers, **mobile Cellular V2X over 5G will be the dominating connectivity technology**. Reasoning is simple, cellular mobile communications and mobile services are and will be covering 99 % of national and local road networks. These networks will be most likely designed, built, maintained and operated (DBMO) by telecom operators for reasons other than traffic safety.

The wireless communication technology ITS-G5 is based on dedicated short-range communications (DSRC) also known as a Wi-Fi type technology. To equip the road networks in Europe for C-ITS messaging over ITS-G5, it is very likely to be the responsibility of national and local road operators or commercial wireless communication network operators yet to be emerged. Road operators may equip the most dangerous hot-spots and major arterials and intersections with DSRC services based on ITS-G5 network of local road-side stations. To cover the national and local networks also down to lower road network and smaller roads with this, is highly unlike to happen by road operators due to missing business opportunities. The business opportunities for 5G networks are with mobile telecom operators (MTO) for general commercial reasons. In addition to commuting and leisure riding in major TEN-T road networks and major urban surroundings, the motorcyclists do indeed ride on the lower road network and smaller roads – and sometimes also outside any road networks – but still reachable with mobile communication means.

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Importance of motorcycle rider upper body movement for rider intention detection and motorcycle state prediction

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***Abstract*—Increasing riding safety for powered two-wheelers is of utmost importance to reduce the number of fatalities in road traffic. Advanced Rider Assistance Systems (ARAS) can help to lower the risk of an accident or the degree of injury. The rider and motorcycle behaviour in the short-term future are valuable information to enable new and to improve existing ARAS. The information of rider upper body movement – which is not used in state-of-the-art ARAS – is investigated in this paper for its significance on rider intention detection and motorcycle state prediction. Therefore, experimental tests are done on a motorcycle especially equipped with sensors measuring rider inputs, including the upper body position. Multiple riders of different skill levels rode well-defined manoeuvres featuring quasi-static as well as transient lateral dynamics on a closed test track. The influence of the rider's upper body movement on the lateral dynamic transfer behaviour is examined to evaluate its importance for motorcycle state prediction. A timing analysis of the upper body movement during the execution of transient manoeuvres investigates its suitability as a predictor of rider intention. Measurements with different riding styles reveal a pronounced influence of the upper body movement in steady state riding and a minor influence in transient manoeuvres. In the timing analysis of the measured transient manoeuvres, the riders each show reactive upper body movement above a characteristic speed of around 50 km/h. The importance of the rider upper body movement for rider intention detection and motorcycle state prediction is finally discussed based on the findings.**

Keywords—motorcycle dynamics, rider behaviour, rider posture, steering torque

I. INTRODUCTION

Predicting motorcycle riding states like roll angle or position on the road into the short-term future is of interest to improve the performance of existing or to enable new ARAS. The measurement of rider inputs into the motorcycle is presumed to entail valuable information for a performant prediction. First, this is for the obvious reason that riders control the physical system with their inputs. But secondly, there is characteristic rider behaviour expected that is depending on the current and planned manoeuvre. For example, it could be a sequence of rider inputs with distinctive pattern. A function estimating manoeuvres that a rider plans to execute in the short-term future is designated as rider intention detection; it would further enhance prediction performance.

This paper deals with cornering of motorcycles, so only lateral and no longitudinal dynamics are considered. There are two different control actions that riders of single-track vehicles can make to affect the lateral riding dynamics. They can exert a steer torque at the handlebar and – in contrast to multi-track vehicles like passenger cars – they can apply a roll torque [1]. The latter is induced by a lateral shift of the rider's weight relative to the vehicle and it affects the torque balance around the roll axis – the virtual axis that connects the contact patches of front and rear wheel. This work focuses on the rider upper body movement as main source for rider roll torque as the upper body (torso, head, arms) constitutes the bulk of the rider's mass and has a much higher ability for lateral movement compared to the lower body (legs, feet).

Neither of the two rider inputs for lateral dynamics mentioned are considered in current ARAS and the question arises whether one needs to incorporate both to enable precise prediction of lateral manoeuvres. Several researchers investigated the effect of steer torque and rider roll torque for directional control of motorcycles in the past and some of the results are presented in section II. Irrespective of the low effectiveness of the rider roll torque input, it's a fact that riders do move their upper body (for diversified reasons that are also mentioned in section II) during normal on-road riding. In this paper, the rider roll torque input is examined by measurement of different riding styles in experimental test rides. Its importance is evaluated twofold: on the one hand, the lateral dynamic transfer behaviour of the rider-motorcycle system is analysed for changes due to the different riding styles (physical motorcycle behaviour), on the other hand, rider upper body movement is examined during transient lateral dynamic manoeuvres regarding its suitability for rider intention detection.

After a wrap-up of the state of research in lateral control of motorcycles and rider behaviour in section II, the setup of the riding tests is described chapter III, highlighting the rider upper body position measurement realized on the test motorcycle. The results of the experimental tests are then presented and discussed in Chapter IV, subdivided into quasi-static and transient lateral dynamics manoeuvres.

II. State of the Art

Investigations of the lateral control mechanism of motorcycles started in the 1970s with the main goal of providing quantitative handling measures to improve motorcycle design. A detailed review of the research activities since then is given by Kooijman and Schwab [1]. Experimental measurement data of steer torque, rider lean angle and motorcycle motion is used to analyse the lateral dynamics transfer behaviour in early research like the one by Aoki [2]; he ascertains the superior importance of steer torque over rider roll torque from rider leaning and thus characterises big motorcycles (high ratio of motorcycle to rider mass) as single input systems regarding lateral dynamics. However, his analysis is based on only a few operating points in each manoeuvre and a single rider, thus not accounting for different amount of rider movements.

Later work, that puts focus on developing rider models for numerical simulations, confirms the statement of much lower effectiveness of rider lean control in experiments as well as in multi-body simulations [3]. Efforts in rider modelling are summarized in the review by Popov et al. [4] on motorcycle control. Despite its low effectiveness, the rider movement control input is not neglected in some applications of steering controllers for simulation models because it is used by riders in practice and thus especially needed for the simulation of realistic manoeuvring close to the physical limits [6] and in specific manoeuvres like lane changes [1]. Evertse [5] states that this is due to the reason that rider roll torque causes the secondary effect of strongly modifying the steer torque transfer behaviour. He measures riders of different experience levels and thus with different usage of rider roll torque in their riding style in a 90 deg cornering manoeuvre. Beside a qualitative description of the differences in rider inputs between the subjects, Evertse quantifies the change of steer torque transfer behaviour by evaluating handling indices. But he is not examining for differences in the timing of rider inputs and steer torque transfer behaviour and is also not distinguishing transient and quasi-stationary sections of the cornering manoeuvre.

Despite rider movement is not an effective control input as described above, rider movement behaviour is observed and qualitatively discussed in scientific research [5, 7, 8]. Katayama et al. [7] find that the rider's upper body lean angle is applied in the opposite direction relative to the motorcycle roll angle and argue that this is chosen for comfort reason, while at the same time a lateral offset of the upper body inside the curve – figuratively speaking a change of the seat point **–** assists the steering torque control. Comfort mainly refers to the fact that the rider's field of vision remains as horizontal as possible [1]. Similarly, Bocciolone et al. [8] notice the "not intuitive" combined usage of an upper body lateral offset into the curve and rider lean angle to the outside in tight cornering experiments; the first contributes to a reduced demand in motorcycle roll angle by shifting the motorcycle-rider systems centre of gravity (CoG) laterally. Evertese [5] observes different riding styles in terms of upper body movement between the subjects in his riding experiment. He justifies rider leaning to the outside of the curve not only with comfort but with enhanced control due to "a more stable steering behaviour" [5].

The descriptions of rider behaviour so far refer to stationary cornering only. Differences in rider upper body movement during transient manoeuvres are used to assess the riding skill of a rider. Bellati et al. [9] identify the timing between steer and roll torque input as a measure for skill, where experienced riders apply roll torque in advance of any steering action to achieve quicker response and more precise manoeuvres. Evertse [5] however observes only reactive rider upper body movement despite measuring experienced test riders amongst others, meaning rider movement is timewise applied after the steer torque input. He describes the rider actions being "almost in anti phase with the roll rate" [5]. Thus, the findings of the state-of-the-art research are contradictory at this point. Prem and Good [10] find that higher skilled riders can handle independent control of steer and rider movement inputs, whereas less skilled riders can feature a strong coupling between both inputs. But Kooijman and Schwab [1] see that control action becomes more similar between different skilled riders with rising manoeuvre difficulty. Evertse [5] observes that the amount of roll torque input in a specific manoeuvre rises when the rider's mental workload increases. Hence the rider is leaning more when riding with higher cornering velocities or on a wet track.

Present work by Nugent et al. [11] investigates activation patterns in arm and back muscles to understand the coupling between steering and rider upper body movement for two different control strategies (only arm or only upper body inputs) for a single rider during slalom riding. They evidence the presence of steering inputs even when riders believe they are controlling lateral dynamics mostly by roll torque. However, their evaluation of the rider actions (amplitudes and timing) is solely based on electromyographic measurements of muscle activation, so correlation with steering torque and upper body lean angle or roll torque cannot be established.

This paper deals with the effects of different rider roll torque usages of different riders on the motorcycle's stationary as well as transient lateral dynamics transfer behaviour and further analyses the timing of the steer and roll torque rider inputs with regards to rider intention detection. A comprehensive study of this type is not known in the state of the art.

III. Experimental Setup

First, the measurement setup for rider upper body position sensing is described. As this signal is not used in any ARAS yet, no off-the-shelf sensor solution is available; different approaches are identified from the near past research where the rider roll torque input is captured either directly by force and torque sensing or indirectly via rider position measurement. Cheli et al. [12] use a single optical marker that is applied at the riders back in the position of the trunk CoG. The rider is then filmed from behind by a camera mounted on the motorcycle. Only using a single marker adversely affects the accuracy of the rider roll angle measurement as the orientation of the marker is utilised. Scherer et al. [13] use a camera filming the rider's back as well but they apply multiple markers along the rider's spine on a protective vest that is worn by the rider. They additionally describe an optical procedure to synchronize the camera and the remaining measurement data using LED's that are flashing into the camera's field of view. Carputo et al. [14] as well examine camera frames filming the back of the rider but they estimate the rider upper body position using a neural network. This work is still in an early stage as it is done in a simulated environment, and it suffers from the high amount of ground truth data needed for training of the neural network. Zhang [15] follows an approach without an optical sensor in his research about bicycle control; cyclist position is estimated by a Kalman Filter that is fusing Inertial Measurement Unit (IMU) measurements from the frame and cyclist as well as saddle and handlebar forces. Direct rider roll torque measurement was realized by Evertse [5] with multiple load and torque transducers on handlebar, tank and seat. The high integration effort of the last two solutions that were presented led to the decision in favour of an optical measurement approach.

A marker-based measurement system with a single camera is build up to realize rider upper body measurement. Here, planar fiducial markers named AprilTags (AT) are selected [16]. They come with a robust detection algorithm and are thus widely used in research. Multiple ATs are positioned along the rider's spine on a protective vest which facilitates high accuracy in sensing the rider lean angle. Additionally, two horizontally aligned ATs act as a reference for the evaluation of accuracy; they feature a constant distance to each other as they are mounted on the same rigid element of the protective vest. The field of view of the camera, which is mounted on the motorcycle's top case, is shown in Fig. 1. The rider lean angle and the upper body lateral displacement relative to the motorcycle centre plane are calculated based on the marker positions. Two ATs applied to the motorcycle tank act as a reference for this centre plane; those are also visible in Fig. 1. The synchronisation between the camera frames and the remaining measurement equipment is realized via LED's that the rider manually triggers at the start and end of each test run. The camera films the rider from behind with 720 pixels video resolution and 100 frames per seconds sampling rate. These values are chosen to achieve

Fig. 1. Marker based optical measurement system for rider upper body position using AprilTags. Rider upper body lean angle and lateral offset are calculated relative to the motorcycle centreline (blue). The rider centreline (green) is calculated with linear interpolation using all AprilTags that are detected along the rider's spine in a single frame. The individiual numbers of the markers that are successfully detected are depicted in red beside them.

TABLE I. DETAILS OF THE EXPERIMENTAL TEST MANOEUVRES

Manoeuvre	Geometries	Velocities
Constant cornering	Radius: 20, 25 m	20-50 km/h
Slalom	Cone spacing: 7, 14, 21 m	30-100 km/h
Lane change	Offset x Transition distance in m: 3.5 x 15, 3 x 20, 2 x 30 [a]	30-105 km/h

[a] Lane width of 1.5 m at the entry and exit of the lane change. Offset and transition geometry are repeated 2 m after the first lane change back to the original lane for double lane change manoeuvres. The geometries are types "TÜV slow", "MDRG Touring" and "TÜV fast" from the publication by COSSALTER AND SADAUCKAS [17].

successful detection of the ATs during the most dynamic rider movements (frame rate) without compromising the post-processing with excessive amounts of video data (video resolution).

The accuracy of the rider upper body measurement was evaluated on real test runs analysing the two horizontal markers with known and fixed distance to each other. The in-plane position sensing (lateral and vertical) of single markers reaches a standard deviation of 0.4 mm while a maximum error of 10 mm occurred. This position accuracy results in a maximum error in rider roll angle relative to the motorcycle of 3 deg – under the premise that all ATs along the spine are detected.

The second lateral dynamics rider input that is measured is the steer torque. Again, no off-the-shelf equipment is available for this task. Strain gauges are applied to the left and right side of the handlebar. This enables independent measurement of the riders left and right arm input. The strain gauges are designed to not only deliver the steer torque around the rotational axis of the steering system but as well the handlebar support torque; it originates from rider force inputs in the direction of the steering axis. Another significant advantage of strain gauges is that the mechanical transmission path of rider steer torque isn't altered as the steer feeling defined by geometry and stiffness remains unaffected.

Several motorcycle state variables are measured, amongst them the main frame and steering frame accelerations and rates via two IMUs. Vehicle longitudinal velocity and body orientation angles (roll and pitch angle) are derived from the internal sensor fusion. Further signals measured with additional equipment are steer angle, front and rear wheel travel.

A large displacement motorcycle of the adventure class is used as test bike. The upright seating position of the rider benefits the upper body position measurement as the riders back is almost ideally parallel to the camera plane. In total, three different riders rode all tests, whereas a minimum of two riders performed each manoeuvre. Their riding experience levels differ between occasional and experienced riding (no novice and no expert riders). The test manoeuvres that are chosen to investigate the rider upper body influence on lateral dynamics can be divided based on their quasi-static or transient nature. A quasi-static manoeuvre means no change in roll angle (zero roll rate) and is realized with constant cornering on fixed radius skid pads; the two different radii that are available and the velocities range realized on each of them are listed in Table I. Transient manoeuvres that are tested are slalom, single and double lane change. The velocity is kept constant during all manoeuvres and is gradually increased between iterations. An overview of the different configurations of the transient manoeuvres is given in Table I as well. High transient dynamics and road realistic evasive actions are experienced in slalom and lane changes when riding at the respective upper velocity values.

It should be noted that the riders were asked to intentional alter their riding style in terms of upper body positioning in the constant cornering and slalom manoeuvres for specific runs; those are specially indicated in the results. The differences in riding styles between the riders occurring in all other test runs are due to their natural riding habits.

IV. EXPERIMENTAL RESULTS

A. Quasi-Static Lateral Dynamics Manoeuvres

The constant cornering riding test is done by stepwise increasing the velocity on a constant radius skid pad up to the maximum speed the rider is comfortable with. This results in a stepwise increased roll angle of the motorcycle. Quasi-static data points are extracted during the times with only small changes in velocity and roll rate. Additionally, only sections of at least a full cycle on the skid pad are considered in the evaluation in which the mean of the signals over a quasi-static section is calculated. Hence the influences of wind, road inclination and – small but always ongoing – path corrections by the rider are cancelled out. Being strict on the quasi-stationary conditions that were just described inevitably leads to a loss of data points for the highest velocities tested. In the diagrams in Fig. 2, the extracted quasi-static data points are displayed using markers and all points from of a single test run are interconnected with lines.

The measurement of a single rider riding in a counterclockwise turn (negative sign of the roll angle) on the 25 m skid pad is analysed exemplarily. The rider was asked to intentionally change the upper body position – and with it the rider roll torque – to check the effect on the quasi-static lateral dynamics transfer behaviour of

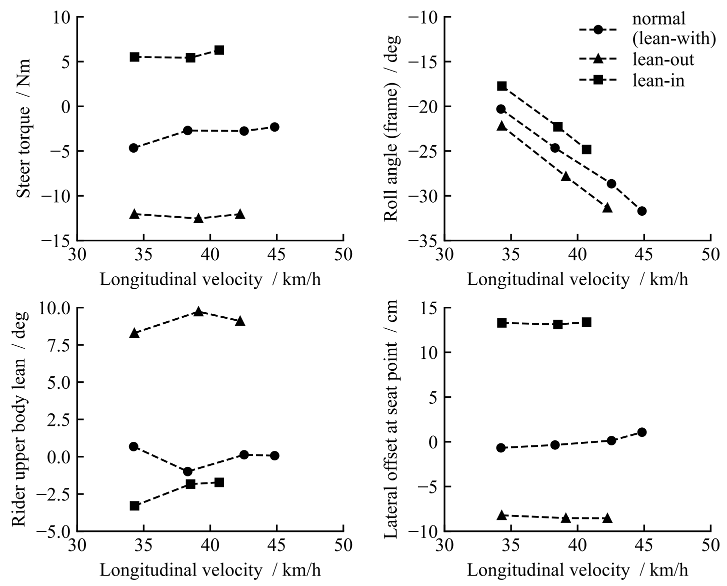

Fig. 2. Effect of the conscious change of rider upper body position (rider upper body lean angle and lateral offset at the seat point relative to the motorcycle) on the necessary amount of steer torque in counterclockwise constant cornering on a 25 m radius skid pad. Marked data points are extracted during sections of quasi-static riding. All data points of a single test run are interconnected with lines. The change of cornering state with different body positioning gets apparent in the motorcycle roll angle signal.

the motorcycle. Apart from the natural riding style, in which this rider sits in a straight line with the motorcycles centre plane (also called lean-with), a lean-out (weight transfer towards the outside of the curve) and lean-in (weight transfer towards the inside of the curve) are realized. The steer torque applied by the rider for constant cornering is displayed over the longitudinal velocity in the top left diagram in Fig. 2. Rider upper body position is represented by lean angle and lateral offset of the seat point (positive to the left when viewed from behind) relative to the motorcycle centre plane, shown in the lower left and right diagrams in Fig. 2. A upper body lean angle of 8 to 10 deg plus a shift of the seat point of 8 cm to the outside in lean-out condition causes the steer torque to rise about 10 Nm in the countersteering direction (towards the outside of the curve). When asked to do lean-in the rider uses considerably more lateral weight shift and less upper body leaning by moving the hip point towards the inside of the corner. The most likely explanation is that the rider aims to keep the head and hence the field of view as horizontal as possible for greater control and comfort. Again, the lean-in riding style causes the steer torque to alter approximately by 10 Nm, but now the change is towards the inside of the curve.

A second effect of the rider's lateral weight transfer lies in the change of the motorcycle cornering state and gets apparent in the top right diagram in Fig. 2. The total CoG of the motorcycle-rider system moves laterally too; that has the effect that the motorcycle takes the same path at the same velocity but with a different roll angle of the motorcycle's frame. The well-known effect that a lean-in riding style allows to take a corner at the same velocity with lesser roll angle is clearly visible. It's also noticeable in Fig. 2 that the rider reaches the highest cornering speed riding with the lean-with riding style what indicates that he feels most comfortable with his normal riding style. The motorcycle's physical limit is not reached in any of the three curves shown in Fig. 2; this is due to the well-known effect of corner fear that means riders having a personal maximum roll angle that they are not able to overcome despite it is physical feasible [18].

The change of necessary steer torque to ride on the same curve with the same velocity when altering the lateral rider upper body position – as shown in the top left diagram of Fig. 2 – reveals that the motorcycles static lateral amplification is altered significantly. The behaviour, that is presented for a single constant cornering manoeuvre here, holds true in the whole speed and roll angle operating range of the motorcycle as the steer torque demand remains in a similar order of magnitude. It can hold as a partial reason for the usage of different riding styles between riders in practice as one can significantly alter the steer torque effort during constant cornering. Other (conflictive) reasons are a reduced motorcycle roll angle demand with lean-in and an enhanced control and comfort with lean-out riding styles. Results from previous research that attest the rider roll torque low effectiveness for cornering remain unaffected by this finding as they relate to transient dynamics during cornering.

It is concluded that rider upper body lateral position measurement proves mandatory if a state prediction based on the steer torque rider input shall be carried out in quasi-static cornering conditions. This is because of its significant effect on the static amplification of steer torque. But it needs to be mentioned that this influence is not the sole cause. Several further factors affect the steer torque during constant cornering in a similar order of magnitude. They pose a great challenge in interpretation of the steer torque signal. Some were experienced during the experiments and their approximate magnitudes (peak-to-peak values) are numbered: presence of permanent stabilization and trajectory correction effort by the rider (5 Nm, filtered signal), noise in the unfiltered steer torque signal due to street irregularities (2-5 Nm, test track asphalt) and change of steer torque due to different tire age (magnitude 3 Nm, tires were changed after preliminary tests). Further influences known from literature that can partially be experienced in simulation come from rider weight (loading), tire compound, tire pressure, tire temperature and friction coefficient in the tire-road contact patch.

The obvious prediction of the motorcycles riding state during a quasi-static manoeuvre (constant rider inputs) is the perpetuation or constant extrapolation of the current states and manoeuvre. Therefore, the rider upper body movement input is not analysed with regards to rider intention. However, the transition from a static towards a transient manoeuvre is especially interesting regarding rider intention; this will be part of the investigation in the upcoming section.

B. Transient Lateral Dynamics Manoeuvres

Slalom experiments are used to analyse the influence of rider upper body movement on motorcycle lateral dynamics transfer behaviour in transient manoeuvres. They allow for a systematic analysis as distinct frequencies are excited during a ride with constant velocity through a slalom with constant offset between the cones. Rerunning the same slalom geometry with different velocities allows for a variation of the excitation frequency; however, the amplitudes of the motorcycle's excitation vary at the same time as a rider adapts his inputs to stay on the slalom trajectory. Different slalom geometries in terms of cone spacings are employed to get diversified excitations in amplitudes and frequencies. As the slalom trajectories were not ridden ideal sinusoidal, rider input signals and motorcycle dynamic states are not ideal sinusoidal either; thus, the excited frequencies are calculated from cone spacing and mean velocity, also signal amplitudes are averaged over multiple spikes.

First, the observed natural riding styles of the two riders doing all slalom runs are described. Both lean their upper body in the opposite with respect to the motorcycle's roll angle; as in constant cornering, this is likely done to keep a horizontal view for better control. Further information about the detailed timing of rider leaning will be given later. The amplitudes of rider lean angle relative to the motorcycle are presented over the slalom frequencies in Fig. 3. Each data point represents a constant velocity run through the slalom; all runs of a rider in a single geometry were measured consecutively with rising velocity and are thus interconnected with lines in Fig. 3. Rider A stays close to a "lean-with" riding style with upper body lean angle amplitudes between 1 to 7 deg at low to high dynamics. Rider B employs more of a "lean-out" riding style with upper body lean angle amplitudes reaching from 2 up to 15 deg at highest dynamics. A change of the rider's seat point and therefore a lateral offset of the upper body does not occur during the slalom. The rider lean angle amplitude is strongly correlated with manoeuvre frequency and not with velocity for both riders; this becomes apparent in Fig. 3 by the fact that the three lines for the different slalom geometries are well congruent for each rider. In addition, two runs with intentional lean-out are done yielding a rider lean amplitude of 25 deg. Made aware of the different usage of the upper body between the riders and the two lean-out runs, any changes of the transient motorcycle transfer behaviour due to the differences in riding styles are highlighted in the following passages.

The transfer behaviour between steer torque – the most important lateral rider input – and the motorcycle roll rate reaction is reviewed first. The so-called amplification is calculated by dividing the roll rate amplitudes (output) by the rider's steer torque amplitudes (input). High amplifications correlate with high agility – often described as good handling – due to a low steer torque effort. They occur in the smallest slalom and at velocities between 30 to 35 km/h as shown in Fig. 4. Steer torque to roll rate amplification is best correlated to velocity and thus plotted over it. One can identify a distinct difference in the transfer behaviour between the riders and

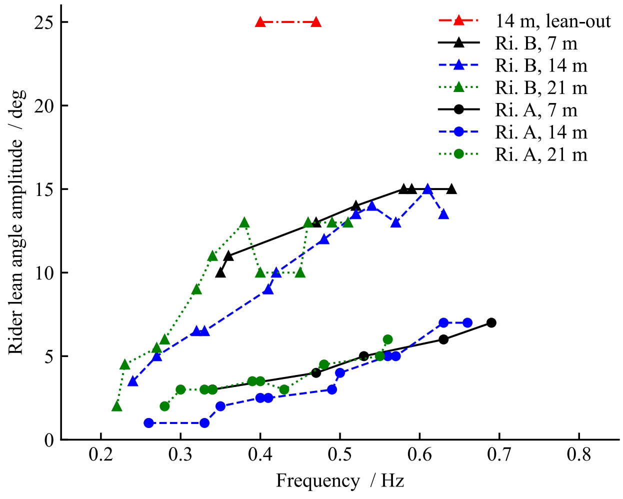

Fig. 3. Rider lean angle amplitudes relative to the motorcycle frame displayed over the excitation frequency for all slalom tests. Two riders (Ri.) rode three different slalom geometries with 7, 14 and 21 m distances between the cones. Two runs are done with an intentional high lean-out riding style.

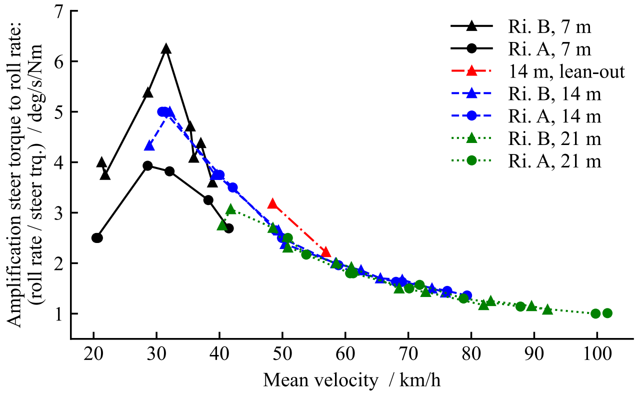

Fig. 4. Amplification of steer torque rider input to roll rate motorcycle reaction plotted over the calculated mean velocity during the slalom manoeuvre. Two riders (Ri.) rode three different slalom geometries with 7, 14 and 21 m distances between the cones. Two runs are done with an intentional high lean-out riding style.

thus the riding styles for the 7 m slalom; the more lean-out style of rider B enlarges the amplification of steer torque to roll rate by 47 % on average over rider A. But for the two larger slalom geometries tested (dashed blue and dotted green lines in Fig. 4), no significant influence of the different rider upper body movements on the system behaviour is found. The two intentional lean-out runs that are displayed in red dash-dotted line in Fig. 4 show an increased amplification of 25 and 12 % over the other riding styles at the same velocities. In general, motorcycle agility decreases and steer torque demand increases with rising velocities. This is mainly caused by the gyroscopic torque that is induced into the steering axis from the spinning front wheel under roll rate, which magnitude rises linearly with velocity [17]. Therewith the importance of gyroscopic torque takes over while the influence rider upper body movements lowers and of even excessive rider roll torque inputs become negligible above 60 km/h.

The time delay between the rider steer torque input and the motorcycle roll rate reaction shows only minor changes due to the different riding styles with 34 ms less delay on average for rider B compared to rider A; a transformation of the time into a phase delay between the sinusoidal signals (multiplication with the respective frequency for each run) illustrates the marginal difference of 5 deg on average. Those differences are constant over all measurement points showing no dependency on velocity or frequency. High intentional lean-out reduces the time delay by further 15 ms or 2.5 deg only. This influence is rated negligible.

It needs to be mentioned that despite rider B experiences better handling according to the amplification of steer torque by using more lean-out in the tightest 7 m slalom, this riding style requires higher maximum roll angles and thus roll rates of the motorcycle to ride on the same trajectory. Therefore, the two riders in our test ended up applying virtually the same absolute amplitudes in steer torque with their different riding techniques as the higher roll rate demand for rider B eats up the handling advantage from the riding style.

Data analysis shows that any intra-motorcycle transfer behaviour like the one from roll rate to roll angle or roll rate to yaw rate remains unaffected in amplification as well as in timing and phasing when riding the slalom with different amounts of upper body lean angle. For this reason, no results of these are presented in detail.

Reflecting on the first research question of the rider upper body movement influence on motorcycle lateral dynamics, it is concluded that the transient lateral transfer behaviour of the motorcycle is not significantly changed by differences in upper body movement and thus rider roll torque for velocities greater than 60 km/h. Differences in steer torque to roll rate amplification do arise at lower velocities in the region of highest agility but riders ended up applying the same amount of steer torque in our tests in the end. It might however be the case that riders feel less effort with one or the other riding style, because they are better able to supply the necessary steer torques by a specific movement pattern of the upper body. This would provide a physiological reason beside the psychological reason of keeping the head and upper body upright for best control that was mentioned earlier. Irrespective of the meaning of the rider upper body movement for the motorcycle transfer behaviour, the timing of rider upper body movement in transient manoeuvres is investigated in the following passages. This is essential to evaluate the signal's suitability as a predictor for rider intention detection.

The timing of the rider lean angle with respect to the motorcycle roll angle is analysed. Therefore, the cross-correlation of the two signals is evaluated that yields the time shift between two sinusoidal like signals. Hereby, the sign of rider lean angle is changed because riders lean in opposite to the motorcycle's roll angle; as a result, a time delay of 0 s corresponds to a rider leaning in ideal anti-phase to the motorcycle. Results for all slalom runs are shown in Fig. 5. The time delay between both signals is best correlated to manoeuvre velocity rather than frequency. Negative time delays mean that the rider lean angle amplitude comes before the motorcycle roll angle amplitude. This happened only for velocities below 50 km/h; above this velocity, rider upper body movement is almost in anti-phase or timewise after the motorcycle movement – this is denominated as reactive rider movement. The assumption holds that riders try to keep the body upright for best control and comfort in

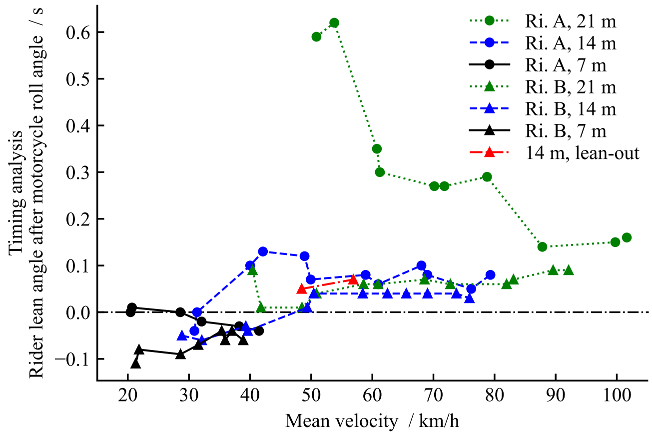

Fig. 5. Timing analysis showing the delay between motorcycle roll angle and rider lean angle in all slalom tests, calculated by cross-correlation analysis. The sign of rider lean angle was changed as riders lean opposite to the motorcycle in slalom. Two riders (Ri.) rode three different slalom geometries with 7, 14 and 21 m distances between the cones. Two runs are done with an intentional high lean-out riding style. At 0 s riders move in exact anti-phase to the motorcycle roll movement.

the first place being so close to 0 s for most of the test runs. Further analysis yields that the timing of rider leaning is not correlated to the lean angle amplitude itself. A big difference in the leaning behaviour occurs for rider A in the 21 m slalom with a relatively strong reactive nature of the upper body movements. It is neither possible to identify a reason for nor an effect of this leaning behaviour yet.

Examining rider leaning from the other perspective, not asking for comfort and control but for physiological coupling, the timing between rider steer torque input and upper body lean angle is investigated. The underlying hypothesis is that a rider moves the upper body unconsciously to best be able to provide the steer torque. From common understanding, riders are better able to push on the right and pull on the left side of the handlebar – which produces a positive steer torque – when having their upper body leaned to the right (positive angle) relative to the motorcycle and vice versa. Fig. 6 shows the timing between steer torque and rider lean angle in terms of a phase delay, where a delay of 0 deg means a synchronous application in the beneficial way as just described. Positive phase angles imply that the steer torque amplitude comes before the maximum rider lean angle, e.g., the rider supplies full positive steer torque (for the upcoming directional change into a right hand bend in the slalom) while still increasing the lean angle towards the right. Whereas negative phase angles imply that riders are already leaning back to the left side when applying the maximum steer torque; this can be imagined as pushing the handlebar away from the body. Almost all phase delays between steer torque and rider lean angle lie in the range between -90 to 90 deg, meaning the upper body is always leaned with the same sign as the steer torque when the latter reaches its amplitude. For the two wider slaloms and for all velocities larger than 35 km/h, the “pushing the handlebar away from the body” timing exists. Additionally, it becomes apparent that rider B is more into the “pushing” timing as rider A for the same velocities and slalom geometries when viewing the triangle markers in Fig. 6. This matches consequently with the fact that rider B is using considerably more rider lean angle as shown earlier in Fig. 3 and it shows why such a lean-out riding style is also referred to as pushing riding style.

Measurements of the slalom manoeuvre show that riders do not use upper body movement as an active input for transient lateral dynamics as its timing is close to or after the motorcycle roll angle, that itself comes already timewise 0.45 to 2 s after steer torque (the latter for lowest velocities). Hence, steer torque is clearly the

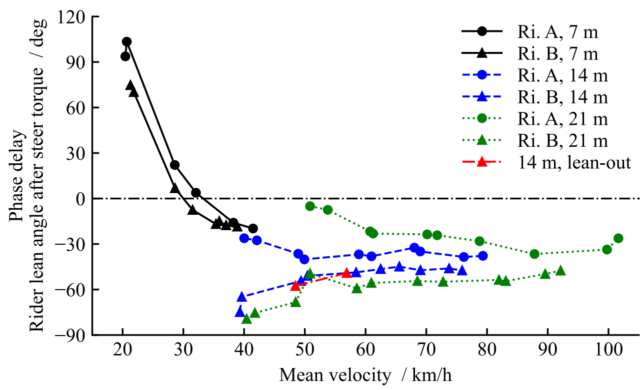

Fig. 6. Timing between rider steer torque input and upper body lean angle relative to the motorcycle – calculated by cross-correlation analysis and represented in terms of a phase delay taking the frequency of all slaloms into account – plotted over the calculated mean velocity. Two riders (Ri.) rode three different slalom geometries with 7, 14 and 21 m distances between the cones. Two runs are done with an intentional high lean-out riding style.

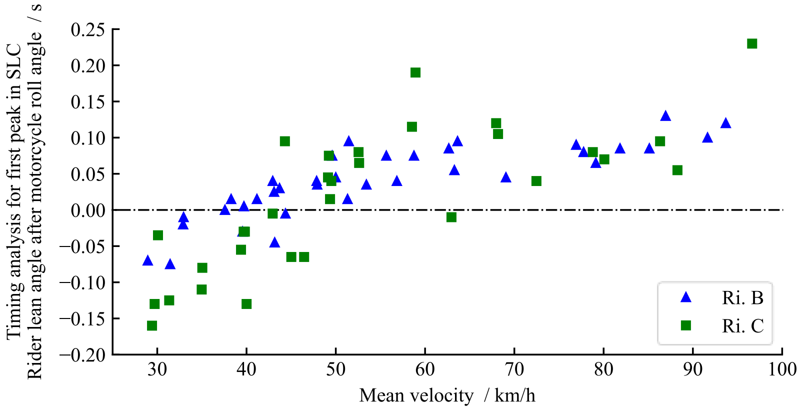

Fig. 7. Time delay between the rider upper body lean action relative to the motorcycle and the motorcycle roll angle for two riders in the single lane change (SLC) manoeuvre. Evaluated for the first peak (entry) of the SLC. Each measurement point refers to a single run through one of three different SLC geometries.

first rider input and rider movement cannot be understood as a predictor for upcoming lateral manoeuvres. To check if those findings hold true in more road realistic manoeuvring, the timing of the upper body movement is investigated in single lane changes (SLC) of different geometries and velocities. Here, the peak values of the initial direction change in an SLC manoeuvre are analysed for their magnitude and timing. Evaluating the transfer behaviour between rider lean angle and motorcycle roll angle yields the time delays that are presented in Fig. 7. As in the slaloms, the timing is best correlated to the manoeuvre velocity that was kept constant through the SLC. Each data point stands for one run through one of the three different SLC geometries. The timings are similar for both riders and again there is mostly reactive upper body movement above a velocity of 50 km/h. As in the slalom both riders are using different riding styles with rider B applying twice as much upper body lean angle, steer torque and roll rate in amplitude compared to rider C. In the end, rider B takes a narrower riding line in all SLCs leading to a one-third increase in execution frequency and maximum roll angle at the same velocity. Thus, the investigation of SLCs leads to the same observation as in the slaloms that riders are not moving their upper body anticipatory but in phase or reactive to the motorcycle roll angle for velocities above 50 km/h.

V. Conclusion

The importance of rider upper body movements on the lateral dynamics transfer behaviour of motorcycles and the rider behaviour regarding upper body movements in transient manoeuvres are of interest in the context of motorcycle state prediction and rider intention detection. An optical measurement system that is capturing the position of the rider upper body in terms of a rider roll angle and a lateral offset relative to the motorcycle centre plane is therefore added to a fully equipped test motorcycle. It is deployed in experimental tests where multiple riders with different riding styles rode well-defined manoeuvres with quasi-static as well as transient nature of the lateral dynamics. The results of stationary cornering tests show that a change in upper body position significantly alters the required steer torque in quasi-static lateral dynamics manoeuvres. It is concluded that steer torque measurements are not meaningful for a state prediction in stationary cornering situations without the knowledge of the rider's upper body position and thus the acting rider roll torque.

Slalom manoeuvres are used to evaluate the transient lateral dynamics transfer behaviour. One cannot see any significant influence of different riding styles above a velocity of 60 km/h. Below this speed, changes in the amplification of the steer torque rider input to the motorcycle's reaction are encountered. None of the intra-motorcycle transfer behaviours is altered by a difference in riding style. So, for transient lateral dynamics it depends on the specific use case of a motorcycle state prediction whether one needs high accuracy at low speeds and thus a measurement of the rider position. Furthermore, the timing of rider movement in transient manoeuvres appears to be reactive to the motorcycle roll angle for longitudinal velocities greater than 50 km/h and it comes timewise after the steer torque input for all transient manoeuvres tested. According to this the rider upper body position information is no direct predictor for upcoming manoeuvres. The explanation for this is that rider movement behaviour arises from a trade-off between comfort, control and physiological coupling with the steer torque rider input. Nevertheless, the hypothesis remains that one can extract indications for rider intention from typical rider upper body movement patterns. But those are most likely only to be observed during real road traffic testing. Such tests are pursued in the near future using the rider upper body movement measurement to check for novel insights in typical rider behaviours.

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CMC- accident analysis to prove ITS applications

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1 Background & Motivation

Cars are increasingly equipped with sensor systems to support ADAS functions. These sensors develop rapidly, since they pave the way to future automation. However, in most of the powered two-wheeler (PTW, i.e., mainly motorcycle) accidents, other participants (often cars) are involved and they often are the main accident causer. According to the ACEM MAIDS[1] report Version 2.0, 72% of collision accidents caused by other vehicle drivers are due to perception failure. Consequently, connectivity via V2X needs to support on-board sensor/warning systems.

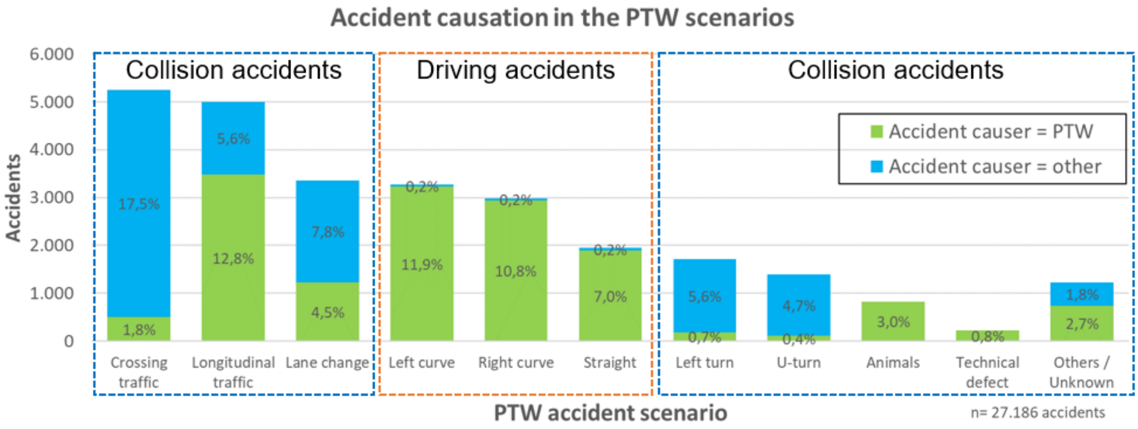
However, when motorcycles talk to cars, their specific requirements have to be taken into account. The Connected Motorcycle Consortium (www.CMC-info.net) has launched its Basic Specification for motorcycle ITS in December 2020. The CMC-Basic Specification is a milestone for further developments of the consortium to close the gaps in defining system requirements for PTWs. CMC is looking how to integrate ADAS systems both on cars as on PTWs to avoid accidents. This applies to driver assistance systems in general but in particular to cooperative communication systems. PTWs require principle-based adaptations to the applications as such (i.e. PTW-specific use-cases), but also hardware and software adaptations to the position accuracy, triggering algorithms, antenna positioning and to the human-machine-interface (HMI).

To pursue the goal "improving motorcycle rider safety and comfort", CMC has studied the most frequent PTW accident scenarios in which PTWs collide with other vehicles in the GIDAS (German In-Depth Accident Study) database with a defined accident scenario from 2005 onwards. For the analyses of the PTW accident scenarios, the latest update of the GIDAS database from 07/2020 was used and extrapolated to the German accident scenarios for 2019. The basis for the analyses of the PTW accident scenarios are 27.186 extrapolated accidents.

As shown in Figure1, the majority of PTW accidents (37, 7%) occurred in crossing or longitudinal traffic. The accident scenarios in longitudinal traffic are more frequently caused by the PTW riders. Accident scenarios in left or right curves and straight roads are driving accidents, where the PTW riders mainly caused these accidents. In addition to the crossing traffic accidents and lane change scenarios, left turn or U-turn manoeuvres of other vehicle drivers are main cause for accidents.

CMC performed a study to better understand the contributing factors of these accidents, explained in this report, using the GIDAS database and GIDAS-PCM (Pre-Crash-Matrix).

Figure 1: Overview of motorcycle accident scenarios



Crossing is the most frequent accident scenario. The reason why left turn was selected prior to other scenarios is that the left turn accidents are likely to result in serious or fatal injuries compared to other scenarios.

2 Methods

2.1 GIDAS and GIDAS PCM database

The accident analysis is composed of two steps. The first step is a fact-based analysis using the GIDAS database (Module 1) with 23 potential influencing factors causing the accident.

The second step (Module 2) is an analysis using the simulation database GIDAS-PCM.
PCM stands for Pre-Crash Matrix and is a specified format which can be used to describe the phase of a road traffic accident before the first collision happens (the so-called pre-crash phase). By means of the PCM, those involved, their dynamics and the surroundings can be depicted and evaluated.

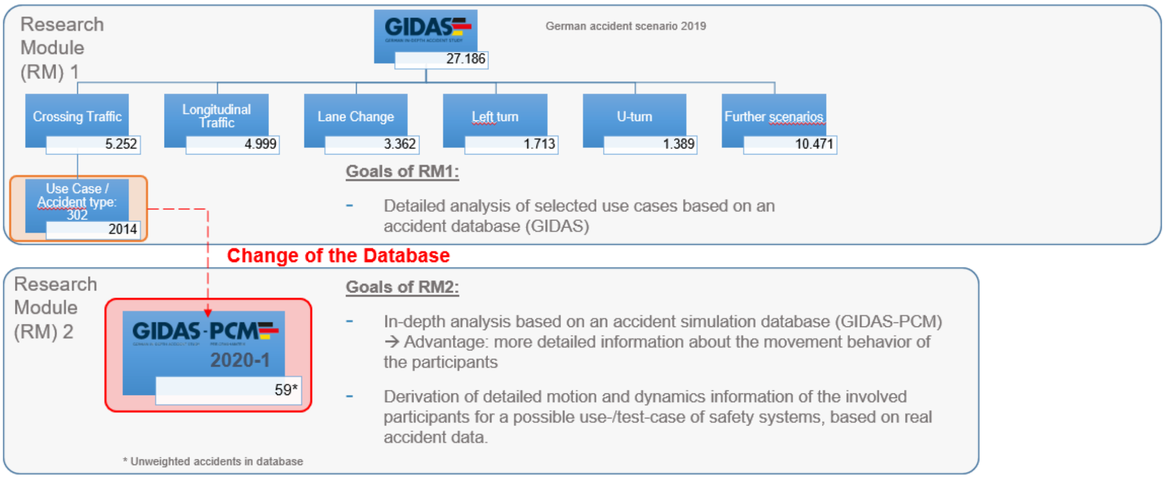
The simulation database GIDAS-PCM, contains more detailed information such as:

- Trajectories
- Manoeuvres
- Speeds
- Decelerations / Accelerations

TTC (Time to Collision) [2] was calculated separately in an extra model.

The principle of both databases is shown in Figure 2.

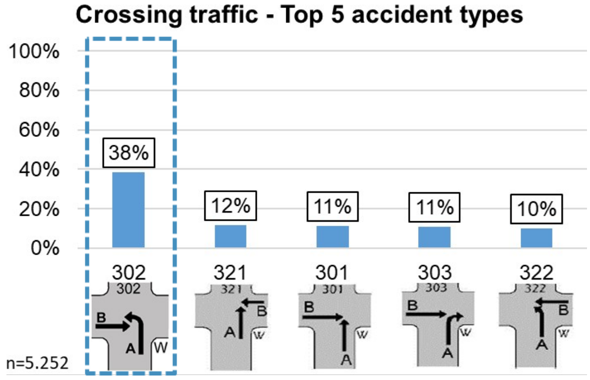
Figure 2: Analysis using module 1 and module 2



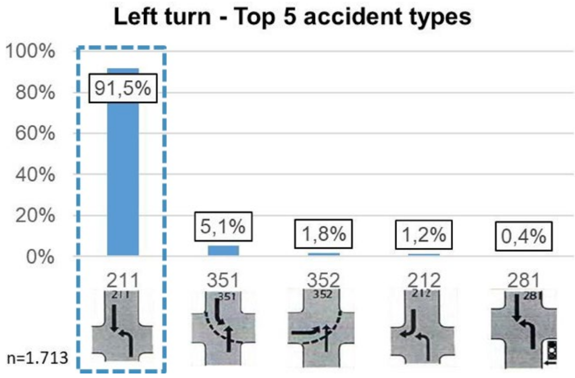
3 Results

Due to the dominance of accident type 302 in the crossing scenario and accident type 211 in the left turn scenario, the focus was on in-depth analyses of these accident types, as depicted in Figures 3 & 4. Accident type 302 for crossing traffic counts for 38% (n=2,014) of all the crossing traffic accidents. Accident type 211 for left turn counts for 91.5% (n=1,568) of all the left turn traffic accident types.

Figures 3: Motorcycle accident types (crossing)



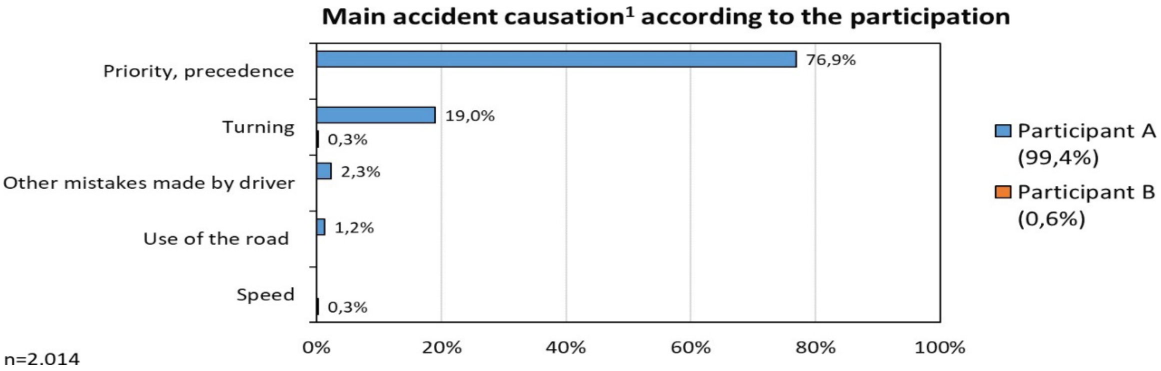
Figures 4: Motorcycle accident types (left turn)



3.1 Accident type 302 (crossing)

The crossing traffic accident type 302 describes a conflict between a left turning road user, mostly a car (participant A) who is obliged to wait ("W" in the figure 3), and a road user, mostly motorcycle (participant B) entitled to the right of way. The accident type 302 may occur at junctions and crossings of roads, field or cycle paths, railway crossings as well as property exits or at parking lots. For the study it was considered irrelevant whether the participant A was obliged to stop or wait due to traffic regulation (e.g., STOP sign, GIVE WAY sign).
The main causation assigned by the police together with the GIDAS technical investigation is shown in Figure 5. It is understood that the sole main reason for the accident was failure of participant A (mostly car driver) to respect priority. For participant B (mostly motorcycle rider), speed only contributed 0,3 % to accident causation. In 99.4% of cases within accident type 302, participant A was the main accident causer and only in 0.6% of cases, participant B was the main accident causer.

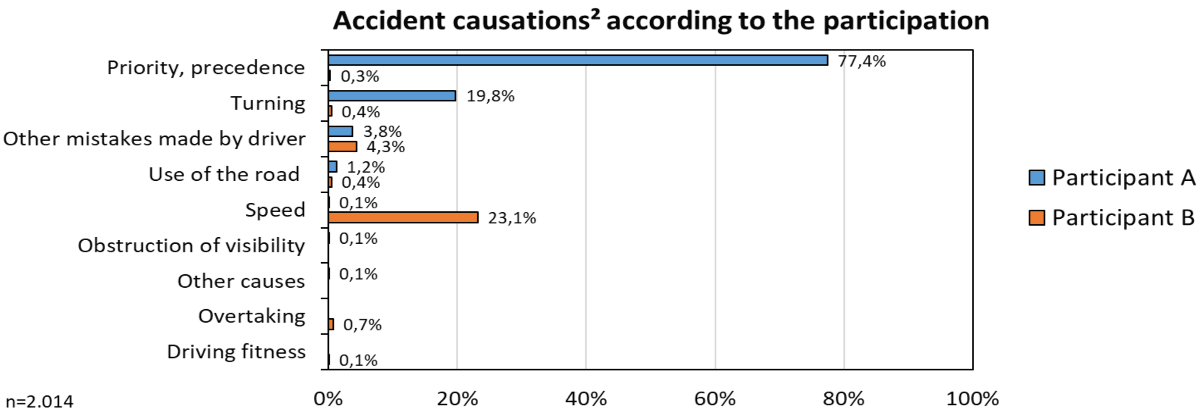
Figure 5: Main causation for accident type 302



1 Police and technical investigation units in GIDAS assign a main accident causer with one main accident causation in each accident.

The police and the technical investigation units in GIDAS can assign up to three accident causations for each accident participant. Consequently, one accident can have several causes depending on the participant and so the sum of the accident causations may add up to values above 100%. Figure 6 shows that speed for participant B (mainly a PTW) is a contributing factor, although it is not the main cause in this accident type.

Figure 6: Contributing factors type 302

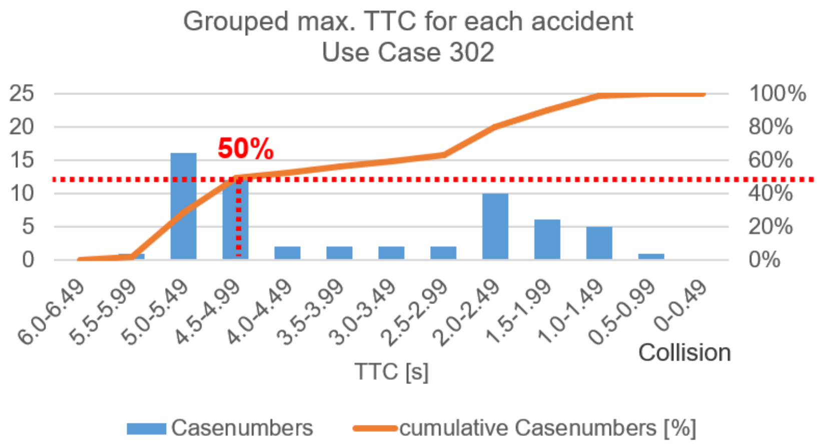


2 Police and technical investigation units in GIDAS assign up to 3 accident causations for each accident participant. Consequently, one accident can have several accident causes depending on the participant and so the sum of the accident causations is ≥100%.

Time to Collision (TTC) [2] is an important safety indicator, as sufficient TTC will provide time for the driver, respectively rider to recognise the danger ahead and will make room for reaction time.

Figure 7 shows cumulative case numbers of TTC and where it crosses the 50% line. It reads from the figure that in 50% of the crossing traffic accident type 302 cases, the vehicle operator can be informed 4.5 seconds before the collision.

Figure 7: Time to Collision for accident type 302



The key findings are:

- More than 90% of these accidents occur at junctions, crossings or property exits.
- In more than 95% of the cases, M1/N1 vehicles (cars and trucks) cause the accidents.
- Participant B is a motorcycle in more than 90% of accidents.
- The speed at collision of participant A is 5-18 km/h, while that of participant B is 26-47 km/h (75%tile).
- In more than 30% of the accidents, there was a view obstruction for participant A.
- Weather condition is not a major factor for the accidents.
- The last two manoeuvres before collision indicate that participant A did not decelerate before collision, but instead, was accelerating in more than 50% of the accidents.
- In half of the cases, a potential collision could already be predicted 4.5 seconds before collision (50%tile of the TTC values).

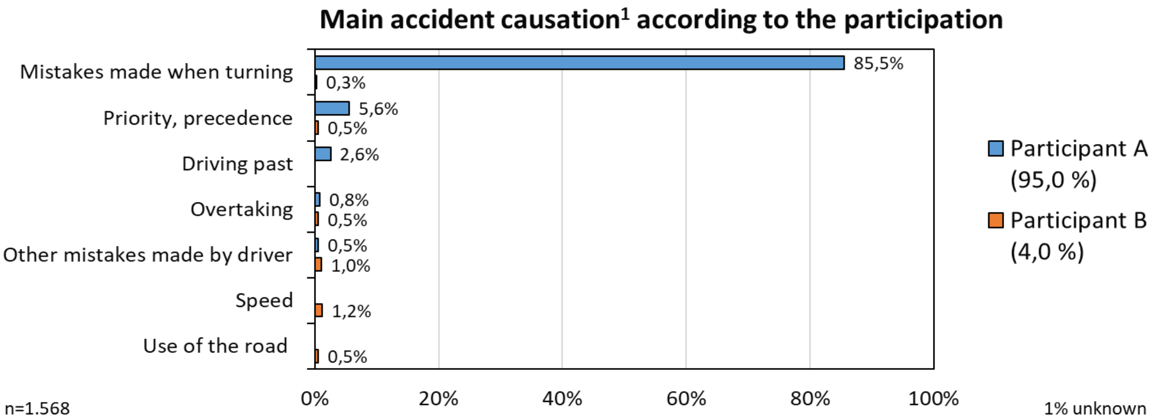
It is commonly understood from investigations such as Breuer, Gleissner, 2006 [3], that a TTC above 3-4 sec. enables most drivers to react properly to a warning. In the described accident type 302, the majority of incidents show a TTC over 4.5 sec., which should allow for an appropriate avoidance manoeuvre of mostly the car driver.

3.2 Accident type 211 (left turn)

The majority of motorcycle accidents type 211 occurred at crossings which accounts for 42.9% of the left turn accidents. The second frequent scene is at junctions that accounts for 35.9%, while accidents exiting from property areas account for 20.4%. It is commonly said that a motorcycle being small size is often misjudged by car drivers regarding its speed and distance and may hide behind a foregoing vehicle. Therefore, it is more challenging for the car drivers to properly estimate the necessary time gap for the left turn maneuver.

While Right-of-way regulation was the predominant (50.8%) traffic regulation at the accident site involving motorcycles. Consequemntly the main couse of accident was considered 'Mistake when turning' (see Figure 8).

Figure 8: Main causation for accident type 211

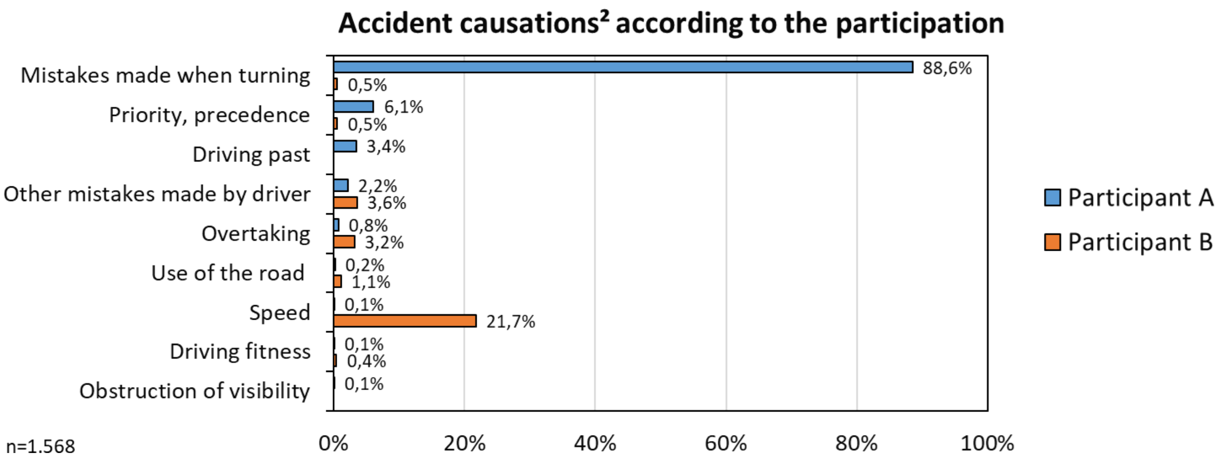


1 Police and technical investigation units in GIDAS assign a main accident causer with one main accident causation in each accident.

For left turn accident scenarios with a motorcycle, in most cases, the participant A represents a M1 / N1 vehicle (passenger cars / light commercial vehicles) and for participant B, motorcycles.

The causation of the accidents is shown in Figure 9. From the figures, it is understood that the main reason for the accident was misperception of speed and distance of the motorcycle, similar to accident type 302 of participant A towards participant B.

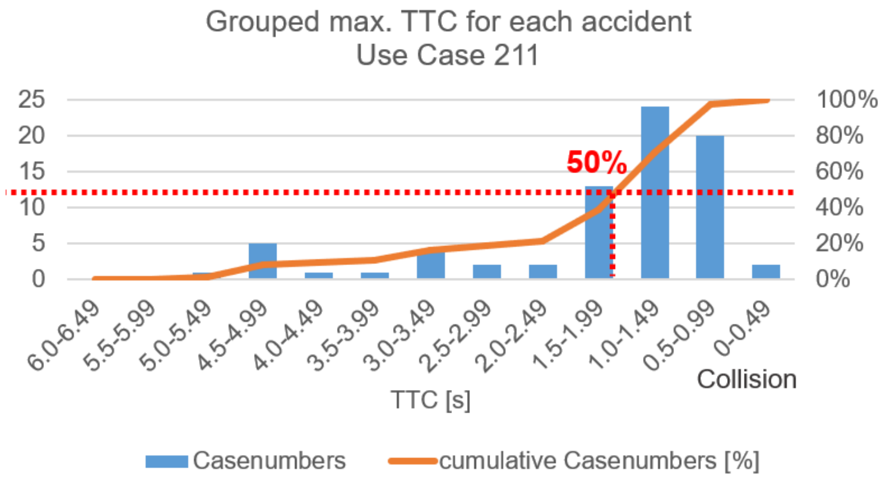
Figure 9: Accident causation for accident type 211



2 Police and technical investigation units in GIDAS assign up to 3 accident causations for each accident participant. Consequently, one accident can have several accident causes depending on the participant and so the sum of the accident causations is ≥100%.

Figure 10 shows cumulative case numbers of TTC and where it crosses the 50% line. It reads from the figure that in 50% of the left turn accident type 211 cases a TTC can only be recorded at 1.5 seconds before the potential collision. This implies that with 50% of the left turn type 211 accidents, the vehicle operator can be informed only 1.5 seconds before the potential collision.

Figure 10: Time to collision for accident type 211



In the described use case type 211, the majority of incidents show a TTC between 0. 5 and 2 sec. This is most likely too little time for most drivers to react after a warning has been displayed. The challenge is, to detect at an earlier stage if and when the participant A (car) is turning left. With current on-board technology this seems unlikely feasible. New detections systems combined with suitable algorithms might bring a solution closer.

The key findings are:

- More than 90% of these accidents occur at junctions, crossings or property exits.
- Accidents are caused by M1/N1 vehicles in more than 90% of the cases.
- In approx. 17% of the accidents, there was a view obstruction.
- Weather condition is not a major factor for the accidents.
- The last two maneuvers before collision indicate that the accident causer did not decelerate before collision in more than 40% of accidents.
- In half of the cases, a potential collision could be predicted not earlier than 1.5 s before collision. (50%tile of the TTC values).

4 Discussion & Conclusion

The study shows good potential for warning systems alerting car drivers that a motorcycle is in their way. This counts especially for crossing traffic accident configurations type 302, whereas left turn configurations type 211 remain critical due to a low remaining warning time (Time to Collision).

As mentioned, new detection systems and methods to detect and to indicate automatic avoiding action might bring solutions closer.

Breuer, Gleissner, 2006 [3]: "It is well known from practical experience that drivers do not always react as quickly as necessary in critical moments - for example, because they are distracted and therefore do not react as quickly as they should and therefore do not heed the warning signals."

According to Breuer, Gleissner, 2006, Time to Collison for longitudinal (FCW) scenarios is separated in following categories:

- >= 0 - <0,6s à severely critical
- >= 0,6 - <1,6s à critical
- >= 1,6 - <2,6s à light critical
- >= 2.6s à uncritical

These thresholds are an indication only since they derive from FCW scenarios. Further investigations might show different values for the different accident scenarios explained in this paper.

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[2] (Amundsen & Hyden, 1977): "A traffic conflict is an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged".

[3] Breuer, Gleissner, 2006, VDI-Berichte 1960, 397, Neue Systeme zur Vermeidung bzw. Folgenminderung von Auffahrunfällen, VDI Verlag.

Abbreviations

ACEM	European Association of Motorcycle Manufacturers
ADAS	Advanced Driver Assistance System
CMC	Connected Motorcycle Consortium
C-ITS	Cooperative Intelligent Transport Systems
FCW	Forward Collision Warning
GIDAS	German In-Depth Accident Study
GIDAS-PCM	GIDAS Pre-Crash Matrix
HMI	Human-Machine Interface
ITS	Intelligent Transport Systems
OEM	Original Equipment Manufacturer
PTW	Powered Two-Wheeler
TTC	Time-to-Collision
V2X	Vehicle-to-X (where X stands for everything)

TITLE: Defining suitable parameters for safe and effective deployment of a motorcycle Pre-Crash Braking system: findings from field testing and crash simulations

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ABSTRACT

Research question / Starting point for investigation

Pre-Crash Braking (PCB) is a promising technology currently under development, aiming to improve motorcyclists' safety by providing automatic braking input and reducing impact speed in pre-crash conditions. However, the implementation of the PCB as a system that influences motorcycle control, remains controversial from the perspective of the users.
This study, conducted within the EC funded project PIONEERS, aims to define suitable parameters of intervention and technical requirements for obstacle detection for a safe and effective application of PCB.

Methods

First, a field test program involving 51 common riders as participants on two test vehicles was executed to assess the feasibility of different levels of autonomous braking intervention. The system was tested in the speed range of 30-50 km/h while performing typical manoeuvres including straight riding and lane change.
Second, 60 crash cases sourced from two different in-depth databases from Italy and France were reconstructed using two different 2D simulation software, to test various obstacle detection system requirements and evaluate the potential safety benefits of the PCB intervention.

Results

In both straight-line and lane change manoeuvres, autonomous braking intervention reaching decelerations up to 5 m/s^2 with fade-in jerk up to 20 m/s^3 for a duration of approx. 1 s were considered manageable on both test vehicles by participants. Overall, the system intervention was tested more than 900 times with no loss of control. The crash simulation analysis indicated that a field of view of 80° and a detection range of 30m or higher can be adequate to effectively identify obstacles and trigger PCB. Tangible safety benefits were found to be achievable with several combinations of the analysed design parameters.

Impacts / Effects / Consequences

Our latest findings show that PCB still has to be considered among the motorcycle safety countermeasures of the future. In fact, by employing design parameters within the up-to-date feasibility thresholds evaluated in this study, the PCB estimated effects had a relevant safety impact.

1 Introduction

This study presents the results of the collaborative research performed within the framework of the European Commission-founded project PIONEERS, whose general objective was to improve the safety of Powered-Two-Wheelers (PTWs) users through an innovative integrated approach to rider protection, based on personal protective equipment and onboard active safety systems.

Within the project, one of the cores of research was Pre-Crash Braking (PCB), being one of the most promising technologies among onboard safety systems in development for PTWs [1]. PCB provides the functionalities of Motorcycle Autonomous Emergency Braking (MAEB) in pre-crash conditions, delivering an autonomous braking action intended to reduce the pre-crash speed of the host PTW immediately before the crash. Such technology showed a positive effect on other road vehicles such as trucks and passenger cars [2].

The working parameters of PCB, intended as braking parameters, which define the performance of the pre-crash autonomous braking action, and obstacle detection requirements, which define the performance of obstacle detection tools required for effectively detect opponent vehicles or objects and trigger the PCB at the proper timing, are the key for safe and effective implementation of PCB on PTWs. As indicated in studies on passengers' cars, different parameters can provide different results in terms of impact speed reduction and injury mitigation [3].

In order to explore suitable parameters for PCB intervention, early studies employed mainly two approaches: field tests to evaluate rider stability during the deployment of Automatic Braking (AB), and crash simulations to estimate PCB potential benefits for injury mitigation [4]. Studies focusing on field testing started in 2010 with professional riders and with a PTW equipped with a laser-scanner and producing automatic decelerations in correspondence with a target obstacle [5]. Further research was performed testing AB with common riders as participants and decelerations up to 2 m/s^2 deployed unexpectedly via remote control [6], and again, with professional riders in lane-change riding scenarios [7]. Crash simulations were also employed to develop decision logic to trigger PCB interventions [8], and to explore its potential benefits on crashes [9], [10].

In order to make PCB a mature technology to be introduced on standard vehicles, further research is required to define safe and reliable working parameters. Some preliminary studies which analysed its effectiveness, suggested that the parameters of intervention field-tested so far may not be sufficient to reduce the likelihood of sustaining serious injuries in case of crashes [11]. In addition, the current technological development of obstacle recognition tools fostered by the introduction of Autonomous Emergency Braking for passenger cars and research for Autonomous Driving, offered in the last few years new reliable tools for obstacle detection, which could pave the way to an effective triggering of PCB.

The goal of this study is to identify suitable parameters of intervention and technical requirements for obstacle detection tools for a safe and effective application of PCB. We performed field tests with two prototype vehicles and participants to assess the acceptability of the PCB among end-users and the controllability of the vehicle with different sets of braking parameters, while computer simulations were used to evaluate PCB effects and its efficacy in reducing impact speed with a broader set of braking parameters and obstacle detection requirements.

2 Methods

This study combines two different methodologies -Field testing and Crash modelling- with the common goal of identifying suitable parameters for safe and effective deployment of Pre-Crash Braking system on Powered-Two-Wheelers (see Figure 1). In this section both the methodologies and the sets of PCB working parameters tested in field testing and simulations will be presented.

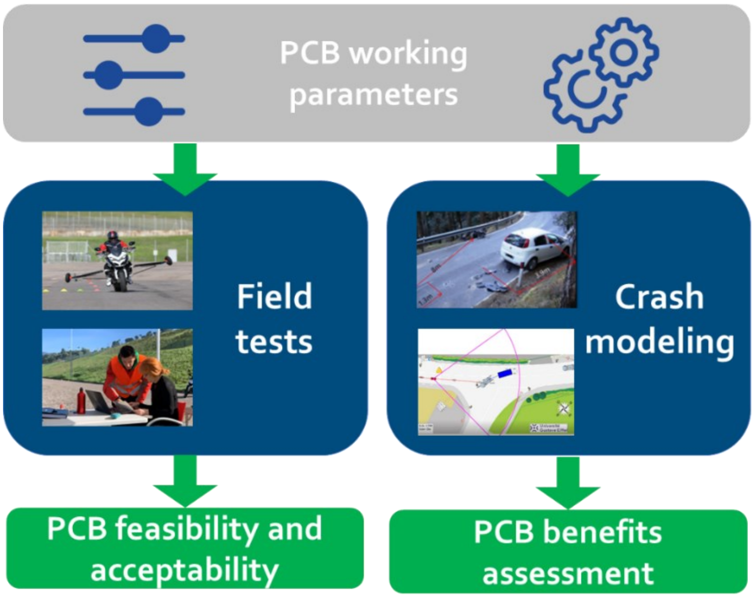


Figure 1 – Methodological approach employed for this study

2.1 Field test methods

Field tests were performed on two different test vehicles provided with Automatic Braking (AB) devices capable of activating braking without rider action. Both vehicles (a sport-touring motorcycle and a two-front wheels scooter, from now on called Multistrada and MP3 respectively) were employed to test the intervention of AB in straight-line and lane-change manoeuvre.

The AB test procedure was developed based on previous studies based on pilot testing and literature review carried out by the authors [12]. The AB interventions were tested at different velocities ranging from 30 km/h to 60 km/h (depending on the requested manoeuvres).

The participants were recruited among active riders with two years or 10000 km of riding experience and aged between 20 and 65. The advertisement for the participants' recruitment was disseminated through the university web page, social media, flyers and biker groups.

This study obtained ethical approval from the Ethics Committee of the University of Florence (Written opinion N. 46, 20/03/2019).

2.1.1 Test procedure and AB parameters

Participants tested the intervention of the AB system by riding with one of the two test vehicles along the test track: the AB activations were manually triggered by one investigator via remote control [13]. The AB was triggered only when the PTW was in precise spots of the track while the participants were performing the specific manoeuvres.

For the Multistrada, the test included two phases with a nominal deceleration of respectively 3 m/s^2 and 5 m/s^2 and fade-in jerk of 15 m/s^3 tested in four manoeuvres (straight-line, lane-change, slalom, and curve). For the MP3, as for the Multistrada, the test included two phases with a nominal deceleration of respectively 3 m/s^2 and 5 m/s^2 and fade-in jerk of 15 m/s^3, tested in two manoeuvres (straight-line and lane-change). The test with MP3, after the above-mentioned phases, also included two other phases with fade-in jerk up to 25 m/s^3.

The participants were not aware of the timing of AB intervention nor the exact position within the test track: this aimed to obtain AB events that were as unexpected for the rider as possible while keeping a low learning effect. Overall, the AB was deployed in the different manoeuvres with an average frequency of one activation every 100 s of riding and with a pseudo-random order. Full details of the test procedure were presented in [14].

2.1.2 Test vehicles

The first test vehicle was a Ducati Multistrada 1260S, a sport-touring motorcycle equipped with Motorcycle Stability Control (MSC), combined braking and semi-active suspensions. The vehicle was provided with outriggers to prevent the vehicle from lateral fall (see Figure 2 - left), since the intervention of AB in lateral manoeuvres such as cornering and slalom was also tested with this vehicle, but it will not be presented in this paper. The second vehicle was a Piaggio MP3 500, a two-front-wheel scooter provided with Antilock Braking System (ABS) (see Figure 2 - right).

Figure 2 – Test vehicles: Ducati Multistrada 1260 (left) and Piaggio MP3 500 (right)

2.1.3 Data recording

A similar data acquisition system was employed on both vehicles to collect data from the PTWs' CAN-Bus (throttle, brake action, steering angle, vehicle tri-axis acceleration and gyro), from an Inertial Measurement Unit (IMU) attached to the back of the participants to record the chest movement during the tests, and from an internal tri-axes accelerometer and GPS receiver. Both test vehicles were also equipped with action cameras to record the driver's body and monitor his/her behaviour during the AB. In order to collect subjective data, questionnaires were adopted to ask participants their opinion on the test, the AB system tested and the controllability of the vehicle during the AB activation in the different manoeuvres.

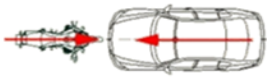
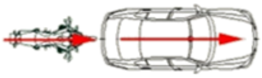
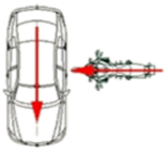
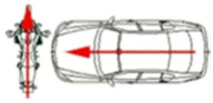
2.2 Crash simulation methods

The second step of this study employed computer simulations to reconstruct real-world crashes and assess the potential benefits of PCB applied with different parameters of intervention. The simulations were designed to cover a broad range of PCB parameters, including those tested in the field test campaign. Also, different levels of performance for the obstacle recognition tools supposed to trigger PCB were analysed.

2.2.1 Crash data source

Crash cases for simulation were extracted from two different in-depth road crash databases: the InSAFE database from the University of Florence (UNIFI), which collects crashes from the Florence metropolitan area, Italy [15], and the EDA database from the University Gustave Eiffel (UGE), which collects crashes from both rural and urban roads in France [16]. In total sixty cases were employed, thirty from each database, extracted and reconstructed based on the detailed description of the crash collected in the database, including for example road configuration, marks documented in the crash scenario, damage to vehicles, injuries of riders, and police reports. Overall, crashes included in the study involved mainly L3 PTWs (77%) and 23% of L1 PTWs only. They occurred mainly at intersections (70%), while only 22% were in straight-line and 8% in curves. The distribution of the crash configuration among the two databases was slightly different: the InSAFE dataset collected more Head-to-side (T-bone) crashes (56%), while in the EDA database 50% of cases were Head-on crashes (see Table 1 – for the detailed definition of the crash configurations see [17]). A lower proportion of Head-to-rear and Sideswipe crashes were included in both databases.

Table 1 - Crash Configuration distribution of 60 cases among the two databases

Crash Configuration	InSAFE	EDA	Total
Head-on 	5 (16.7%)	15 (50.0%)	20 (33.3%)
Head-to-rear 	3 (10.0%)	2 (6.7%)	5 (8.3%)
Head-to-side 	17 (56.7%)	7 (23.3%)	24 (40.0%)
Sideswipe 	5 (16.7%)	6 (20.0%)	11 (18.3%)
Total	30 (100.0%)	30 (100.0%)	60 (100.0%)

2.2.2 Crash reconstruction tools

Crash reconstructions were performed on two different 2D simulation tools developed by UNIFI and UGE based on previous studies on PCB [9]. Among the 60 cases included in the study, 20 were simulated in both crash simulation tools (10 from each database), to compare results from the two different software. Each crash case was first reconstructed in the virtual environment and validated using all the information collected in the database (e.g., comparing the impact speed at the crash and the incidence of the two vehicles involved in simulations with detailed data from crash investigators). Then, the intervention of PCB with different parameters was simulated (see the following section). The effect of PCB was measured in terms of Impact Speed Reduction (ISR), as the difference between the impact speed without and with PCB.

Figure 3 – Crash simulation tools employed for the study by UNIFI (left) and UGE (right)

2.2.3 PCB tested parameters

Crash simulations were employed to assess the influence on PCB effectiveness of five parameters, three related to the automatic braking system (Triggering Strategy, Deceleration and Fade-in Jerk), and two related to the obstacle recognition system (Field of View and Range). See Table 2 for full details about the ranges and the incremental steps used for simulations.

The ***Triggering Strategy*** defines the timing of deploying PCB based on the detection of the inevitable collision state: the time in which the crash between the PTW and the opponent vehicle/object becomes unavoidable. Based on different thresholds of deceleration in longitudinal and lateral directions achievable by the PTW, it is possible to define different triggering strategies. These correspond to a different time to collision at which the PCB is triggered. Full details of the definition of triggering strategies are presented in [18]. For this study, three triggering strategies (called "Conservative", "Standard" and "Progressive") were simulated in both crash simulation software. In order to have a more realistic PCB behaviour, the software employed by UGE added to PCB simulation a constraint on times to collision with the realistic values of 0.6 s (Conservative), 0.8 s (Standard) and 1 s (Progressive).

Three values of PCB ***Deceleration*** were employed in crash simulations: two of these values (respectively, 3 m/s^2 and 5 m/s^2) were devised by field tests performed with participants (see section 2.1.1), while the highest value of deceleration (7 m/s^2) was tested to assess what could be the potential benefits of PCB with decelerations even higher than those currently field-tested with participants. Similarly to deceleration, the two levels of ***Fade-in Jerk*** tested with participants were also employed in simulations.

The ***Field of View*** represents half of the width in degrees of the detection zone of the obstacle recognition system. Combining its value with the ***Range***, we can define the obstacle recognition cone in which an opponent vehicle or object can be recognised by the system (see Figure 3). This defines the timing when the other vehicle is detected by embedded sensors on the PTW and therefore PCB can be triggered. The Range is the maximum distance at which the PCB can detect an opponent vehicle/object. For both parameters, a wide range of values was tested in simulations, based on the state-of-the-art radar technology. It is evident that state-of-the-art sensor devices are capable to have a wider range. However, to limit simulation time, for PCB with progressive triggering strategy the range does not extend 90 m.

Table 2 - PCB Parameters variation

Parameter	Range	Incremental step
Triggering strategy	[conservative, standard, progressive]	-
Deceleration	[3 m/s^2 -7 m/s^2]	2 m/s^2
Fade-in Jerk	[15 m/s^3 -25 m/s^3]	-
Field of View	+/- [10°- 70°]	15°
Range	[30 m - 90 m]	15 m

* NOTE: this value represents half of the whole FOV of the detection cone

The wide number of parameters tested allowed us to assess the influence of each parameter on PCB performance (see section 3.2.1). However, 450 different combinations of PCB parameters tested did not allow us to obtain a realistic assessment of the expected benefits provided by the system. Three combinations of parameters were therefore selected to analyse the potential effectiveness of PCB considering a pessimistic (low efficiency), an average, and an optimistic (high efficiency) implementation of parameters. The sets of parameters selected for the three configurations are displayed in Table 3.

Based on results from field testing (see section 3.1.4), for the PCB deceleration, the more conservative setting (3 m/s^2) was selected for the pessimistic configuration while for the average and progressive configurations the deceleration of 5 m/s² was chosen. Similarly, the fade-in jerk was set to 15 m/s³ for the pessimistic configuration and 25 m/s³ for both the average and optimistic configurations.

Table 3 - Sets of parameters for the three PCB realistic configurations

Parameter	Pessimistic	Average	Optimistic
Triggering strategy	Conservative	Standard	Progressive
Deceleration (m/s²)	3	5	5
Fade-in jerk (m/s³)	15	25	25
Range (m)	30	30	30
Field of View (°)	+/-15	+/-45	+/-45

3 Results

3.1 Field test results

The results of the field-testing activity will be presented in this section: actual PCB working parameters field-tested for both test vehicles will be related to their feasibility in different riding conditions and acceptability among users.

3.1.1 Test participants

Overall, 51 participants (10 women, 41 men) were included in this study, testing only one of the two vehicles. Thirty-one participants tested AB on the Multistrada, while 20 on the MP3. Participants were selected based on their main usage of PTWs: the majority of participants who tested AB on Multistrada were mainly leisure riders while participants selected to test the AB intervention on the MP3 were mostly commuters. The age of participants ranged from 21 to 59 years, and they were characterized by different levels of education and a broad range of riding experience. For further details on the sample of participants included in the study please see [14].

3.1.2 Tested Automatic Braking intervention and manoeuvres

Table 4 reports a summary of the AB-tested intervention for the two test vehicles in the two manoeuvres considered in this study: straight-line riding and lane change reproducing an avoidance action (see Figure 4). Due to weather conditions, not all the participants were involved in testing the AB in all the manoeuvres and with all the levels of intervention planned in the test protocol.

Overall, the AB was tested with the Multistrada almost 250 times in straight line and lane change, whereas considering also the trials in different conditions and manoeuvres more than 500 AB tested interventions were recorded. With the MP3 the AB intervention was tested approx. 290 times the same manoeuvres.

For the Multistrada, the AB was deployed at two different levels of nominal deceleration (respectively 3 m/s² and 5 m/s²), and with a fade-in jerk level of 15 m/s³. These nominal values were also measured after testing. Similarly, for the MP3 the two values of deceleration (3 m/s² and 5 m/s²) were measured in the trials, while the two levels of fade-in jerk (respectively 15 m/s³ and 25 m/s³) set for the test resulted in a wide distribution of values of fade-in jerk, with peaks reaching up to 30 m/s³.

The AB duration for both vehicles was approx. 1 s (respectively, 1.08 s and 0.97 s for Multistrada and MP3), while the riding speed at AB trigger ranged from 37 to 45 km/h.

Table 4 – Summary of AB tested interventions

Test Vehicle	Participants	Manoeuvre	Nominal deceleration [m/s²]	N° of PCB activations	Initial Speed [km/h]		Event duration [s]		Deceleration [m/s²]		Fade-in jerk [m/s³]	
					Mean	SD	Mean	SD	Mean	SD	Mean	SD
Ducati Multistrada	31	Straight-line	3	63	47.6	4.7	1.07	0.03	2.9	0.3	15.0	4.0
		Lane change		65	41. 7	6.0	1.05	0.11	3.0	0.4	12.6	4.1
		Straight-line	5	63	49.1	4.7	1.14	0.03	4.7	0.4	20.2	3.9
		Lane change		65	41.5	5.4	1.05	0.20	4.8	0.4	19.6	7.3
Piaggio MP3	20	Straight-line	3	42	40.7	3.8	0.97	0.12	3.1	0.3	15.3	3.4
		Lane change		34	38.8	3.2	0.96	0.13	3.6	0.3	17.2	3.9
		Straight-line	5	40	41.1	4.7	1.00	0.00	4.7	0.4	18.9	3.2
		Lane change		33	39.4	3.3	0.93	0.19	5.2	0.5	20.5	4.4

Figure 4 – AB activation in the two manoeuvres: 1) Multistrada in straight-line, 2) Multistrada in lane-change, 3) MP3 in straight-line, and 4) MP3 in lane-change.

3.1.3 PCB intervention during avoidance action

Being the feasibility of PCB intervention when the rider is performing lateral maneuvers one of the main open issues when assessing its safety and applicability, an in-depth analysis of PCB intervention during lane-change maneuver reproducing avoidance action was performed [19].

Vehicle dynamics in the lane change manoeuvre with and without automatic braking were compared (see Figure 5): minor effects were found on vehicle dynamics -except for those produced by the automatic braking- which never questioned the controllability of the vehicle. For both vehicles, participants were always able to manoeuvre the lane change by avoiding the virtual obstacle without executing other actions or braking. Due to the automatic deceleration and lower speed, minor differences in the vehicle lean were reported. No loss of control was reported by the participants in the questionnaire nor recorded by cameras.

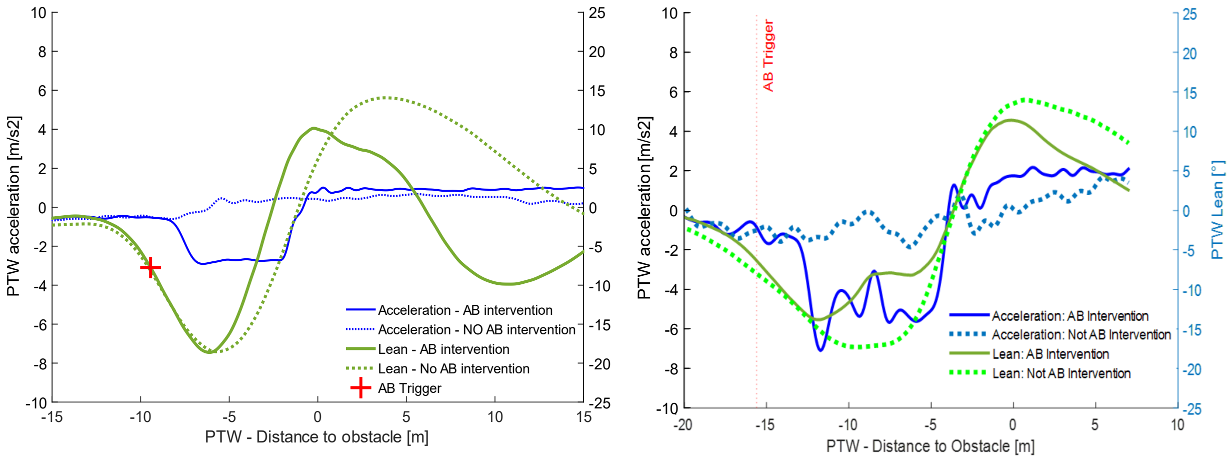


Figure 5 - Comparison of acceleration (blue) and vehicle lean (green) between a lane change with (solid) and without (dotted) AB. Left – 3 m/s² AB intervention on Multistrada; Right – 5 m/s² AB intervention on MP3

3.1.4 Users' acceptability of 5 m/s² PCB deceleration

At the end of the test, the participants assessed the Automatic Braking system based on the conditions they experimented. Even if after testing the AB there were few negative opinions about it, for both test vehicles all the participants managed to complete the whole test without asking to interrupt the trials due to the intervention of the AB or other reasons. Moreover, no potentially dangerous situations were created by the intervention of the AB or the participants' behaviour.

The perception of the intensity of AB intervention in terms of braking deceleration and fade-in jerk is displayed in Figure 6 for both test vehicles.

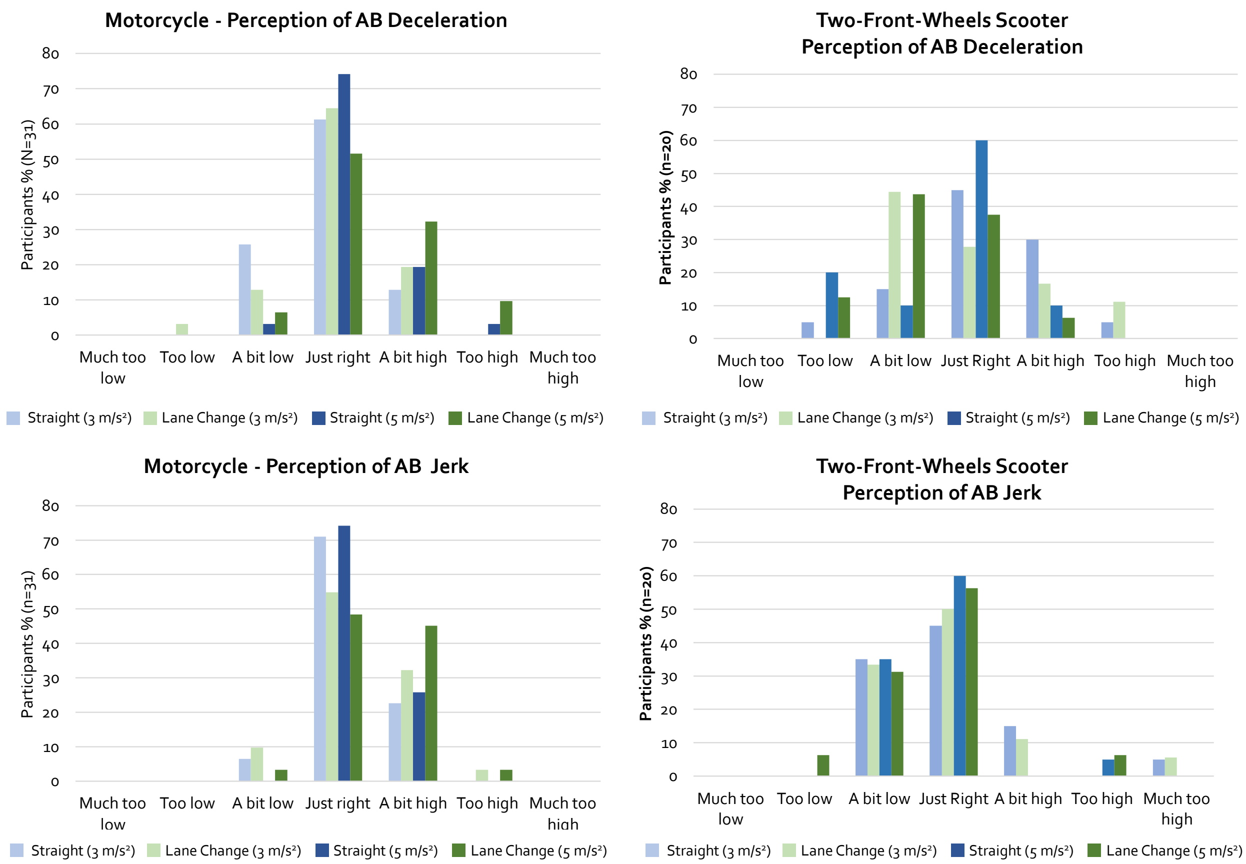


Figure 6 - Perception of AB intervention for Multistrada (left) and MP3 Scooter (right)

3.2 Crash simulation results

The results of the crash simulation activity will be presented in this section: first, the influence of different PCB working parameters on Impact speed Reduction will be presented, second, the effect of three different sets of PCB parameters (an optimistic, average, and pessimistic configuration) will be compared.

3.2.1 Influence of PCB parameters

A total of 60 crash cases (half from the InSafe database and half from the EDA database) were employed to assess the influence of PCB working parameters such as triggering timing, braking deceleration and the fade-in jerk. The same set of 60 cases was also used to simulate the effect of obstacle recognition parameters such as Field of View (FOV) and Range.

In order to assess the influence of each parameter, simulations were performed employing a standard set of parameters (Standard triggering, Deceleration = 5 m/s², Fade-in jerk = 25 m/s³, Field of View = 40°, and Range = 30 m), and by varying only one parameter at a time.

Triggering

Setting all the other parameters to the standard value and varying only the triggering strategy, median reductions in impact speed of 5 km/h (conservative), 7.5 km/h (standard) and 12 km/h (progressive) were obtained (see Figure 7).

Deceleration

The PCB deceleration turn out to provide the highest influence on impact speed reduction: comparing ISR produced by 3, 5 and 7 m/s² PCB deceleration, the median speed reduction obtained by PCB intervention was, respectively, 2.5 km/h, 7.5 km/h and 9 km/h, using the standard setting for the other parameters (see Figure 8).

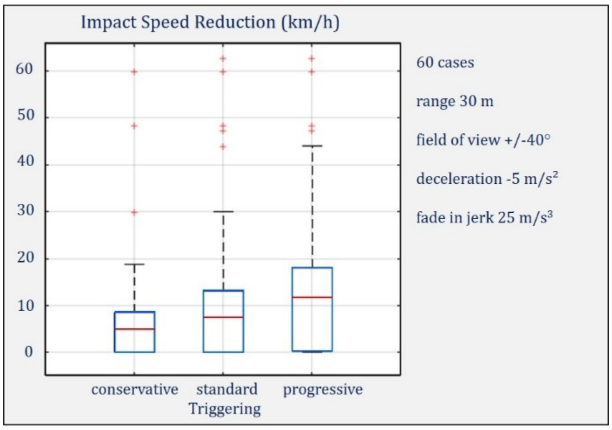


Figure 7 - Influence of the Triggering in PCB simulation

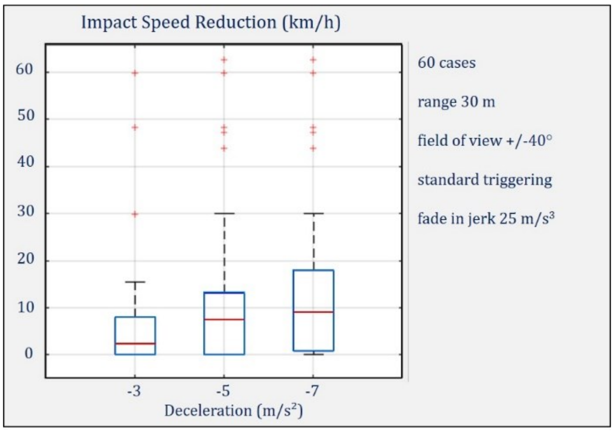


Figure 8 - Influence of the Deceleration in PCB simulation

Fade-in jerk

Regarding the fade-in jerk, its influence on ISR among the two levels tested in the simulations was found to be limited (about 1 km/h) among the 60 cases (Figure 9). A median impact speed reduction of 6 km/h was estimated for a Fade-in jerk of 15 m/s³ using standard values for all the other parameters, while 7 km/h ISR was obtained for a Fade-in jerk of 25 m/s³.

Field of View

Figure 10 shows the influence of the Field of View employing the standard set of parameters. With a FOV of 10° (on either side of the longitudinal axis of the PTW, i.e., 20° of total aperture), the detection was zero in at least half the cases. At 25° FOV, the median impact speed reduction was 4 km/h, at 40° it was 7.5 km/h while beyond 40° the ISR gain was very limited.

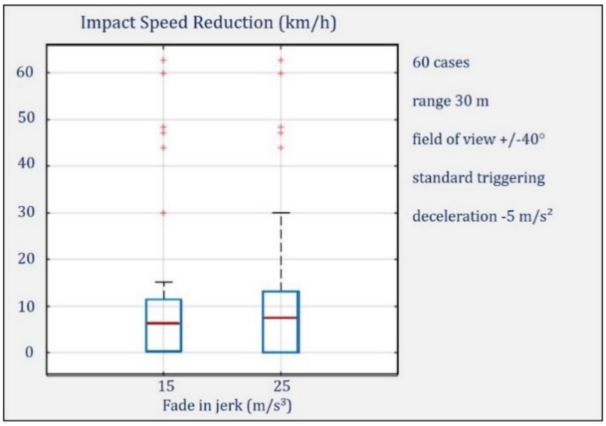


Figure 9 - Influence of the Fade-In Jerk in PCB

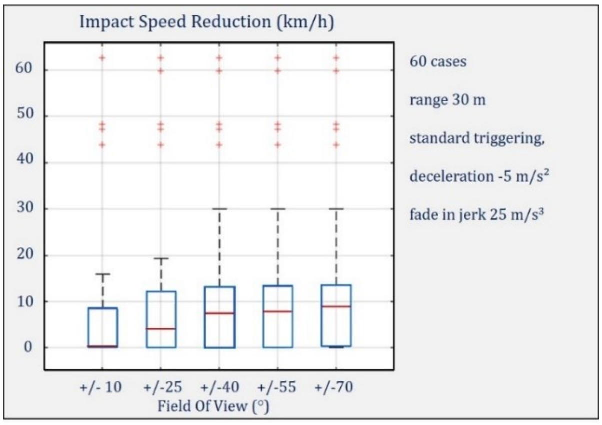


Figure 10 - Influence of the Field of View in PCB

Range

Due to limitations in the simulation tools, the influence of the Range on ISR was analyzed by employing only 40 cases simulated by Univ. Eiffel: 30 cases from EDA and 10 from InSafe. The influence of the Range was however very limited: using the standard set of parameters, only a small difference between a range of 30 m and a range of 45 m was found (ISR increase of 0.2 km/h), while beyond 45 no increase of ISR was measured. Also using a different set of parameters (defined as "optimistic" - see section 2.2.3), the difference between the Range of 30 m and 40 m was limited (an increase of the average ISR of 0.4 km/h).

3.2.2 Realistic PCB configurations

From the large number of parameters considered in this study for the analysis of PCB effects, three realistic combinations of parameters were selected to represent typical system effects assuming a pessimistic (low efficiency), average, and optimistic approach (high efficiency).

Considering all 60 simulated crashes in the three configurations, median reductions in impact speeds of 0.0 km/h, 7.4 km/h and 11.6 km/h were obtained (see Figure 11 - left). In 15 crash cases, the PCB was not triggered with any of the three configurations, or its intervention did not produce any effect (e.g., in cases in which the opposing vehicle was not detected in time, or the rider is manually braking with a higher deceleration than that produced by PCB). Excluding these cases, and therefore selecting crashes in which PCB is applied effectively, the median ISR was, respectively, 2.8 km/h, 10.7 km/h and 15.1 km/h for the three PCB parameter configurations (see Figure 11 - right). In 8 crash cases, at least one of the three configurations prevented the crash.

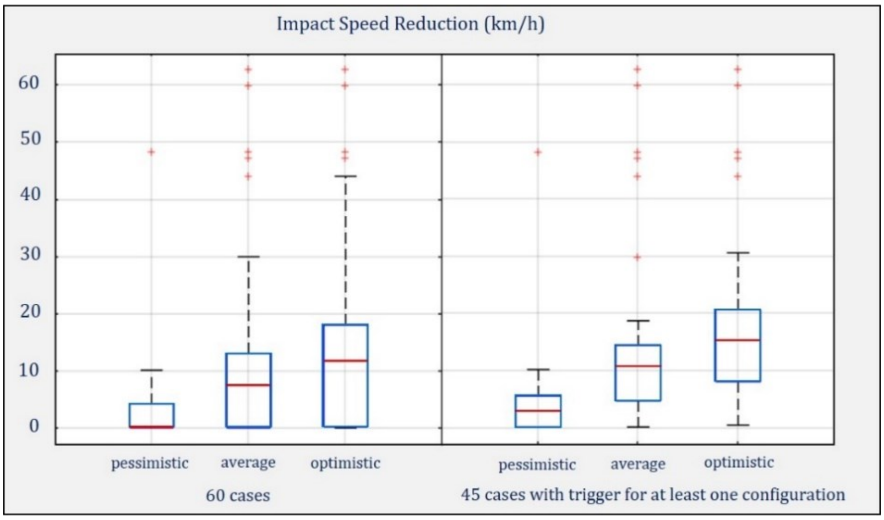


Figure 11 - Impact speed reductions for the three realistic PCB configurations considered
(Left: all 60 cases – Right: 45 cases with PCB really triggered)

4 Discussion

The identification of suitable working parameters is the key to the future introduction of Pre-Crash Braking (PCB) on standard Powered-Two-Wheelers (PTWs). This study, results of the EC-founded PIONEERS project, merged two different approaches, field testing in the real world with common users as participants and crash simulations, to identify a set of appropriate parameters which can make PCB safe and effective in reducing injuries to PTW users.

The field tests campaign, which involved 51 participants and two different test vehicles, aimed to assess the feasibility and acceptability of PCB in the real world for a broad range of working conditions and parameters, which were never been tried before [22]. The sample size of participants employed for field testing was the widest so far in the field research concerning autonomous braking (PCB and MAEB). The system intervention was tested more than 1000 times on the two different types of vehicles with different parameters and manoeuvres. All the participants completed the experiment and agreed to test the intervention of the AB unexpectedly in the conditions proposed by the investigators and no dangerous situation occurred in the context of the deployment of AB. The sample of participants was characterized by a wide range of ages, sex, riding experience and motivations for riding. However, despite this large sample and the wide variability, the participants involved in this study may not be completely representative of all PTW user populations. They expressed generally a positive opinion about the system tested in both test vehicles, as the controllability of the PTWs was never at risk. Participants were always able to execute the avoidance manoeuvres, even with the highest level of PCB deceleration. The subjective assessment [21] and objective data analysis performed based on these tests [19]–[21], [23] indicated the applicability and feasibility of PCB with 3 m/s^2 and 5 m/s^2 of deceleration and up to 20 m/s^3 of fade-in jerk, for interventions of up to 1 s duration.

The computer simulation approach was applied to sixty real-world crashes sourced from the InSafe and EDA databases, which were employed to estimate the effects of PCB and explore the influence of different sets of working parameters on its efficacy. Using two different simulation tools developed by the University of Florence and the University Gustave Eiffel, crashes were kinematically reconstructed and the PTW impact speed reduction provided by PCB was used as a reference for its efficacy, being strictly related to injury reduction [24]. A large number of parameters were considered in the analysis concerning the autonomous braking performance (deceleration, fade-in jerk, and triggering) and obstacle recognition tools performance (field of view and range). This allowed for a comprehensive assessment of the influence of each parameter on impact speed and the identification of three realistic combinations of PCB system settings. Deceleration and triggering were found to be the most important parameters to maximize the effects of PCB, while a Field of View of the obstacle detection system equal to or higher than 45° (so overall 90° of view) was found not to be beneficial to increase PCB capabilities to detect obstacles. The three realistic sets of parameters representing respectively, pessimistic, average and optimistic conditions for PCB parameters provided median impact speeds reductions of, respectively, 0 km/h, 7.4 km/h and 11.6 km/h. These values, which are affected by different riding conditions and manual braking actions of the rider, are in line with studies focusing on different traffic environments and are potentially capable to mitigate injuries and fatalities [25].

This study identified the influence of the key working parameters of Pre-Crash Braking, one of the most promising technologies to enhance the safety of PTW users, on its effectiveness in terms of braking action and obstacle recognition. These results can be employed by manufacturers and researchers to tune the braking intervention, design the detection system and develop the triggering algorithms and therefore further develop Autonomous Braking for PTWs, towards its introduction on standard vehicles. Also, the combined approach of field-testing computer simulation developed for this study can be a reference for future studies aiming at the development of new active safety systems for PTWs.

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Benefit estimation of the Power Two Wheelers Advanced Rider Assistance System on accidentology

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Abstract

➢ Research question

The advanced riding assistance systems (ARAS) are technologies developed and integrated into cars and Power Two-Wheelers (PTW) in order to improve their safety. Cars have several technologies of ADAS, which have reduced their accident rate. But, what are the improvements developed for PTW?

Despite a general decrease in accidents, the PTW are still a particularly risky mode of transport classifying their users in very vulnerable category. Based on this problem, the aim of this project is to analyze and evaluate the effectiveness of ARAS developed for PTW and estimate their benefits on accidents.

➢ Method

Firstly, a state-of-the-art on ARAS technologies of the PTW was made. Lots of ARAS have been identified like CAT (Collision Aversion technology), MSC (Motorcycle Stability Control), ACC (Active Cruise Control), with the precision of their dynamic benefits. Then, from the in-depth accident database (EDA) available at the LMA, a sample of real PTW accident cases was analyzed to determine the causes and parameters of each accident. Finely, three different methods have been developed for MSC, CAT and ACC, in order to analyze their effects on PTW accidents.

➢ Results

After a kinematic reconstruction and a specific analysis of each EDA case, the results of each technology presented according to the objectives. For the MSC and the ACC three classes identified concerning their influence in the accident: "accident avoidance", "accident mitigation" and "no effect". In turn, and for the CAT, the distance between the motorcycle and the obstacle vehicles have been analyzed at each moment during the accident. The objective was to determine the detectability of these vehicles and to propose possible improvements for this technology.

➢ Impacts

This study allows to statistically evaluating the effectiveness of the ARAS developed for PTW, by projecting their dynamic benefits on a sample of real accident cases. Future studies will focus on the numerical modeling of some ARAS, in order to develop a complete multi-body accident reconstruction model for PTW, allowing a dynamic evaluation of the gains in terms of road safety by using these technologies.

1. Introduction

Road traffic accidents are the eighth leading cause of death for all age groups and are now claiming more victims than HIV/AIDS, tuberculosis, or diarrheal diseases. These injuries are currently the main cause of death for children and young adults aged 5-29 years [1]. Therefore, the improvement of road safety represents a main and priority axis for the preservation of human life.

Accidentology is the field that deals with and analyzes accidents and road risk [2], with the aim of identifying the causes and factors of each accident, and then proposing possible improvements to increase the safety of users [3]. The primary parameter of this discipline is the accident, which in the scientific field defined as a story. This story unfolds with the interaction of different components of the user-vehicle-environment driving system [4]. This story lends itself to an analysis of different situations. It begins with the driving situation and ends with the aftermath situation, passing through the moment of rupture, the emergency and impact situations. The first situation (driving) sets the scene and defines the actors. The rupture phase confronts the participants with a problem that they must solve. The latter pushes the actors to a hasty search for a solution that defined as an emergency. Finally the impact situation concludes the failure of the solution[5], and the post impact situation represents the consequences linked to the malfunctioning of each of the previous stages, the latter situation stops when the vehicles reach their final position. The analysis of the accident is done by going back in time [5], the impact and post-impact phases can be treated numerically and experimentally (crash-test) [6]. The pre-impact phase, which includes the driving, rupture and emergency situations, is more difficult to approach and will be the subject of this study.

Among the solutions used to reduce the number of accidents and improve the safety of users, we find the driver assistance systems (Advanced Driver Assistance System ADAS) or (Advanced Rider Assistance System ARAS), their interventions can be passive (information) or active (control), they operate inside the vehicle but they can be connected to external sources [7]. Different ARAS developed or in progress for development for Power Two-Wheelers (PTW), a list of these technologies would have given below:

- *Anti-lock Braking System (ABS)*: ABS is a system that manages the operating conditions of braking by modifying the braking torque through modulations of the braking pressure by means of application/release cycles, in order to avoid wheel locking [8].
- *Motorcycle Stability Control (MSC)*: Also known that as cornering ABS, it is an improved version of the conventional ABS. It adapts the braking on the wheels by taking into account the roll angle in a curve and the speed of the vehicle, which avoids the straightening of the motorcycle in a curve, which is the disadvantage of the conventional ABS [9].
- *Traction Contol (TCS)*: TCS is a system that reduces the power transmitted by the engine in a fraction of a second in order to balance the force of the rear wheel and the grip of the tire with the road surface [10].
- *Anti-Wheelie (A-W)*: A system that prevents the front wheel from coming off by reducing the engine power when it loses contact with the road [11,12].
- *Stoppie Control (S-C)*: Contrary to the A-W, the stoppie is when the rear wheel has a tendency to take off and lose contact with the road, to this effect this system prevents this movement and offers a better longitudinal stability [13].
- *Active Cruise Control (ACC)*: It adapts the speed of the vehicle to the traffic while maintaining the chosen safety distance from the vehicle in front [14].
- *Launch Control (L-C)*: Launch control is an electronic aid that controls the amount of torque applied to the rear wheel during hard acceleration from a standing start, preventing the rear wheel from spinning or the bike from coasting. [15] [16].
- *Combined Braking System (CBS)*: Also known as coupled braking, it combines the rear brake with the front brake. It helps the rider to achieve an almost ideal distribution of braking force in different conditions [17].
- *Autonomous Emergency Braking (AEB)* (in progress): A system composed of a camera and a radar capable of anticipating a frontal collision and of warning the driver beforehand, and of initiating the braking of the vehicle [18].
- *Anti-Skid (A-S)* (in progress): When there are wet leaves, an oil puddle or gravel on the road, the wheels will start to slide sideways if they can no longer exert sufficient lateral force when turning. Bosch thought of applying an additional external lateral force to help the driver stay on course, in the form of a gas that escapes under pressure to create a force in the opposite direction of the skid. [28].

- *Dangerous Turn Warning*: An application developed by Liberty Rider to warn drivers about dangerous turns according to their instantaneous speeds [19].
- *PCB (Pre-Crash Braking)* (in progress): A system that is similar to the AEB, based on radar and braking actions, but this one only aims to mitigate the impact by reducing the speed. While an AEB aims to avoid or mitigate the impact [20].
- *Smart Helmets (S-H)* (in progress): The connected helmet has several sensors to provide multiple functions. It monitors the driver's alcohol and drug levels and checks if they exceed a certain threshold. If so, this system first warns the rider, then if he or she is still driving, emergency contacts will be notified so they can handle the situation [21].
- *Collision Aversion Technology (CAT)*: Developed by RIDE VISION, this passive system monitors the surroundings of the vehicle at 360°, it works by cameras placed in front and behind. All cameras are connected to a central box that analyzes and calculates in real time the data received by sensors and detects the approach of a vehicle [22].

In France, despite a general decrease in the accident rate, Power Two-Wheelers (PTW) are still a particularly risky mode of transport that classifies its users as very vulnerable. According to the latest report of the CNSR (National Committee for Road Safety) published in February 2021, "*in 2019, 820 of the 3,498 fatalities in France were PTW users (23.4%), ..., Nearly one out of four fatalities is a PTW user while their estimated share of road traffic is less than 2%. The risk of losing one's life on French roads for the same number of kilometers traveled is about 22 times higher for these users than for users of light vehicles (24 times for drivers of heavy motorcycles > 125 cm3)*"[23].

ARAS technologies have been played an important role in the decrease of the accident rate for Power 4-Wheelers[2], but what would be the effect of these solutions on the dynamic behavior of PTW in an accident situation?

Several studies carried out on the subject. *Green et al* [8] compared the decelerations of PTW on different systems: standard braking, with ABS, with ABS and CBS. They have shown that ABS and CBS systems gain 5 to 10% in braking distance compared to a standard system. *Kumaresh a al* [24] evaluated the benefits of ABS in real PTW crashes using an analytical method, which is based on the calculation and comparison of crash speeds with and without ABS. They determined that ABS was 57% effective in a sample of crash cases in Indonesia. *Ondruš & al*[25] and *Vavrynet & al* [26] conducted a study to evaluate the impact of ABS on the experience of motorcyclists by comparing their decelerations and braking distances. Their results show that novice riders achieve higher decelerations with an ABS-equipped system, in contrast to experienced riders where ABS has no effect. *Hoffmann et al* [27] developed a method to compare braking systems with and without ABS in real accident situations. The core of this method based on the choice of deceleration values as well as the times gained on each braking device; these times have been chosen randomly which makes the method less meaningful. *Kato & al*[28], *Anderson et al*[29], compared different decelerations obtained by multiple braking systems, and this by performing track tests. *Kato & al* showed that braking with ABS offers higher decelerations compared to a standard system (for a slip coefficient of 0.8: Braking with the lever = 8.7m/s², braking with the pedal ≈ 9 m/s²). The tests of *Anderson & al* give in turn values of decelerations with an ABS system varies between 5.9 and 7.8 m/s². *Teoh & al* [30], compared different insurance data, which presented crash frequencies of PTW with and without ABS. The fatal accident involvement rate of motorcycles in the study equipped with ABS was 37% lower than that of motorcycles not equipped with ABS. *Sevarin & al* [31], *Lich & al* [32] have evaluated the benefits of cornering ABS (called Motorcycle Stability Contol) using a numerical approach. This approach based on the calculation of a maximum deceleration allowed by the MSC, and then it used to calculate a new final speed of the motorcycle and to deduce the new consequences of the accident. The results presented by *Sevarin* show that cornering ABS or MSC could have prevented 57% of real accident scenarios in Australia, and *Lich* results show an effectiveness of 32% on a German accident database. *Savino & al* [33] quantitatively evaluated the potential benefits of MAEB (Motorcycle Autonomous Emergency Braking) on real accident scenarios extracted from the "Swedish tansport Agency 2013" database. The accident reconstruction was done using the PreScan numerical tool, and the dynamic behavior of the PTW is obtained using a multi-body model generated by BikeSim[34]. An experimental design was built for each case to analyze the effect of several parameters selected by the author (lateral position on the road - Initial speed of the PTW - Reaction time of the driver), the response chosen for this design is the impact speed which is directly related to the dissipated energy and injuries. The results presented by the author conclude that automatic emergency braking was initiated in 5 of the 7 selected cases. The 2 cases where AEB did not activate were due to evasive maneuvers initiated by the driver. The author shows in this study that AEB can reduce the impact speed up to 4m/s. *Naude & al* [20] have conducted a study to determine the effect of PCB (Pre-crash braking) on the impact speed of PTW, by analyzing real accident cases on different databases. The developed method consists in testing several configurations of parameters (deceleration, detection distance, vision angle, triggering) of the PCB according to optimistic, average and pessimistic scenarios, and then analyzing the obtained results with respect to the impact speed. The results presented by the authors show that on the 3 defined configurations (Optimistic - Average - Pessimistic) the PCB allows a reduction of impact speed of 11.6 km/h, 7.4 km/h and 0 km/h respectively. *Terranova & al* [35] conducted a study to compare the applicability of 5 active safety systems (ABS, MAEB, collision warning, curve warning and curve assist) for PTW in Australia, Italy and the USA, using different databases of real crash situations. The method developed by the authors is to use the crash factors to determine which technologies are potentially applicable and can have an effect on crash consequences. *Terranova & al* find that ABS and collision warning are the most applicable technologies in the analyzed databases.

Given that the presented studies are interesting, but they do not deal with the various ARAS dedicated to PTW. Therefore, the analysis of other technologies that are not well studied on real accident scenarios, allows to enlarge the number of analyzed ARAS and to make a better selection of technologies to integrate on PTW to improve their safety.

Based on this problem, and taking into account the study already done on the theoretical effectiveness of all ARAS [36] , we conducted a study to analyze and evaluate the effectiveness of 3 other technologies (Active Cruise Control, Motorcycle Stability Control, Collision Aversion technology), based on the accidentality of this means of transport.

2. Materials and Methods

In order to deal with the effect of each technology on real accident situations, we have developed three different methods which will be explained in this chapter (see 2.2 - 2.3 - 2.4). The analyzed accidents extracted from the EDA database (Detailed Accident Study see 2.1) available at the LMA (Accident Mechanisms Laboratory).

2.1. Detailed Accident Studies (Les Études Détaillées d'Accidents - EDA)

Created since the 1980s by the Accident Mechanisms Department of National Institute for Transport and Safety Research (INRETS). The methodology based on the collection of detailed data in real time at the scene of the accident, in order to determine its causes, factors and consequences. The objective is to study the dysfunction of different accident situations[37]. In contrast to police reports, which intended to provide information about the responsibility for the accident, or for the establishment of national statistics by governmental bodies, the EDA tries to understand and explain the course of the accident, while identifying the psychological behavior of the driver, and vehicle dynamics.

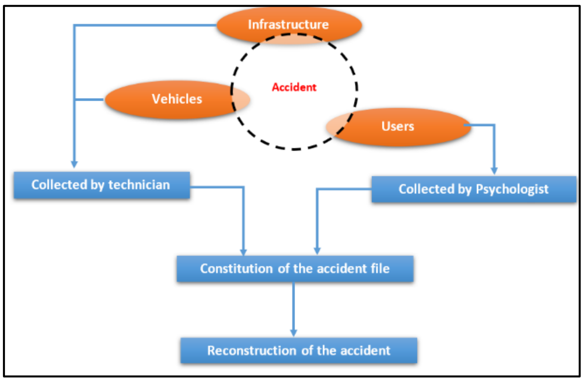

Diagram 1. EDA Methodology [5]

2.2. Collision Aversion technology

On the first technology, we have analyzed the detectability of the vehicles involved in relation to the motorcycle, below the hypothesis and the objective traced this part.

- Assumption :

- The cameras implemented on the device allow monitoring the surroundings of the motorcycle in 360°.

- Objective :

- Determine an optimal detection distance interval, by analyzing the position of the vehicles involved at different time intervals before the impact in each accident.

➢ Filtering of cases EDA :

The EDA database consists of 210 PTW cases. From this database, we removed all the motorcycle-only (loss of control) cases, which gave us a new list of 172 cases. This list filtered according to the data of each accident to check the possibility of kinematic reconstruction, and this gave the final list analyzed for this technology, which consists of 85 cases.

➢ Method :

Each accident case was kinematically reconstructed in order to have the space-time continuum of the motorcycle and the obstacle vehicles during the accident and this until 5s before the impact. Then the positions of the motorcycle and the obstacle vehicle were defined starting from the instant of the impact (t=0s) until their positions (at t = -5s) with an increment of 0.5s. To do this, the distance and the angle of the obstacle vehicles recorded at each instant with respect to the motorcycle position (diagram 2).

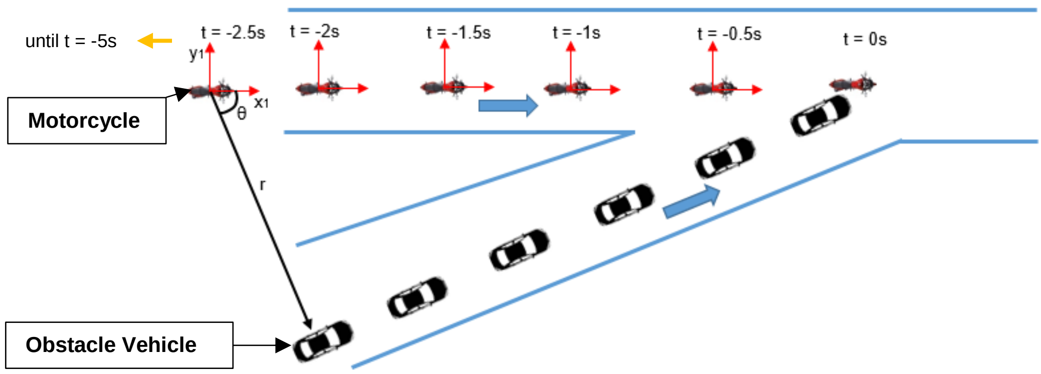

Diagram 2. CAT Methodology

2.3. Motorcycle Stability Control

➢ Assumptions :

- New consequences of each accident can be estimate from the determination of a maximum deceleration allowed by the MSC, depending on the angle of inclination and the adhesion coefficient.

- The braking distance is equal to the distance measured at the scene of the accident if it exists; otherwise, it is equal to the distance between the beginning of the curve and the beginning of the fall / Collision / Lane departure.

- ABS is no longer effective in curves from an angle of inclination $\alpha > 20°$ [32]

➢ Objective: Evaluate the effect of the MSC on the database of EDA.

➢ Filtering of cases EDA :

Starting from the database of the EDA (210 cases), we extracted all the accidents of PTW in curves that were caused by loss of control and/or lack of braking. This gave us a new list of 27 cases that we analyzed.

➢ Method :

The method used to determine the effect of MSC on the EDA accident database is the same one developed in the previous studies *Sevarin & al* [31], *Lich & al* [32]. It based on the calculation of a maximum deceleration using the traction circle.

1. Calculation of the angle of inclination (α) using the initial speed (V_i) and the radius of curvature (r):

$$\alpha = \arctan(\frac{V_i^2}{g*r}) \qquad (1)$$

2. Calculation of the maximum deceleration (a_{max}) using the force circle:

$$a_{max} = \sqrt{(g.\mu)^2 - [g.\tan(\alpha)]^2} \qquad (2)$$

3. Calculation of the new collision speed V_f' taking into account the maximum deceleration calculated in step 2 and the braking distance measured at the accident site (d):

$$V_f' = \sqrt{V_i^2 - (2.d.a_{max})} \qquad (3)$$

4. Estimated results:

$$V_f' = 0 => Accident\ avoided$$

$$V_f' \neq 0 :$$
$$\alpha < 20° => Accident\ avoided\ by\ standard\ ABS$$

$$V_f' < V_f => Accident\ Mitigated$$

V_f': *New calculated impact speed of the motorcycle*
V_f: *The original impact speed*

2.4. Active Cruise Control (ACC)

In order to analyze the influence of the latest technology (Active Cruise Control) on the dynamics and the accident rate of PTW, we based on the only existing version developed by BMW [14]. This device already presented in the introduction is composed of 3 variable detection distances (Short - Medium - Long) and 2 deceleration modes (Comfortable - Dynamic).

Due to the lack of technical information on how to calculate different distance levels (i.e. SHORT - MEDIUM - LONG), we have oriented this study to the analysis of fixed distance levels (10 - 20 - 30 - 40 - 50 meters). This is in order to evaluate the effectiveness of this technology according to several levels, and to define an optimal Detection Distance (DD).

Furthermore, the difficulty with active ARAS is not to surprise the motorcyclist. Indeed, on a PTW, unlike a P4W, there is a notion of balance that the driver must manage. During acceleration or deceleration caused by the ARAS, if the driver surprised by a strong change in speed, his posture and weight distribution will not be adapted to such a maneuver and this becomes very dangerous for the user.

It is therefore necessary not to act abruptly on the vehicle dynamics. The purpose of ACC is primarily to ensure the safety of the driver, so too much braking by ACC would compromise our objectives.

As already indicated in the definition of the system, the BMW device includes 2 deceleration modes: a "comfortable" mode, and a "dynamic" mode.

Due to the lack of numerical data on the deceleration values of the 2 different modes, and given that strong braking on dry ground is about -8 m/s² on the one hand. Moreover the most accepted emergency braking technology is -5m/s² [38], on the other hand. An assumption has been made to attribute a deceleration of -5 m/s² for dynamic braking and -3 m/s² for comfortable braking.

- Assumptions :

  - When the ACC brakes before the motorcyclist perceives the obstacle, the motorcyclist's reaction time considered to start at the moment of ACC braking and not at the same moment as in the real accident.

  - When the ACC brakes after the perception of the obstacle by the motorcyclist, it is considered that the duration of ACC activity ends at the moment when the motorcyclist brakes in the real accident (thus the ACC does not activate if the driver brakes before the ACC, which is logical since the driver's braking takes priority over the ACC).

  - We begin our reconstruction of this new accident by placing ourselves directly at the DD.

- Objective: To determine the influence of an ACC system on the accident rate of PTW and this with a fixed DD setting mode.

- Filtering of cases EDA :

Based on the requirements of the device developed by BMW, namely:

- Frontal-rear impact.

- Vehicle obstacle in motion.

Moreover, after filtering the cases from the list of accidents available in the LMA, we found that only 4 cases can meet these requirements. Nevertheless, we can extend this list by imagining a device able to detect immobile objects and to operate on front-lateral situations; this gives us a new list of accidents detailed below.

<table>
<tr><th colspan="2">Situation</th><th>Number of accident</th></tr>
<tr><td rowspan="2">Frontal-rear impact</td><td>Mobile vehicles</td><td>4</td></tr>
<tr><td>Vehicle / obstacle not moving</td><td>8</td></tr>
<tr><td colspan="2">Frontal-lateral impact</td><td>18</td></tr>
<tr><td colspan="2">Total</td><td>30</td></tr>
</table>

Note: The results presented detailed according to each situation.

- Method :

The method developed to evaluate the efficiency of the ACC based on the principle of discrete modeling, (the result of a step calculated according to the result of the previous step). Diagram 3 illustrates the different steps.

- 1st step: We look for the presumed moment of the impact, i.e. the moment when the positions of the vehicles coincide, and this from the initial parameters of the motorcycle and the obstacle vehicle (speed and deceleration).

- 2nd step: The final speed of the obstacle vehicle was calculated from :
  - The presumed impact time calculated in step 1,
  - The initial parameters of the obstacle vehicle (initial speed and deceleration).

- 3rd step: From the final speed of the obstacle vehicle calculated previously, this step is dedicated to the research of the distance covered by the obstacle vehicle as an intermediate parameter.

- Step 4: Here the data calculated in the previous 3 steps were used to obtain the final speed of the PTW by disjunction of the cases.

First, let's see if the obstacle vehicle is in motion, i.e., if $vf_2 \neq 0$. If this is the case, we look to see if the final speed of the motorcycle is positive, if it is not, so $vf_1 = 0$. (Because this would mean that, the vehicles are colliding as they back up when we want them to stop when their speed is zero).

Now, if the obstacle vehicle stopped at the time of the impact ($vf_2 = 0$). We look if this vehicle comes in the opposite direction (we look at the sign of v_0). Then we look again if the final speed of the motorcycle is positive by going through the formula: $v_f^2 - v_i^2 = 2ax$ (here we cannot go through the time because the presumed impact instant is wrong; it calculated as if the obstacle vehicle was going backwards). If this is not the case then $vf_1 = 0$, because the braking is too strong to travel the distance and hit the obstacle vehicle (resulting in a negative root which produces an error)

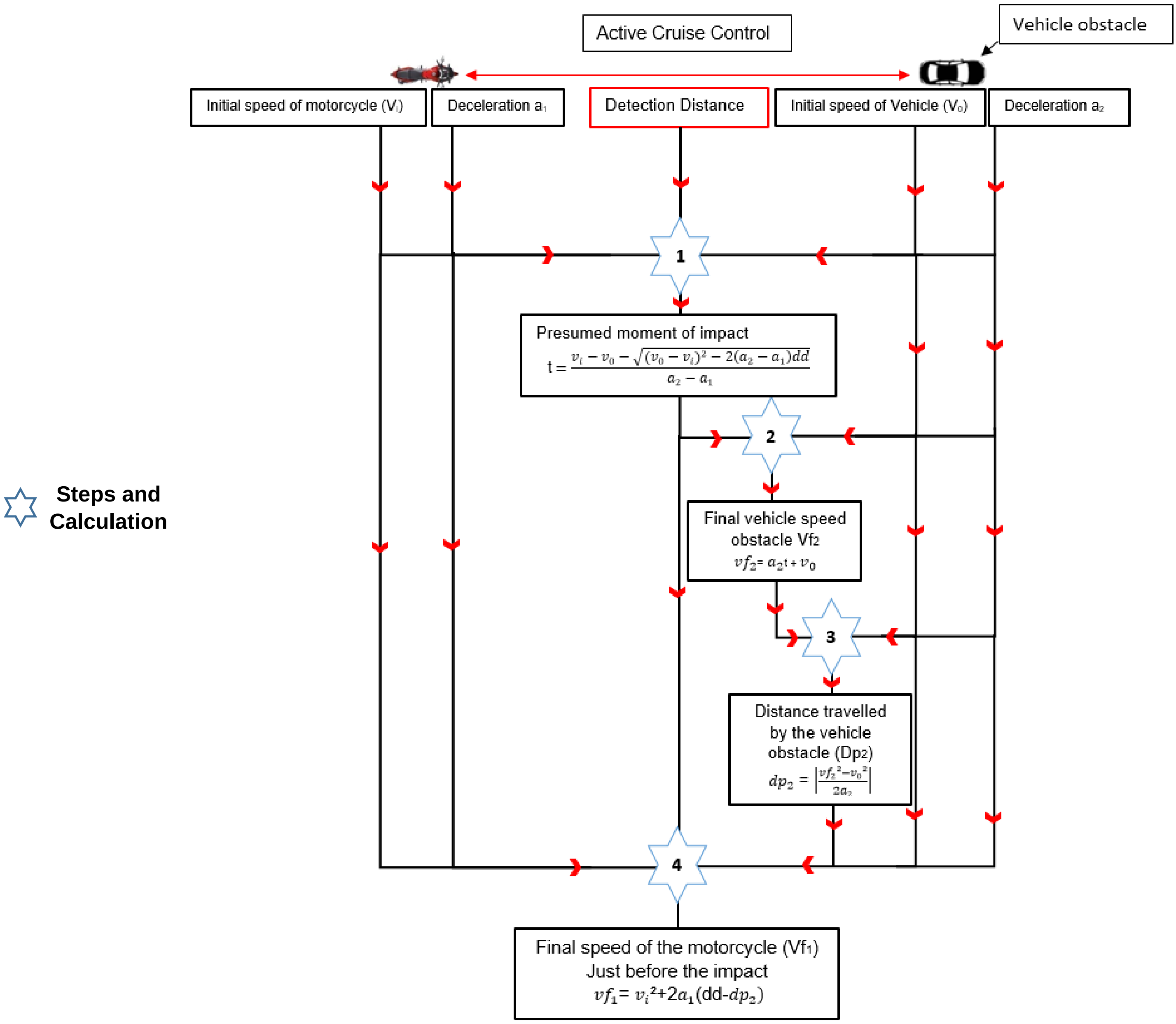

Diagram 4. Evaluation method of ACC

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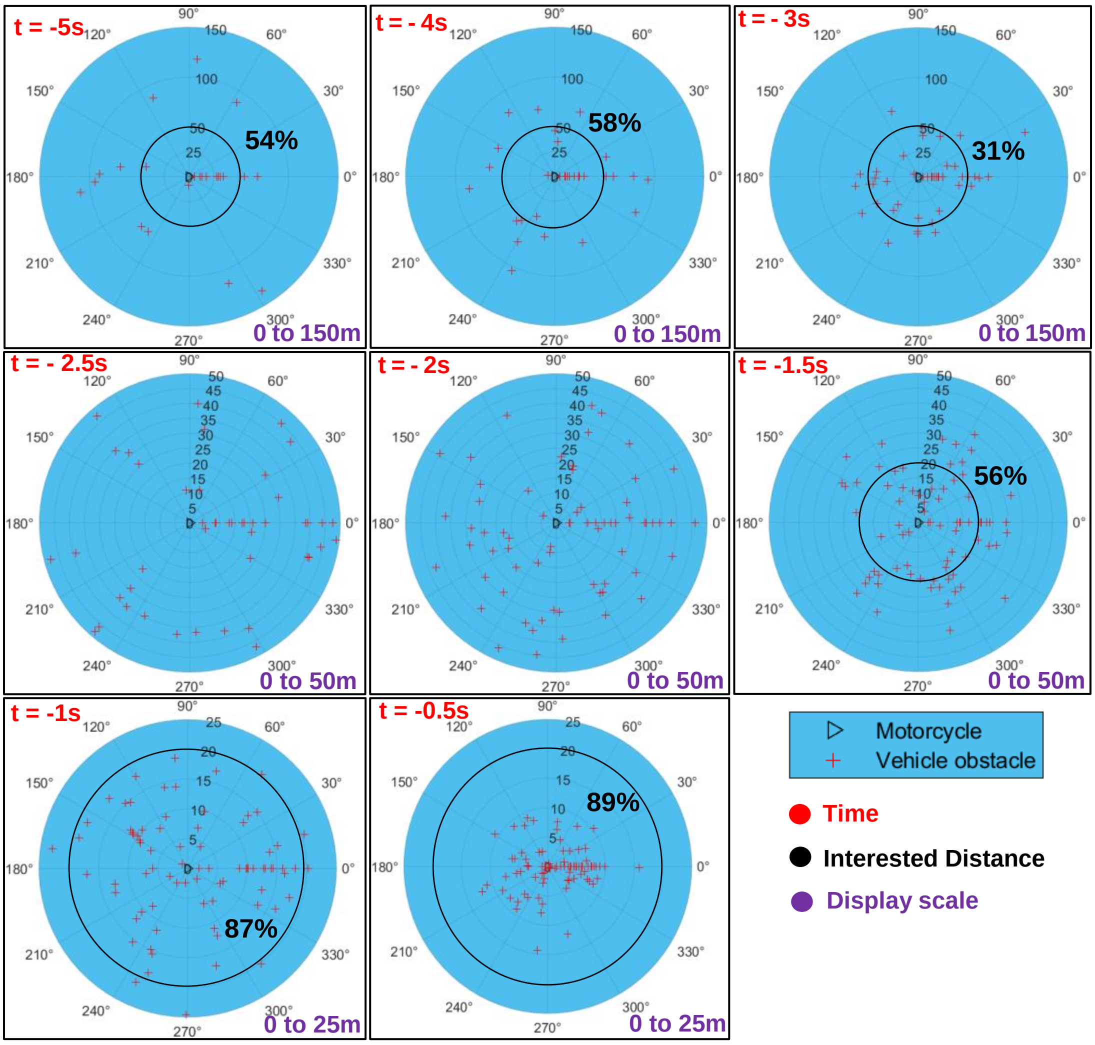
3. Results and interpretation

Following the analyses carried out according to the methods described for each technology, several results obtained and which presented below according to each ARAS:

3.1. Collision Aversion Technology

CAT technology is very beneficial for improving the safety of PTW users, as it allows the detection of other vehicles approaching the motorcycle and warns the motorcyclist to take evasive action or to brake, thus avoiding a collision or accident. To this end, the correct choice of the detection distance allows to perfect this ARAS based on the principle of the shortest and safest detection distance.



Graph 1. Variation of the number of cases as a function of time with respect to the distance between motorcycle and other vehicles

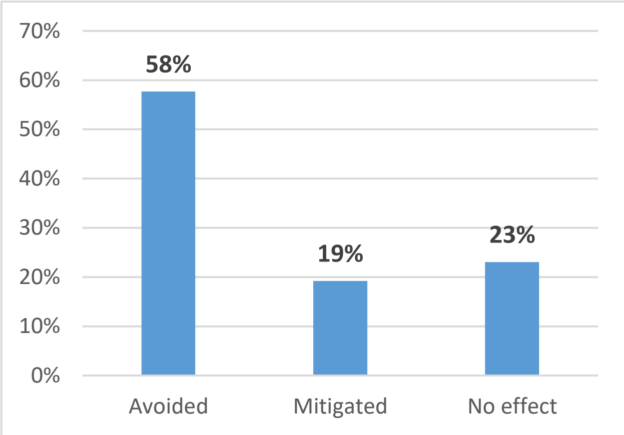
The graph above shows us the variation of the number of cases as function of time and with respect the distance between the motorcycle and the vehicles involved on the 85 cases treated. By analyzing this graph, we notice that starting from 5s before the collision until 3s, the distance between the motorcycle and the other vehicles was higher than 50m for the majority of the cases (i.e. 54% in 5s - 58% in 4s and 31% ins 3s). Moreover, and by going further in the decomposition of the graph we also find that until 1.5s before impact, the distance was greater than 20m on most cases (i.e. 56%). These large values of distances on very short durations before the impact show us the high degree of the speed at which the vehicles are driving on the analyzed accidents, and what reflects the same case for the majority of the PTW drivers.

Furthermore, this graph also indicates that it was necessary to wait until 1s before the collision to see small distances between the vehicles (lower than 20m), and that on the majority of the cases (that is to say then 87%). Finally, at the instant of 0.5s before the collision we observe that almost all the vehicles involved are at a distance lower than 10m (89%).

Following the results presented, a detection distance of 15m to 20m seems to us more adequate for a collision detection system. This related to the reaction time of the PTW drivers estimated between [0.8-1] s, and to allow them to perform an avoidance maneuver in order to avoid the accident or to mitigate the impact.

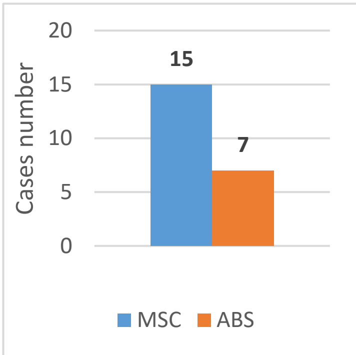
3.2. Motorcycle Stability Control

The obtained results show that the Motorcycle Stability Control has an influence of 77% on the 26 cases, that is to say 20 cases, this influence varies between avoidance and mitigation. We find that on 58% of the treated accident cases, that is to say 19 cases, the MSC could have avoided the incident. Furthermore, it is noted that on 19% of the sample, i.e. 5 cases, this ARAS could have mitigated the impact. Finally, the analyses also show that in 23% of the accidents treated, i.e. 6 cases, the Motorcycle Stability Control would have no effect on the accident. This can be explained on the one hand by the risk-taking and exorbitant speeding of some PTW drivers, and on the other hand by the vulnerability of this type of means of transport which, despite the multiple ARAS developed or to be developed, motorcyclists do not escape the accident and its consequences.



Graph 2. Frequency of MSC intervention according to the consequences

Another interesting result is the comparison between ABS (Antilock Breaking System) and MSC (Motorcycle Stability Control) according to the presented method, and this on the 15 avoided cases of the analyzed sample. The graph below shows us that the MSC can intervene on the 15 avoided cases, while the ABS can intervene only on 7 cases. This describes the efficiency of the MSC which represents 2 times more avoided cases than an ABS on situations of loss of control or lack/absence of braking in curve. This efficiency is due to the improvements integrated in the ABS for the development of an MSC. Taking into account the roll angle to adapt the braking pressure on both wheels, the scope of the ABS technology has been extended to cornering situations.



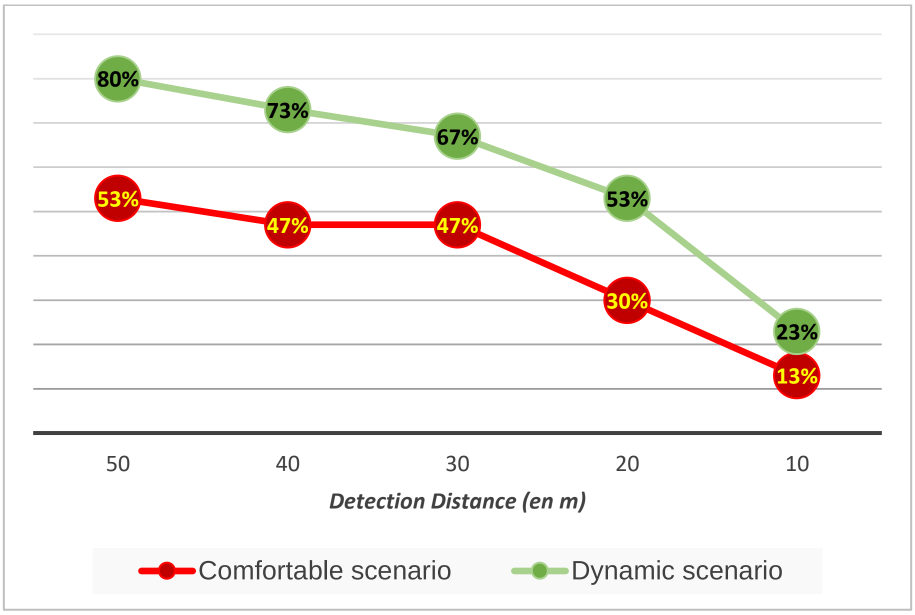
Graph 3. Avoided accidents comparison between ABS and MSC

3.3. Active Cruise Control

In order to evaluate the ACC and estimate these effects on the sample of 30 treated accident cases, three classes of benefits then formed:

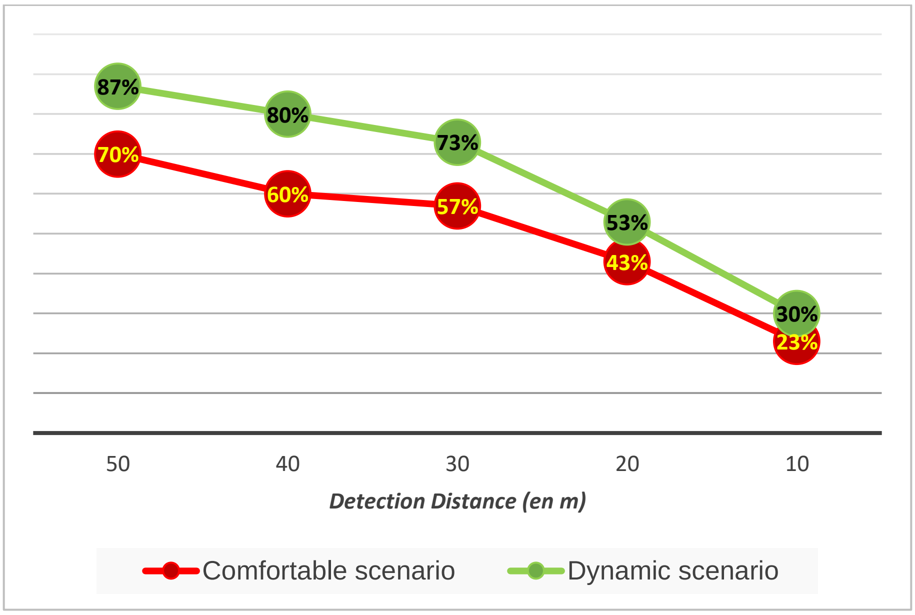
- Avoided: Accident avoided.
- Mitigated : Collision unavoidable but ARAS could have mitigated the impact
- No effect.

The obtained results from the analyses carried out according to the mentioned methodology presented below.



Graph 4. Percentage of impact avoided as a function of DD

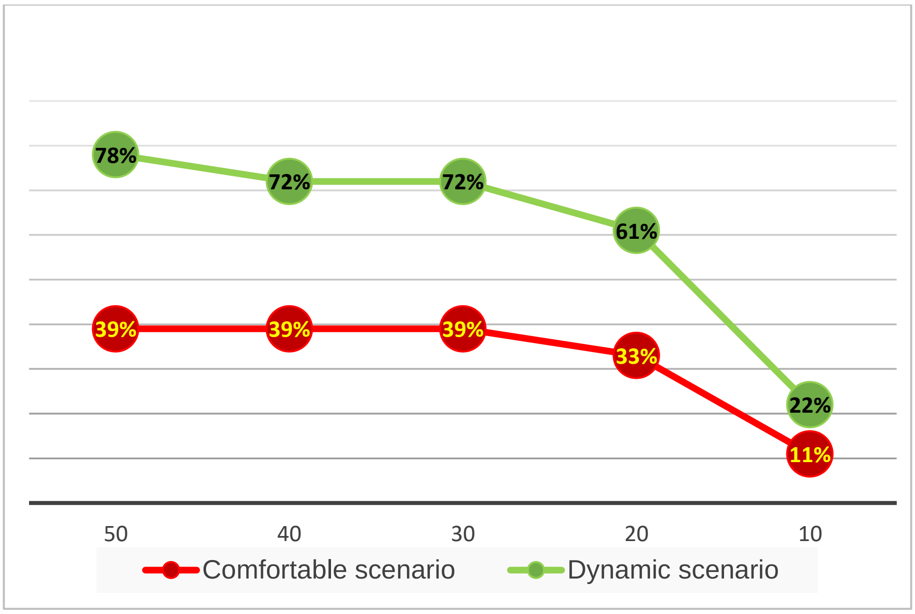
Graph 4 shows the percentage of crashes avoided on the 30 cases according to the triggering distance. We notice that the ACC offers a remarkable efficiency in terms of avoided accidents, where we can see clearly that on a dynamic scenario and from a distance of 20m, more than 50% of the treated accidents avoided. On the other hand, even in a comfortable scenario (with low deceleration) we can see that from a distance of 30m, the frequency of avoided cases is about 50%. We also notice that there are 4 cases (13%) very easily avoidable even in unfavorable situation (avoided with a DD at 10m and a comfortable braking).



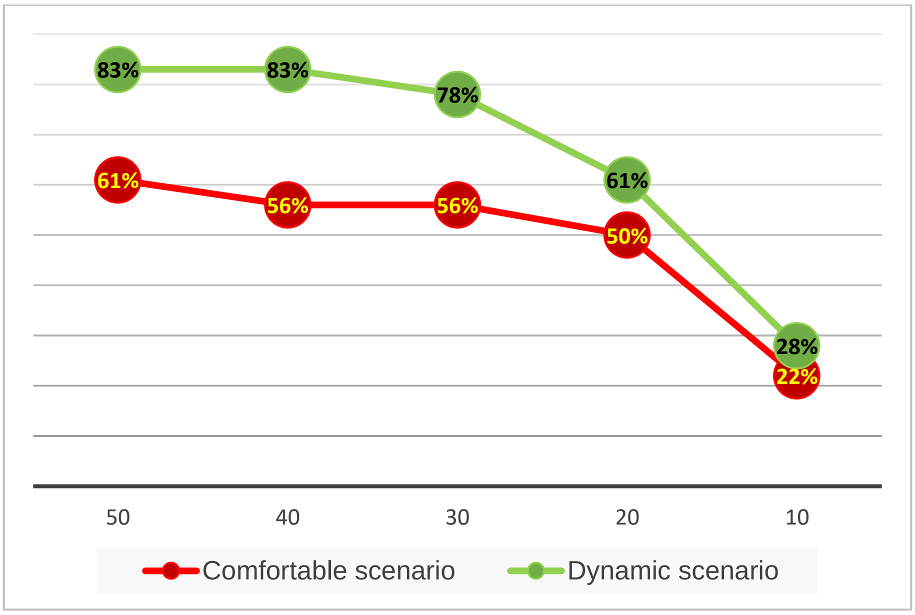
Graph 5. Percentage of impact avoided or reduced by more than 50% depending on the DD

Graph 5 establishes the percentage of impact avoided and reduced by more than 50% as function of speed impact, on the 30 cases according to the triggering distance, still distinguishing the two scenarios. This time we can see a significant increase in the number of cases in a comfortable mode compared to a dynamic mode, where at 50m for example we go from 53% to 70% while on the other side we go from 80% to 87%.

On the two previous graph, a distance seems to stand out. Indeed, on the two graphs we notice that from 30 m, we have less gain of avoided or strongly reduced impact.



Graph 6. Percentage of impact avoided as a function of the DD (frontal-lateral impact).



Graph 7. Percentage of impact avoided or reduced by more than 50% depending on the DD (frontal-lateral impact).

We reproduce the same graphs but this time selecting only the frontal-lateral impacts. The same remarks can easily visualized on the graphs 6 and 7 compared to the previous graphs, according to the level of efficiency of each scenario, and the frequencies of variation of this efficiency while adding the attenuated impacts. Moreover, graphs 6 and 7 show us a possible enlargement field of the BMW ACC, and that to cover the situations of accidents in frontal-lateral impact. Finally, we find that a distance around 20m seems to be optimal, because it represents a tipping point of the slope of the different curves.

Conclusion

This study quantitatively evaluated the effectiveness of three driver assistance systems developed for PTW, namely “Collision Aversion technology”, “Motorcycle Stability control”, and “Active Cruise Control”.

Different methods developed to determine the influence of these technologies on the accidentality of PTW, by following the functioning of each ARAS. In a first step, the EDA database (Detailed Accident Study, which consists of 210 cases) available in the LMA (Accident Mechanisms Laboratory) was filtered according to the requirements of each technology, in order to select the case samples to be treated. The first method intended to estimate the effectiveness of the CAT; it based on the detectability of the obstacle vehicles. This method consists in kinematically reconstructing the accident in order to have the space-time continuum of the motorcycle and the obstacle vehicles at each instant. Then the distance and angle of the obstacles vehicles recorded in order to follow the variation of their positions as a function of time with respect to the motorcycle. Furthermore, the effect of the MSC analyzed by following a numerical method already developed in previous studies. This one based on the calculation of a maximum deceleration allowed by the system, and then the determination of the new consequences of each accident with this new deceleration. The last method developed was to analyze the effectiveness of the ACC, and this based on the only device developed by BMW. It based on the principle of discrete modeling, (the result of a step calculated according to the result of the previous step).

Different results obtained from the analyses carried out. On the CAT device, we notice that at 3s before the impact, most of the cases were at a distance higher than 50m, and we had to wait until 1.5s before the impact to see this distance lower than 20m on the majority of the cases. Therefore, a detection distance of 15 to 20m seems to us more optimal to offer a sufficient reaction time to the motorcyclist, so that he can perform an avoidance or braking maneuver. The analysis carried out on the MSC shows us that this technology has an influence of 77% on the accidents treated; this influence varies between avoidance and mitigation. We find that 58% of the treated accidents could avoided, and that on 19% of the treated cases the impact could mitigated. This study also allowed us to compare ABS (Antilock Braking System) and MSC (Motorcycle Stability Control). It allowed us to conclude that the MSC can intervene in 58% of the cases avoided, while the ABS can only intervene in 27% of the cases. This describes the effectiveness of MSC that represents 2 times more cases avoided than ABS on situations of loss of control or lack/absence of braking in curves. The last result shows us that ACC offers a remarkable efficiency in terms of avoided accidents, where we can clearly see that in a dynamic scenario, we manage to avoid more than 50% of the treated accidents. On these results, a distance seems to stand out. Indeed, we notice that from 30 m, we have less gain of avoided or strongly reduced impact. Moreover, we can see a possible expansion of the BMW ACC, to cover the situations of accidents in front-lateral impact.

Future studies will focus on the numerical modeling of these ARAS, in order to develop a complete multi-body accident reconstruction model for PTW, allowing a dynamic evaluation of the gains in terms of road safety by using these technologies.

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Swappable Battery Stations to boost Electric Motorcycles

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1 Background & Motivation

With the amount of people living in urban areas constantly growing, the challenge of improving air quality and reducing carbon emissions becomes more and more prominent. In this context, the European Commission launched the European Green Deal, with ambitious objectives for the transport sector to reduce greenhouse emissions. Same approaches are starting in other regions too, namely in India or Japan

A widely accepted solution to achieve these targets is the electrification of vehicles.
With this perspective, the motorcycle industry is bringing together all key stakeholders to develop a common technology to boost electric mobility worldwide.

The motorcycle industry clearly understands that electromobility will play a key role in the future transport of people and goods.
By working together on common battery specifications, this will allow and enable the introduction of swappable battery stations in an efficient way.
Swappable batteries allow riders to exchange their vehicle's batteries at battery stations for fully charged ones. Instead of a full tank of gas, the clients get a fresh battery.
And those batteries are swappable, exchangeable with any SBMC vehicle of the consortium members, which represent a big share of todays 2-wheeler L-cat producers

Swappable battery technology will drastically shorten charging time, delete range anxiety, and reduce costs for the final users.
Moreover, it will facilitate the re-use and re-purpose of batteries for a second life, according to a circular economy approach.

The Swappable Batteries Motorcycle Consortium (SBMC) turns the global challenge of urban mobility and its green transition into a unique opportunity. As the reference organisation in that area, the SBMC accelerates the deployment of Swappable Batteries to L-Vehicles and beyond: we provide a global ground for industrial players along the L-Vehicle electrification value chain to harmonize the framework of this deployment and pave the way to an environmentally viable and user-friendly urban mobility.

In order to do so, the SBMC has following Targets/Approach

1 Core requirements

1. Suitable for different vehicle categories and usages:
    - L1e-B, L2e, L3e-A1/A2, L5e, L6e, L7e → Drivetrain power up to 11kWnom (~20kWp)
    - Commuting, sport, light off-road
    - Worldwide usage
2. Portable battery: Weight below 12kg, battery energy up to 2000Wh
3. Battery within voltage Class A limits: Safety against electrical shock while maintaining cost efficiency
4. Vehicle usage with single or multiple battery connection possible max 2 in serial and max 8 in parallel

2 Standardization scope

1. External geometries and vehicle mechanical interface
2. Connectors
3. Communication protocol with vehicle and swapping station
4. Electrical, Mechanical and Safety requirements

3 Goal's

1. Develop common technical specifications of "the battery systems"
2. Try & confirm common usage of the swapping systems
3. Make & promote the Consortium's common specifications a standard within European and International standardization bodies (de jure standard)
4. Expand the use of the Consortium's common specification to global level (de facto standard)

4 Consortium

The Swappable Batteries Motorcycle Consortium (SBMC), founded in September 2021 by KTM, Honda, Piaggio and Yamaha, has quickly grown to 21 members (and counting). Founded with the mission to accelerate the deployment of swappable battery systems by developing and promoting new common technical specifications towards global and open standardization, in its first six months, the consortium took essential steps at an incredible pace.

The current members are: AVL, Ciklo, Fivebikes, Forsee Power, Hioki, Honda, Hyba, JAMA, Kawasaki, KTM, Kymco, Niu, Piaggio, Polaris, Roki, Samsung, Sinbon, Sumitomo, Suzuki, Swobbee, Vitesco, VeNetWork, Yamaha

Do motorcyclist injuries depend on motorcycle and crash types? An analysis based on the German In-Depth Accident Study

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Abstract

To design effective injury protection for motorcycle riders, detailed knowledge is required on injuries sustained in crashes and what is causing them. Protection requirements might vary by crash and vehicle type. We aim to analyze differences in the injury spectrum for (1) riders of powered two-wheelers (PTWs) that fall before any other collision, (2) upright crashing riders of scooter type motorcycles and (3) upright crashing riders of non-scooter type motorcycles. When comparing the latter two, the influence on injury outcome of riding a scooter versus non-scooter can be quantified.

We used data from the German In-depth Accident Study (GIDAS) to look for injuries of PTW riders, classified by the Abbreviated Injury Scale (AIS) version of 2015. As injury thresholds we used at-least-moderate (AIS2+) and at-least-serious (AIS3+).

On the AIS2+ level the most commonly injured body regions were the upper extremities, lower extremities and head. We identified tibia and femur fractures to be more common for upright crashes (both groups), while injuries to the rib cage were more common in crashes where riders fall. In frontal crashes with cars, the frequency of femur fractures increased for upright scooter riders while for upright riders of other types of motorcycles pelvic ring fractures became more prominent.

On the AIS3+ level the most commonly injured body regions were the thorax, lower extremities and head. Femur fractures were proportionally much more common for the group of upright scooter crashes. Whilst not uncommon in either upright group, injuries to the thorax (rib fracture, lung injury, thoracic cavity injury) showed up with higher frequencies for falling riders.

While the same body regions are affected, and protection needs are therefore broadly similar, the identified differences might allow tailored protection to be designed. Focus on femur protection for upright scooter riders in frontal impacts and head protection for other motorcycle riders might be needed.

1. Introduction

As many as 4,188 powered two-wheeler (PTW) riders died on roads in the European Union in 2019 (European Commission, 2021a). The European statistics differentiate between: moped riders – riders of a two or three wheeled motor vehicle equipped with engine size of maximum 50 cc and maximum speed that does not exceed 45 km/h; and motorcycle riders in one of two categories – riders of a two or three wheeled motor vehicle, with engine size up to 125 cc, or maximum speed exceeding 45 km/h and riders of a two or three wheeled motor vehicle, with engine more than 125 cc (European Commission, 2021b). The distinctions can be important because of differences in vehicle mass and top speed, but also rider characteristics such as age and personal protective equipment (European Commission, 2021a). The 3,578 motorcyclist and 610 moped rider fatalities account for 16% and 3% of all road fatalities in the EU in 2019; a significant proportion (European Commission, 2021a).

US statistics for 2019 recorded 5,014 fatally injured motorcyclists, accounting for 14 percent of all traffic fatalities (National Center for Statistics and Analysis, 2021). In these statistics, motorcycles include two- and three-wheeled motor vehicles designed to transport one or two people, including motor scooters and mopeds. Motorcycles with engine size up to 50 cc accounted for a minority, 372 fatalities or 7%, of all motorcyclist fatalities (National Center for Statistics and Analysis, 2021).

Globally, it is estimated that powered two- and three-wheelers account for as many as 28% of the 1.35 million road traffic fatalities: with PTW riders making up high proportions of fatalities in Southeast Asia and high numbers in the highly populated countries India and China (WHO, 2018).

To prevent powered two- and three-wheeler rider injuries, protective solutions are sought. A detailed understanding of injury causes is required in order to develop tools and assessment methods replicating the mechanisms in laboratory settings, thus allowing effective and efficient development and evaluation of solutions to protect riders from these injuries.

Motorcyclist crashes have complex and varied kinematics encompassing a multitude of injury mechanisms. One differentiation can be the occurrence or absence of loss of control before the crash as it influences pre- and in-crash kinematics and potentially the effect of protection such as frontal airbags (Rizzi, 2016). In a recent study based on hospital data from Pakistan, single-vehicle crashes (involving impacts with the road surface) were found to be less severe than other types of crashes (fewer polytraumas and a shorter hospitalization), with significantly lower probability of abdominal and head and neck injuries (Martins et al., 2022).

A study using German In-Depth Accident Study (GIDAS) data presented an in-depth injury review and differentiated between 3 crash types: Motorcyclist crashes with cars (two-participant crashes between one PTW and one car where the injury is caused by any part of the car), objects (single-vehicle crashes where the injury is caused by a roadside object) and road surface (single-vehicle crashes where the injury is caused by the road surface) (Gidion et al., 2021). Priority injuries were identified and besides some differences seemed fairly consistent across all three groups: Fractures of the rib cage, femur fracture, tibia fracture, radius fracture, cerebrum injury, and cerebral concussion (Gidion et al., 2021).

It has been shown in tests (Berg et al., 2004) and simulations (Ballester et al., 2019) of car-to-PTW crashes that not only crash type, but also PTW type and design can influence injury outcome. In frontal ("head-on") impacts, for example, motorcycle riders experience forces between the fuel tank and the pelvis early on while scooter riders impact the rear surface of the frontal fairing with their legs first and the handlebar with the thorax before flying off (Ballester et al., 2019). This leads to different types of impacts to the affected body regions. Similarly, employing simulation methods, Bourdet et al. (2021) suggested that motorcycle riders have more impacts towards the sternum and the middle of the upper thorax while scooter riders have fewer impacts to the sternum.

Comprehensive reports on two-wheeler safety including crash data analysis and recommendations for safety interventions thankfully exist (e.g. DEKRA, 2020; Allianz, 2022). In Malaysia, a world-first NCAP rating system for motorcycles is in the making (Zulkipli et al., 2021). However, the detailed question on how injuries differ between crash and motorcycle types remains underexplored.

The objective of the current study was to analyze differences in the injury spectrum for (1) riders of powered two-wheelers (PTWs) that fall before any other collision, (2) upright crashing riders of scooter type motorcycles and (3) upright crashing riders of non-scooter type motorcycles. When comparing the latter two, the influence of scooter versus non-scooter PTW crashes on injury outcome can be seen in the observed injuries and their priorities based on proportional occurrence.

2. Data and methods

In this study data from GIDAS were used (release of January 2022), a road crash database with sampling locations in and around Dresden and Hanover, Germany. For a crash to be considered in the database at least one person needs to be injured as a consequence of it (Liers, 2018). GIDAS investigation teams are notified by the police. Therefore, for a crash to be recorded, it needs to: involve at least one injured person, occur within the shift time (two 6-hour-shifts per day), fall within the investigation areas, and be the most recent accident (in case several were reported by the police before the team can be dispatched).

2.1 Data sample

The following filters were applied to create the data sample for the subsequent analyses:

- Fully reconstructed cases (The GIDAS variable “STATUS” equals 4)
- Motorcycles of type L1e and L3e (KLASSECE is 10 or 12)
- Main rider (driver), no pillion rider (PSKZ is 31)
- Rider was wearing a helmet (or unknown helmet wearing, ZWHELM is not 2)

We analyzed AIS2+ and AIS3+ injuries of PTW riders with respect to the following three groups

- Falling/sliding – any MC: Fall before contact with another participant (KINGRP is 1) and any type of motorcycle (FZGKLASS is 40, 42, 43, 44, 45 or 46))
- Upright - Scooter: Free flight (i.e., without contact to another participant), scooping or collision without scooping (KINGRP is 2, 3 or 4) and type of motorcycle is scooter (FZGKLASS is 42)
- Upright - any other MC: Free flight (i.e., without contact to another participant), scooping or collision without scooping (KINGRP is 2, 3 or 4) and type of motorcycle is any other than scooter (FZGKLASS is 40, 43, 44, 45 or 46)

Statistics describing the sample divided in the three groups are shown in Table 1. Upright – Scooter crashes occurred more often in urban areas and at lower speeds compared to the other groups. The “travel speed” is defined as the speed in km/h before a critical situation was recognized. In the case of the primary collision it is the initial braking speed or the speed at which a rider reaction occurred; in subsequent collisions it is the coasting speed of the preceding collision.

Table 1: Descriptive statistics of the crash groups within the working sample.

	Falling/sliding – any MC	Upright – Scooter	Upright - any other MC
Number of cases	838	237	770
Number of riders	839	237	775
Number of AIS2+ injuries	1799	478	2319
Number of AIS3+ injured riders	196	56	289
Number of AIS3+ injuries	463	99	717
Split: urban/rural	67% / 33%	86% / 14%	68% / 32%
Mean rider age	37.8	39.6	34.6
Travel speed (V0)	54.9 km/h	39.9 km/h	59.5 km/h

2.2 Injury coding

For this study, injuries are grouped using the structure of the Abbreviated Injury Scale (AIS) code book. The AIS is an injury classification system issued by the Association for the Advancement of Automotive Medicine (AAAM, 2016). It lists roughly 2000 different traumata that are assigned severities from 1 to 6. Namely these severity levels are minor (AIS = 1), moderate (AIS = 2), serious (AIS = 3), severe (AIS = 4), critical (AIS = 5) and maximal (AIS = 6).

Headlines (body region) and sub-headlines (area or tissue type of respective body region) in the code book give the first two possible aggregation levels e.g., all thorax injuries (1st level) or all skeletal upper extremity injuries (2nd level). The headline structure is followed by levels of indentation with each new row/line corresponding to more descriptive information about the injury and the ability to assign an increasingly precise AIS code and injury category, e.g.,

Femur fracture

Femur shaft fracture

complex; comminuted; segmental; Winquist IV

open

The injuries could be aggregated on any of those levels (all femur fractures; all femur shaft fractures; etc.). This study made use of aggregating by the base level of indentation, in the above example namely “femur fracture”, thereby including those to the proximal or distal end of the femur, to the femoral shaft and those “NFS” (not further specified).

2.3 Analysis and presentation

Descriptive data are presented, comparing injury data among the three groups. GIDAS data were not weighted to national statistics, i.e. raw case counts are presented (as in, e.g., Gidion et al., 2021). The proportion of injured body regions within the AIS-severity distribution is highlighted for both, AIS2+ and AIS3+ injuries. Also displayed are the top five AIS2+ and top five AIS3+ injuries with their respective distribution of injury-causing parts.

3. Results

At the AIS2+ injury severity level the most commonly injured body regions were upper extremities, lower extremities and head (see Figure 1). Thorax injuries were more pronounced for falling/sliding motorcyclists than both groups of upright motorcyclists. Extremity injuries dominated at this level with lower extremity injuries occurring most frequently and being followed by upper extremity injuries in upright crashes, while it was the other way around for the upper and lower extremities in falling/sliding crashes. Injuries to the spine were more common for the non-scooter riders.

On the AIS3+ level the most commonly injured body regions were thorax, lower extremities and head. The head is more often and more severely injured for upright riders of other types of motorcycles.

Figure 1 shows the distribution of injuries per body region and by AIS severity level for the three groups in the sample and by AIS2+ (left charts) and AIS3+ (right charts).

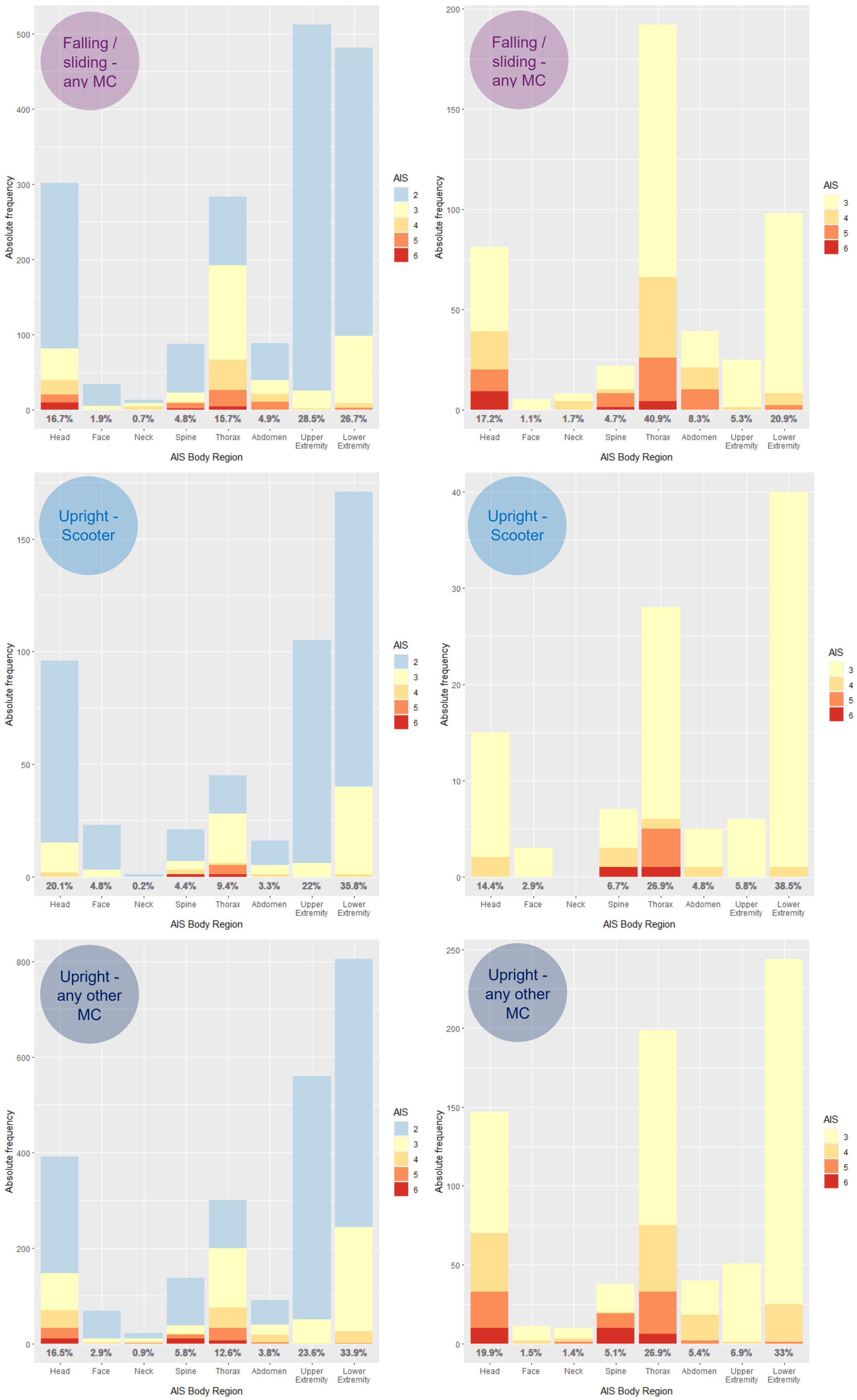

Figure 1: Injuries per body region divided into Falling/sliding – any MC (top), Upright – Scooter (middle), Upright – any other MC (bottom) as well as AIS2+ (left) and AIS3+ (right).

Looking at the most common AIS2+ injuries (Table 2), the body region trends are reflected with injuries in the thorax region, rib cage fractures, being common (top 3) for falling/sliding motorcyclists and tibia fractures (a lower extremity injury) ranking higher for the upright groups. Notably, cerebral concussion was the most frequent injury for all groups in spite of the fact that only riders with helmets were included in the study. Overall, the top 5 AIS2+ injury types were quite similar across the three crash groups, although their ranking within each group did vary to a certain degree.

The top 5 AIS 2+ injuries accounted for 31%-38% of all AIS 2+ injuries sustained in the three crash groups.

Table 2: Top 5 AIS2+ Injuries by crash group

Falling / sliding - any MC	Upright - Scooter	Upright - any other MC
1. Cerebral concussion 10.0%	1. Cerebral concussion 15.3%	1. Cerebral concussion 7.8%
2. Clavicle fracture 8.3%	2. Tibia fracture 6.3%	2. Tibia fracture 7.4%
3. [Fracture to the] rib cage 6.1%	Femur fracture 6.3%	3. Radius fracture 6.4 %
4. Radius fracture 5.5%	4. Clavicle fracture 5.9%	4. Femur fracture 5.1%
5. Tibia fracture 5.0%	5. [Fracture to the] rib cage 4.2%	5. [Fracture to the] rib cage 4.6%
	Radius fracture 4.2%	

When considering only frontal crashes of motorcyclists colliding with a car (i.e. crashes with a principal direction of force of 11, 12, and 1 o'clock for the motorcyclist where at least one injury was caused by a car), femur fractures became even more prominent for upright scooter riders, outranking tibia fractures, while for upright riders of other motorcycles, pelvic ring fractures made the top 5.

The top 5 AIS2+ injuries in the falling/sliding group were predominantly caused by contact with the road surface (46-87% of all injury causing contacts, see Figure 2). A notable fraction of radius fractures was caused by the rider's own vehicle (19%) while the share was lower for other injuries. In upright crashes, injuries more often originated from a contact with a car. Notably, only few injuries were coded as originating from the rider's own vehicle. Less than 10% of the tibia fractures were sustained from contact with the rider's own vehicle while more than half were sustained in contact with the car as crash opponent. None of the femur fracturs of upright scooter riders was coded to originate from their own vehicle.

Looking at the most common AIS3+ injuries (Table 3), femur fractures are proportionally much more common for the group of upright scooter crashes; and whilst not uncommon in either upright group, injuries to the thorax (rib fracture, lung injury, thoracic cavity injury) show up with higher frequencies for falling riders. Similarly to the results for AIS2+ injury, the top 5 AIS3+ injury types were quite similar across the crash groups, although with varying frequencies. However, the top 5 AIS3+ injuries accounted for a larger share of all AIS3+ injuries sustained in the crash groups, ranging from 52% (upright - any other MC) to 63% (upright scooters).

Table 3: Top 5 AIS3+ Injuries by crash group

Falling / sliding - any MC	Upright - Scooter	Upright - any other MC
1. Rib cage [fracture] 17.2%	1. Femur fracture 28.9%	1. Femur fracture 16.5%
2. Femur fracture 13.0%	2. Rib cage [fracture] 12.5%	2. Rib cage [fracture] 11.1%
3. [Injury to] lungs 11.3%	3. [Injury to] lungs 7.7%	3. Tibia fracture 9.3%
4. Cerebrum 7.2%	4. Tibia fracture 6.7%	4. [Injury to] lungs 8.0%
5. Thoracic cavity injury 5.7%	Skull base (basilar) fracture 6.7%	5. Base (basilar) fracture 7.2%

Compared with the AIS2+ injuries, the top 5 AIS3+ injuries were less often caused by road surface contact (Figure 2); although, road surface contact is still a major injury causation even for AIS3+ injuries in upright crashes. For the falling/sliding group roadside objects became a more prominent cause of injuries. Like for AIS2+, also the more severe (AIS3+) tibia fractures occurred much less frequently from contact with the rider's own vehicle (29% for upright scooter riders, 6% for upright other motorcyclists) than from contact with a car as crash opponent (57% for upright scooter riders, 73% for upright other motorcyclists).

AIS2
Falling / sliding - any MC
Relative frequency
100%
75%
50%
25%
0%
Category
Car
Own PTW
Roadside Object
Road Surface
Runover
Truck
Non-contact
Unkn/Oth
Cerebral concussion
Clavicle fracture
Rib Cage
Radius fracture
Tibia fracture
Top 5 Injuries
AIS3+
Falling / sliding - any MC
Relative frequency
Rib Cage
Femur fracture
Lungs
Cerebrum
Thoracic cavity injury
Top 5 Injuries
AIS2
Upright - Scooter
Cerebral concussion
Tibia fracture
Femur fracture
Clavicle fracture
Rib Cage
Top 5 Injuries
AIS3+
Upright - Scooter
Femur fracture
Rib Cage
Lungs
Tibia fracture
Base fracture
Top 5 Injuries
AIS2
Upright - any other MC
Cerebral concussion
Tibia fracture
Radius fracture
Femur fracture
Rib Cage
Top 5 Injuries
AIS3+
Upright - any other MC
Femur fracture
Rib Cage
Tibia fracture
Lungs
Base fracture
Top 5 Injuries

Figure 2: Injury causing part (color-coded by categories) for the top 5 AIS2+ and AIS3+ injuries.

4. Discussion

The current study used German in-depth crash data to investigate the injury spectrum among helmeted motorcycle drivers, depending on the crash posture and motorcycle type (scooters vs non-scooter motorcycles).

It was found that the top 5 AIS2+ injuries accounted for roughly one third of all AIS2+ injuries, while the 5 most common AIS3+ accounted for 52% (upright - any other MC) to 63% (upright scooters) of all AIS3+ injuries. This may suggest that long-term injury prevention strategies targeting AIS2+ injuries might need to be more comprehensive than strategies targeting AIS3+ injuries.

Upper extremity injuries are a priority at the level of at least 'moderate', AIS2+ injury severity. However, little is known now about how best to protect riders from these injuries. Stability improvements, such as with anti-lock braking systems (ABS), should go some way to reduce the number of falling/sliding events in general. Motorcycles are intrinsically unstable vehicles and therefore the question can be posed whether more can be done for existing PTWs with protective strategies. Wearing protective clothing has been associated with a lower risk of soft tissue injury to upper and lower limbs (Wu et al., 2019), but this protective effect was mainly due to a reduction in abrasions/lacerations rather than contusions. Those authors noted that protective clothing (gloves, jackets and boots) did not reduce the risk of fracture, dislocation, or sprain. Therefore, it may be that improvements in protective clothing are needed to enable protection against the clavicle and radius fractures which are identified as being a priority. Why we see more radius fractures for upright motorcyclists and more clavicle fractures for scooter riders may be of interest when considering the mechanism of injury for the upper extremity. As well as the PTW type, the urban/rural collision ratio and the travel speed was different between scooters and motorcycles, and it is possible that those features may also relate to the relative frequency of upper extremity fractures occurring. A clavicle fracture is rarely going to be the most serious injury in high speed and high severity crash events (Barrow et al., 2018), but it could be a relevant injury prevention focus for an urban scooter rider.

Despite being the most frequently occurring AIS3+ injury for both upright scooter and upright other MC riders, a difference in the proportion of riders sustaining a femur fracture is evident between the two groups. Proportionally more femur fractures were observed with the scooter riders. This observation may support the simulation results from Ballester et al. (2019), suggesting an initial pelvis-fuel tank force transfer in upright non-scooter riders in frontal impacts. It may be that the pelvis interaction protects the femurs to some extent at the expense of the pelvis. For that group of riders, pelvic ring injuries were notable although still outranked by femur fractures.

Lower extremity injuries, particularly femur and tibia fractures were commonly observed in all groups, as mentioned, most prominently for upright scooter riders, and consistent with the suggested kinematics of initial lower leg contact with the interior/rear surface of the front fairing. Notably though, the scooter was rarely cited as the injury source - the opponent car was. Indeed, none of the femur fractures in the upright scooter group were attributed to an injury-causing contact with the rider's own scooter. Therefore, whilst a contact between the knee or lower leg may have occurred with the scooter, we need to look elsewhere for the highest priority in lower extremity injury mitigation.

The prevalence of tibia and femur fractures linked with an opponent vehicle as being the contact causing the injury suggests that containment of the lower legs remains a promising concept (Watson, 1979). Further work would be needed to elucidate the relative merits of containment of the lower extremities so that they are shielded from external contacts; compared with the option, at least for upright scooter riders, of adding energy absorbing structures in front of the legs. This comment acknowledges the potential complexity of such countermeasures and the need for balance with desirability (and hence market feasibility) and intended versus unintended consequences (Rogers, 1994). On the other hand, there is some evidence (Hurt et al, 1981; Rizzi, 2016) suggesting that leg injuries are less common among riders of motorcycles with boxer-twin engines (a horizontally opposed flat-twin engine with cylinders overhanging horizontally in front of the riders' legs). While boxer-twin engines were not originally developed to improve motorcycle crashworthiness, such findings do suggest that more could be done to improve leg protection through vehicle design.

In agreement between all three groups within this sample is the priority of thoracic injuries (rib fractures and, at AIS3+ level, lung injuries). Based on Figure 1, AIS2+ thoracic injuries are at least as important in the falling/sliding group of crash events as for the upright groups. Furthermore, at the AIS3+ severity level, the thorax is the clear priority in the falling/sliding group. Even for the upright groups, the rib cage and lung injuries are often associated with the ground, or roadside object, contacts. This prioritization and injury-causing insight may be important information when considering the protective technologies that could best prevent such loading (keep the rider from hitting the road surface) or mitigate its severity (energy absorption that is effective beyond the first upright interaction of PTW and car).

Head injuries to motorcyclists have been cited as a priority before (by many, but for example Gidion et al. 2021) and certainly cerebral concussion is the top injury at the AIS2+, at least moderate, severity. However, head injuries with an AIS severity of 5 or 6 were completely absent from the upright scooter group. This may point towards a couple of potential explanations. Firstly, as mentioned regarding lower extremity injuries, that the first engagement of the rider and PTW is different between scooter type vehicles and other motorcycles; and that consequential movement of the scooter rider is less likely to lead to severe head injuries. Secondly that there is some confounding factor between scooter and other motorcycle crashes that influences the prevalence of the most severe head injuries.

From the descriptive statistics of the sample, Table 1, the mean speed is almost 20 km/h faster for the upright motorcycle group (approximately 60 km/h) compared with the upright scooter rider group (approximately 40 km/h). The level of polytrauma (simply calculated by dividing the number of injuries in the group by the number of riders) is also higher for any motorcycle (approximately 3 AIS2+ injuries per rider) than for the scooter group (approximately 2 AIS2+ injuries per rider). From this we can surmise that the combination of factors for motorcyclists leads to more severe interactions with the injurious structures around the rider and this affects the number of injuries and the frequency of serious and more severe head injuries. The higher speeds for the upright motorcycle crashes compared with scooter riders may exceed the protective ability offered by the helmet or place the head in conditions that exceed the design domain in some way (e.g. runover or roadside object contacts). This speculation suggests that future helmet developments (for motorcyclists, at least) may need to target cerebral concussion prevention as well as high energy impact protection, both ends of the severity spectrum.

Finally, a few limitations and recommendations for future research could be discussed. The present study used German data and included helmeted riders without pillion riders. While these data are representative for Germany and possibly for other European countries, previous studies have shown significant differences between German, Chinese and Indian crash data with regard to crash configuration, helmet use, number of pillion riders etc. (Puthan et al., 2021). It is therefore recommended to carry out similar research in other regions of the world to support the development of a global injury prevention strategy for PTW riders.

Furthermore, the present study described the injury spectrum by using a relatively straight-forward approach: grouping motorcycle crashes in three categories. While interesting results were found, we need to acknowledge that motorcycle crashes can be very complex events with several factors affecting the final injury outcome. Some of these factors were locked-in at the beginning of the analysis (helmet use, no pillion riders) but some others were not, for example, collision speed and collision partners, riding style and rider attributes. Therefore, it cannot be excluded that a more advanced statistical analysis could have been able to detect further similarities and differences between scooters and non-scooter motorcycles.

5. Conclusion

Injuries of riders of powered two-wheelers that fall before any other collision are broadly similar to those of upright crashing riders of scooter type motorcycles and upright crashing riders of non-scooter type motorcycles. The head, lower extremity and upper extremity are the most frequently AIS2+ injured body regions. The most common injuries are cerebral concussion, tibia fracture, femur fracture, clavicle fracture, radius fracture and fractures of the rib cage.

At the AIS3+ level, the head, lower extremity, and thorax are most frequently injured. Fractures to the base of the skull, cerebrum injuries, femur fracture, tibia fracture, rib cage fractures, and injuries to the lungs or thoracic cavity occur frequently.

Some differences exist: femur injuries were more frequent for upright scooter riders than for other types of motorcyclists or those falling before a collision. The majority of femur fractures originate from contact with a car.

Despite wearing helmets, powered two-wheeler riders still sustain head injuries and riders of other types of motorcycles sustain more head injuries and more severe head injuries than scooter riders.

Protection needs for the listed body regions and injuries appear therefore broadly similar. Particular focus on femur protection for upright scooter riders in frontal impacts and head protection for other motorcycle riders might be needed.

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A Theoretical and Practical Course on Motorcycle Safety

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Abstract

This work presents a course on motorcycle safety focused on preventive riding, to help minimize the number of accidents involving motorcycles, or at least lessen the gravity of their outcomes. The course is divided in a theoretical and a practical part. The theoretical part is held on the day before the practical and lasts about four hours, and the practical part takes about eight hours on the next day. The theoretical part addresses physical concepts on motorcycle geometry and balance, the functions of the different motorcycle controls, the procedures to be observed during the ride in several common daily situations, as well as information on safety and preventive riding. The practical part consists of several exercises that enhance the rider´s ability to control the motorcycle and simulate common traffic occurrences, such as slow riding, U-turns, controlled stops, emergency braking, obstacle avoidance, different types of curves, etc. The method has been applied successfully to teach both beginners and experienced riders of different motorcycle styles and sizes.

1. Introduction

Although the motorcycle industry has developed several technologies to make motorcycle riding safer, and these rider assistance systems are very important, nothing substitutes a well-trained rider when the subject is safety.

Unfortunately, many motorcycle schools are mostly concerned with training the rider to pass the driver´s license examination. As a result, many people ride with minimum skills, being exposed to accidents that risk their lives and those of other traffic participants. Even many advanced riding courses focus on practical skills and do not pay much attention to the theoretical part.

The My Way MS (Motorcycle Safety) project considers the theoretical part as important as the practical and, thus, has developed a motorcycle riding course method that focus on both theoretical concepts and practical exercises. The theoretical part addresses physical concepts on motorcycle geometry and balance, tires, traction, braking, curves, riding on different types of environments and pavements, riding with a passenger (pillion), group riding, among other topics, and gives information on safety and preventive riding, including the analysis of motorcycle accidents. The practical part consists of several exercises that enhance the rider´s ability to control the motorcycle, and simulate common traffic occurrences, such as correct positioning, the use of head and eyes, throttle and clutch control, proper wheel placement, slow riding, in-line and offset slaloms, circles, U-turns, ninety-degree pull-out and curves, controlled stops, emergency braking, obstacle avoidance, different types of curves, etc. The theoretical part takes four hours and is presented on the day prior to the practical part, which lasts one full day of riding exercises. The method has been applied successfully to teach both beginners and experienced riders of different motorcycle styles and sizes and is presented in detail and with some examples in the following sections.

2. The Concept of the Course

My Way MS offers basic to advanced training on preventive riding using its own methodology, in an exclusive area or, sometimes, in other adequate places. The concept “Preventive Riding” is used to emphasize that the rider has to take the necessary and adequate precautions and procedures to avoid going into the “Defensive Riding” stage, when he/she is already in a situation where he/she has to defend him/herself.

The course is meant to prepare the motorcyclists who already have their driver´s licenses in the Category A (valid for all types and sizes of motorcycles in Brazil) to be able to ride in any real situation on the regularly paved streets or roads. This is unfortunately not the case of the courses given by the majority of Motorcycle Schools in Brazil, that are only concerned with the preparation of the rider to pass the license test, which is very simple and, thus, does not guarantee that the rider is really able to ride safely both for him/herself, his/her possible passenger, and for the other traffic players.

Thus, the course provides the participants with technical and practical information about riding techniques applied to all types and sizes of motorcycles, aiming at the enhancement of their knowledge about motorcycling and preventive riding, with the goal of avoiding accidents and/or reduce their quantity and severity. The used techniques and exercises are internationally employed and well-proved, and range from mounting and dismounting, correct use of the center stand (if available), motorcycle lifting techniques after a drop, the correct use of head and eyes, throttle and clutch control, low speed maneuvers, controlled stop, emergency braking, among other preventive riding techniques.

The course held at the My Way MS Motorcycle Training Center (MTC) facility can be individual or, for logistical, practical and safety reasons, for up to five participants. This allows the exercises to be adapted to the ability and the needs of the riders.

The course is divided in a theoretical and a practical part. The theoretical part is held in Belém, the state capital of Pará, the day before the practical and is divided in two sessions of 100 minutes each, separated by a 30-minute interval for a coffee-break. This part is very important as a prerequisite for the practical, since it helps the rider understand why he/she is doing each specific exercise, and so he/she will do it much better and without fear. In this part, the fundamental processes behind each technique are explained, as well as how the common everyday situations can be dealt with.

For the practical part the participants are asked to arrive with a full-tanked motorcycle, with the correct tire calibration, and in good operating conditions. A poorly maintained machine is not accepted for the training. Besides, the riders must wear the minimum needed protective gear, consisting at least of full-face helmet (either fixed or retractable), full-finger riding gloves, riding boots, riding pants, and riding jacket, without which they are not allowed to take part in the course. Since the course is based on low to medium-speed maneuvers, other protective equipment or patches are optional, as well as the jacket during the training, when the temperature is very high.

The practical part starts with breakfast in a bakery just outside from Belém, that is the start point to leave for the MTC. After breakfast and a short briefing, the trip to the MTC takes place and is used by the instructor to observe the riding ability of the participants, their posture on the motorcycle, their behavior in the group riding, among other features. The instructor chooses one rider to lead the group and another to be the sweep rider, and he keeps moving alongside the group, to observe the participants and make possible corrections in the group positioning.

During the eight hours of training, short intervals are made for hydration (mineral water, fruit juices, and energy drinks) and light food (fruits, like apples and bananas, and cereal bars). After the first four hours, the participants leave for lunch in a restaurant in the nearby city of Santa Isabel do Pará, and during this short round trip the group riding training is again practiced. The MTC also provides comfort infrastructure for the participants, such as a restroom with shower. The participants also receive a throttle-grip locker, a My Way MS shirt and sticker, and a certificate of completion (Figure 2.1).

Figure 2.1 – Receiving the certificates of completion.
Source: Photograph by the author.

After the practical part, the participants are asked to anonymously fill in an evaluation form, in which they give their opinion about the several points of the course. This serves as a parameter for possible future modifications of some features of the course. The points covered in the evaluation form are as follows.

Concerning the theoretical part:

1) I found the subjects ( ) uninteresting ( ) less interesting ( ) of some interest ( ) interesting ( ) very interesting

2) The presentation content was ( ) very bad ( ) bad ( ) reasonable ( ) good ( ) very good

3) The instructor explanation was ( ) very bad ( ) bad ( ) regular ( ) good ( ) very good

4) I found the presentation duration ( ) very short ( ) short ( ) good ( ) long ( ) very long

5) The presentation helped me ( ) nothing ( ) very little ( ) somewhat ( ) a lot ( ) very much indeed

Concerning the practical part:

1) Highlight the exercise that you consider the most important, justifying why.

____

2) Same for the one you consider the least important.

____

3) Do you consider that any exercise did not contribute to your apprenticeship?

____

4) What exercise(s) would you like to be inserted in the training program?

____

5) What was the biggest difficulty you encountered in the training?

____

6) Highlight a positive point of the training.

____

7) Same to a negative point.

____

Concerning the course as a whole:

1) The used resources were ( ) very bad ( ) bad ( ) regular ( ) good ( ) very good

2) What grade would you give to the course as a whole? ( ) Bad ( ) Insufficient ( ) Regular ( ) Good ( ) Excellent

3) I would ( ) in no way ( ) not ( ) perhaps ( ) surely ( ) strongly recommend the course to other people.

Express below any other opinion you consider convenient.

____

After filling in the evaluation forms the participants are asked to vote for the rider they consider to have had the best performance during the training. Each participant receives a ballot where he/she writes two different names (a ballot with two equal names or only one name is not considered valid). The votes are then counted, and the most cited rider receives a trophy.

3. The Motorcycle Training Center

The MTC is located in the municipality of Santa Isabel do Pará, on the left side of the state road PA-140 (in the direction of the city of Vigia de Nazaré), 9.5 km after leaving the federal road BR-316, and approximately 60 km from the state capital, Belém.

The MTC consists of two parts designed to provide motorcycle training at low and medium speeds, both on- and off-road. Besides, the MTC also has other facilities for equipment storage, theoretical classes, feeding and hydration, resting room with shower, etc.

To enable the realization of the course, some materials available at the training center for the theoretical part are: a notebook connected to a large screen, some motorcycle scale models, a bicycle wheel, a broom, and a real motorcycle; and for the practical part: a toolbox with the necessary tools to make the adjustments of the motorcycle commands, rubber blankets to protect the motorcycle parts during the lifting exercise, several pieces of wood (2 by 4 inches) to be used for the throttle and clutch control exercise, small and large cones and tennis balls cut in half for the marking of the exercises, small obstacles to be runover, and a doppler radar with tripod for the braking exercises.

The on-road part has a concrete-paved area measuring 15 m x 30 m, with colored marks for the several exercises that are done during the training, and a support shed to keep the material and provide a place for resting and hydration during the training. Figure 3.1 shows some views of the on-road training area.

Figure 3.1 – Views of the on-road training area.
Source: Photographs by the author.

The paved area is painted with markings in different colors, that are used for the exercises to be done, according to the practical program of the course. Figure 3.2 shows some of these markings, with different colors for each exercise. During the training, according to the exercises to be done a set of small or large cones is put on the corresponding markings. After the group of exercises is finished, a pause is made for resting and hydration, and a new set of cones is put on the markings for the next group of exercises.

Figure 3.2 – Some of the colored markings where the cones are put according to the exercise to be done.
Source: Photographs by the author.

Figure 3.3 shows some exercises being done on the on-road training area of the MTC.

Figure 3.3 – Curves and short slalom being performed at the on-road training area.
Source: Photographs by the author.

Besides the support shed, that is shared by both training areas, the off-road space consists of two parts, with dimensions of 20 m x 80 m and 40 m x 80 m, with ground surfaces with various grips and having markings and different equipment that allow several exercises to be done, such as the ones shown in Figures 3.4 and 3.5. In addition to these areas, there are two forest trails with around one kilometer each.

Figure 3.4 – Riding through the sand and stone boxes.
Source: Photographs by the author.

Figure 3.5 – Riding over the tire tracks.
Source: Photographs by the author.

Although most of the training is made at low and medium speeds, and thus the risk of having serious accidents is very low, My Way MS has always an ambulance with mobile Intensive Care Unit (ICU) with its team of attendants (Figure 3.6) available during the whole period of the practical part of the course. Fortunately, it was never necessary to use this service.

Figure 3.6 – The ambulance with mobile ICU and its team of attendants.
Source: Photograph by the author.

Videos with examples of training courses carried out at the MTC can be seen in the YouTube channel of My Way MS, as for example in the links: https://youtu.be/0ewed65x00I, https://youtu.be/U9fgJ_IYeoA, https://youtu.be/vdamI9lxzPs, https://youtu.be/9tXH5-TX7Yc, https://youtu.be/RJeNnbyXQaU. Other videos with tips and information about motorcycle safety can also be seen in the channel.

4. The Theoretical Part

The theoretical part is held on the day prior to the practical training, either in an adequate place in Belém or in the MTC. Figure 4.1 shows the theoretical part being presented to a group of cruiser and touring bikes riders.


Figure 4.1 – The theoretical part for a group of riders of cruisers and touring motorcycles.
Source: Photograph by the author.

The theoretical program consists of fourteen topics as follows:

1. The Basics of Motorcycle Physics;
2. The Choice of the Adequate Motorcycle;
3. The Choice of Protective Riding Gear;
4. Motorcycle Controls Adjustments and Riding Posture;
5. Adequate Care with the Rider and the Passenger;
6. The Three A´s Rule;

7. The Correct use of the Motorcycle and Rider Resources;
8. Techniques of Slow Speed Maneuvers;
9. Braking Techniques;
10. Cornering Techniques;
11. Riding in the Dark, Rain, Cold, and other Adverse Conditions;
12. Preventive Riding;
13. Riding with a Passenger and Load; and
14. Group Riding.

The Basics of Motorcycle Physics is presented in about twenty minutes and addresses subjects such as the motorcycle movements (Figure 4.2), including center of mass displacement and weight shifting; static and kinetic friction (Figure 4.3); pavement types; traction; tire contact patch; aquaplaning; forces acting on a motorcycle at low, medium and high speeds, braking, and curves; motorcycle balance in slow, medium and high speeds, including gyroscopic effect, inverted pendulum, etc.; motorcycle inclination in curves; and Kamm´s Circle (Figure 4.4).

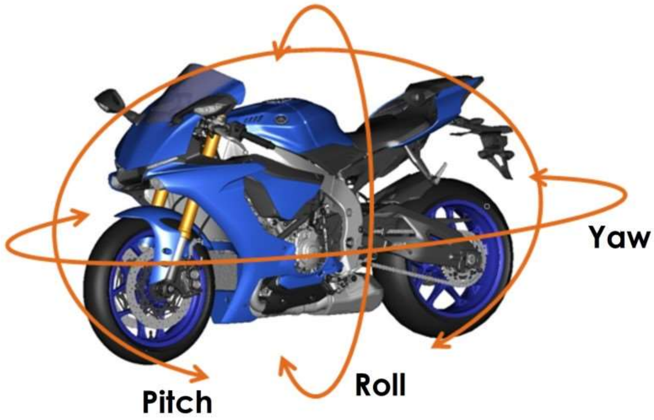

Figure 4.2 – The motorcycle movements.
Source: [Ride Review: 2015 Yamaha YZF-R1 & R1M - Asphalt & Rubber (asphaltandrubber.com)](https://asphaltandrubber.com).

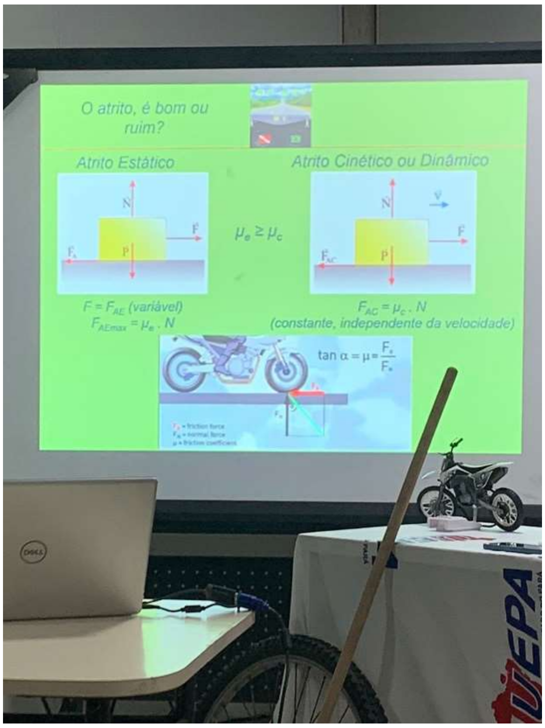

Figure 4.3 – An example of the theoretical part, with Power Point presentation, motorcycle scale model, broom, and bicycle wheel.
Source: Photograph by the author.

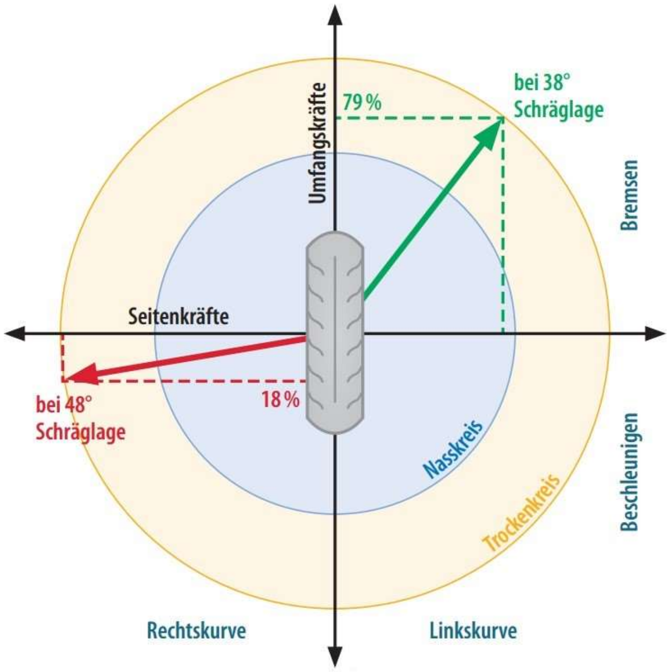

Figure 4.4 – The Kamm´s Circle.
Source: Motorrad fahren gut und sicher, IfZ Brochure, 2021, available at [Broschüren – Institut für Zweiradsicherheit (ifz.de)](ifz.de).

The presentation of the Choice of the Adequate Motorcycle takes around ten minutes and approaches the most common motorcycle types and styles, including touring, cruiser, sport/naked, standard/street, dual-purpose, enduro/trail, motocross, trial, scooter; rider size and strength; the importance of ergonomics; and motorcycle modifications.

The next ten minutes address the Choice of Protective Riding Gear, comprising helmet types, emphasizing the importance of full-face closed helmets; gloves; boots; pants; jackets; and other equipment and patches for protection of knees, elbows, spine, neck, hips, etc.

Another important feature presented is the Motorcycle Controls Adjustments and the Riding Posture, that takes nearly ten minutes, and shows the importance of adjusting all the motorcycle controlling commands (handlebar, brake and clutch levers, throttle grip, gear-shifting and brake pedals, etc.), and how the rider should position his/her body, hands, feet, and knees, to be able to use the controls correctly.

The Adequate Care with the Rider and the Passenger, that is also an important characteristic to guarantee a safe motorcycle operation, deals in ten minutes with features like health, mental state, hydration, food, drugs use, fatigue, personal limits, etc. both for rider and pillion.

In the next ten minutes the Three A´s Rule (Attention, Assessment, Action) is explained, detailing how each of these A´s must be observed by the rider.

In continuation, the Correct use of the Motorcycle and Rider Resources, for which the acronym "COFRES" (Portuguese word for Safe or Vault) is used, is detailed in twenty minutes. Each letter in the acronym stands for two resources, as follows: C – Cérebro / Cabeça (Brain / Head); O – Olhos / Ouvidos (Eyes / Ears); F – Força / Freios (Power / Brakes); R – Retrovisores / Regulagens (Rearview mirrors / Adjustments); E – Embreagem / Equipamentos (Clutch / Equipment); and S – Sinalização / Serenidade (Signaling / Serenity).

The next twenty minutes are dedicated to the explanation of the Techniques of Slow Speed Maneuvers, including motorcycle balance, counterbalancing, correct use of head and eyes, throttle and clutch control, use of the rear brake, and front wheel placement.

The explanation of Braking Techniques follows in the next twenty minutes, beginning with the description of the most common rider mistakes (not enough braking, too much braking, swerving while braking), and continuing with the importance and functions of front and rear brakes, braking assistance systems (ABS, CBS, Cornering ABS, etc.), braking in curves, trail braking, braking phases and distances, braking posture, and influencing factors.

Cornering Techniques, such as the forces acting in corners, push steering (counter steering), correct body positions (leaning, pushing, hanging-off), correct curve lines, linked curves, and the use of the Limit Point, are approached in around twenty minutes.

The recommended procedures and special cares for Riding in the Dark, Rain, Cold, and other Adverse Conditions take the next ten minutes of the theoretical part.

The concept of Preventive Riding is introduced in this course as being a set of precautions and procedures that should be taken before, during and even after the riding, to avoid the different traffic traps and dangers. Topics like lane positioning, safety distance, overtaking and being overtaken, etc. are approached in twenty minutes.

Riding with a Passenger and Load is another important topic to teach the rider what changes occur in the motorcycle handling and what adjustments should be made to account for the extra weight and weight shift, as well as to make recommendations on how the pillion should behave and what clothes and accessories should be avoided. Ten minutes are reserved for this topic.

The last ten minutes of the theoretical part are devoted to Group Riding, including the requirements for a safe and pleasant tour, the basic rules and signaling, the roles of the leader, the angel and the sweep rider, the rider formation, how overtaking should be made, and the procedures for tanking and parking.

Some of the above-mentioned topics may have their presentation times changed or even not be presented at all, depending on the knowledge level of the participants.

At the end of the theoretical part each participant receives a copy of the rules and signaling of group riding that will be used on the next day on the way to and from the MTC, as well as on the trip for lunch.

5. The Practical Part

The day of the practical part begins with a breakfast and briefing, either from 07h30 to 08h00 in the training center, or from 07h00 to 07h30 in a coffee shop near Belém. In the last case, there is a group ride of about half an hour to the training center, with the arrival at the MTC occurring at about 08h00. This group ride is used by the instructor to observe the skills of each participant.

Upon arrival at the MTC, the practical training begins and follows the program shown below, that is divided in five parts, with intervals between them to allow for the set of marking cones to be changed and to let the participants take a break for resting and hydration.

Part one:

1. Adjustment of the motorcycle commands, use of the central stand (if available), ways of mounting and dismounting, correct riding position – 30 minutes, from 08h00 to 08h30.
2. Learning the motorcycle static balance and how to lift a dropped motorcycle – 15 minutes, from 08h30 to 08h45.
3. Throttle, clutch and rear brake control – 15 minutes, from 08h45 to 09h00.
4. Learning the motorcycle balance during motion – 15 minutes, from 09h00 to 09h15.
5. Slow ride (Turtle Race) – 15 minutes, from 09h15 to 09h30.
6. One-hand control, with one hand at a time – 15 minutes, from 09h30 to 09h45.

   Interval for resting and hydration – 15 minutes, from 09h45 to 10h00.

Part two:

7. Slaloms: short (3 to 4 m), medium off-set (5 to 6 m), and long (8 to 9 m), depending on motorcycle type and rider ability level – 30 minutes, from 10h00 to 10h30.
8. Controlled stop – 30 minutes, from 10h00 to 10h30 (together with the slaloms).
9. Circles with diameters of 15 m, 11 m, 8 m, 6 m, and 5.5 m, depending on motorcycle type and rider ability level – 30 minutes, from 10h30 to 11h00.
10. Figure eight 20 x 10 m or smaller – 30 minutes, from 10h30 to 11h00 (together with the circles).
11. U-turn with 7 m width or smaller – 30 minutes, from 10h30 to 11h00 (together with the circles and figure eight).
12. 90-degree pull-out – 30 minutes, from 11h00 to 11h30.
13. 90-degree right and left turns – 30 minutes, from 11h00 to 11h30 (together with the 90-degree pull-out).
14. Off-set cone weave (Snake Trail) – 30 minutes, from 11h00 to 11h30 (together with the 90-degree pull-out and 90-degree turns).

Interval for resting and hydration – 15 minutes, from 11h30 to 11h45.

Part three:

15. Group riding to a nearby restaurant – 15 minutes, from 11h45 to 12h00.

    Lunch and rest – 60 minutes, from 12h00 to 13h00.

16. Start on a slope – 30 minutes, from 13h00 to 13h30 (including displacement from the restaurant to the place of the exercise).

17. Group Riding back to the training center – 15 minutes, from 13h30 to 13h45.

    Interval for resting and hydration – 15 minutes, from 13h45 to 14h00.

Part four:

18. Emergency braking on dry and wet pavements – 30 minutes, from 14h00 to 14h30.

19. Obstacle swerving with and without braking – 30 minutes, from 14h30 to 15h00.

20. Obstacle runover – 15 minutes, from 15h00 to 15h15.

    Interval for resting and hydration – 15 minutes, from 15h15 to 15h30.

Part five:

21. Intersection (Iron Cross) (7 m wide x 7 m long) – 30 minutes, from 15h30 to 16h00.

22. Cornering (on a 3.5-m lane and 7.5-m radius) – 30 minutes, from 16h00 to 16h30.

Closure, course evaluation, and certificates delivery – 15 minutes, from 16h30 to 16h45.

Return to Belém and observation of the participants´ skills – 45 minutes, from 16h45 to 17h30.

Some of the practical exercises may have their duration times modified or even not be done at all, depending on the knowledge and skill level of the participants.

Figures 5.1 to 5.10 show some of the above-mentioned exercises being done during the course.

Figure 5.1 – Learning the motorcycle static balance.
Source: Photograph by the author.

Figure 5.2 – Practicing motorcycle static balance.
Source: Photograph by the author.

Figure 5.3 – Practicing clutch and throttle control.
Source: Photograph by the author.

Figure 5.4 – Doing the one-hand control.
Source: Photograph by the author.

Figure 5.5 – The medium off-set slalom (left) and the running through the narrow lane (right) before the controlled stop box (blue cones).
Source: Photograph by the author.

Figure 5.6 – Performing the U-turn.
Source: Photograph by the author.

Figure 5.7 – Performing the 90-degree pull-out.
Source: Photograph by the author.

Figure 5.8 – Emergency braking on wet pavement.
Source: Photograph by the author.

Figure 5.9 – Practicing the brake-and-swerve exercise.
Source: Photograph by the author.

Figure 5.10 – Running over small obstacles.
Source: Photograph by the author.

6. The Exercise Patterns

To perform the exercises of the practical part, several patterns are marked on the paved area in different colors, each one for a specific drill. For each group of exercises, according to the program presented in the previous topic, sets of small and/or large cones, or other markers, are placed on the colored markings during the resting intervals. Most of the used patterns are internationally used by motorcycle riding schools, training programs and competitions all over the world, and many of them can be seen at http://conepatterns.com. Figures 6.1 to 6.5 show some of the patterns used in the training.

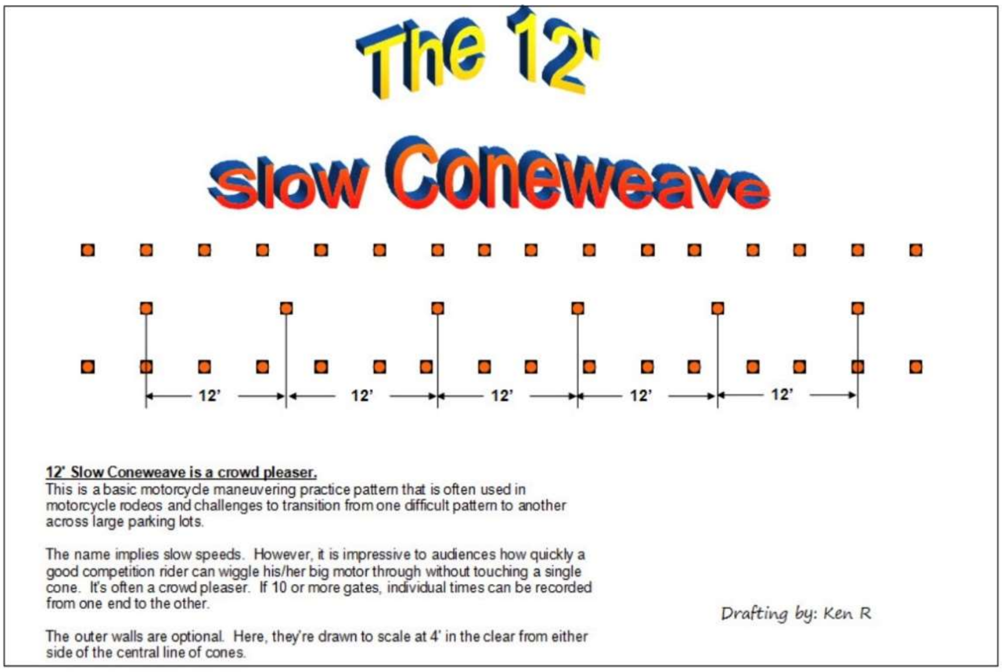

Figure 6.1 – The short slalom pattern.
Source: http://conepatterns.com.

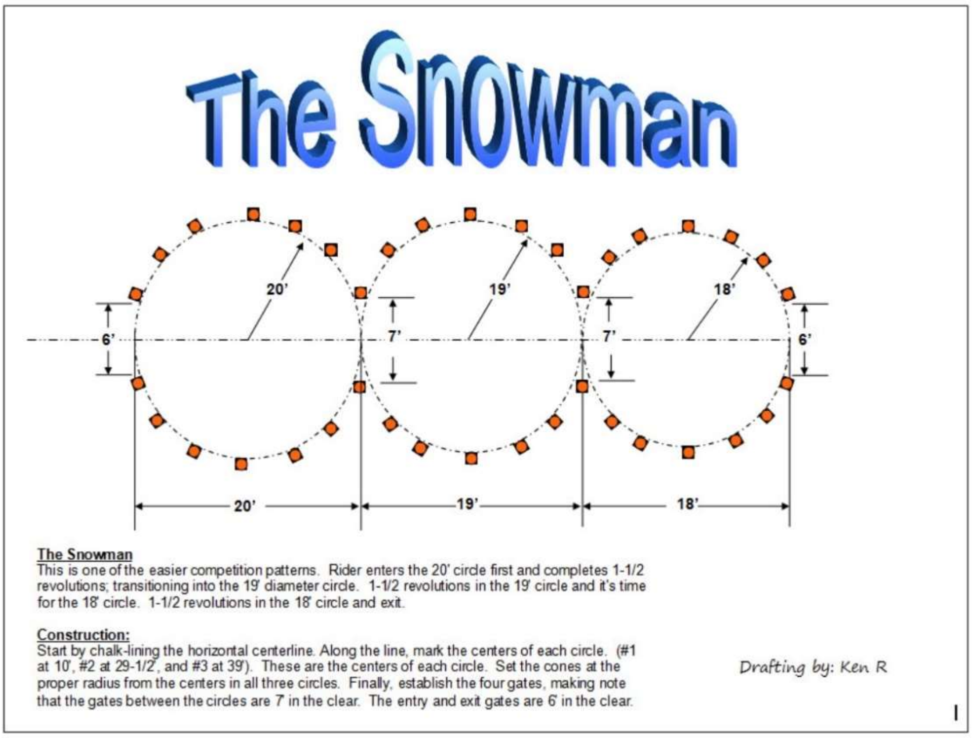

Figure 6.2 – The pattern for circles with different diameters.
Source: http://conepatterns.com.

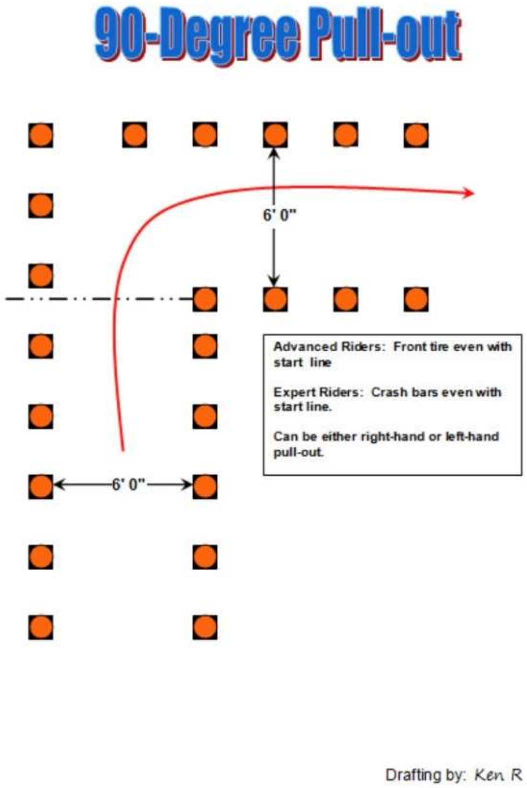

Figure 6.3 – The pattern for the 90-degree pull-out, that is marked for both right and left directions.
Source: http://conepatterns.com.

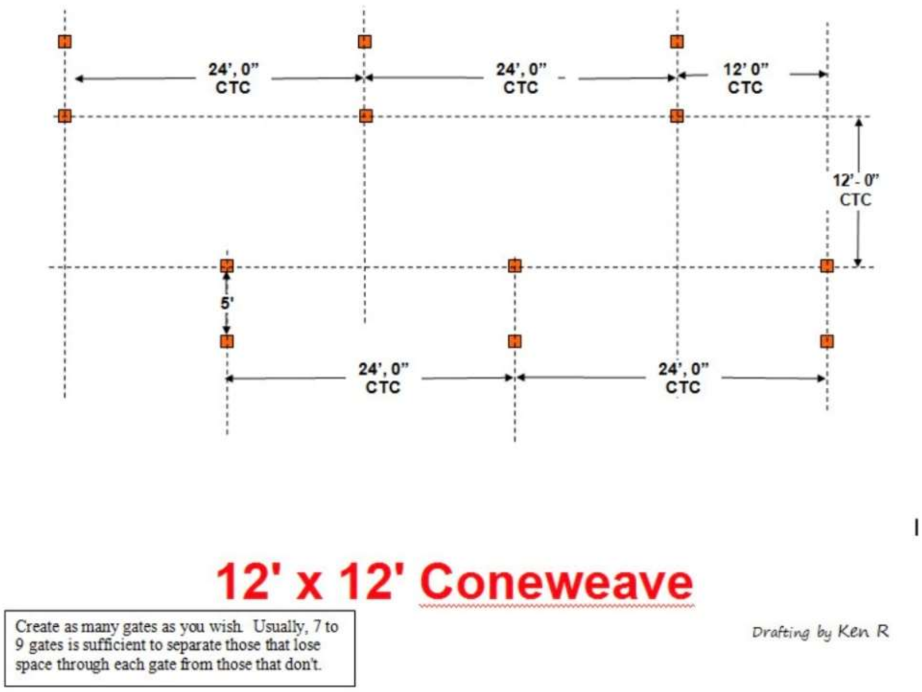

Figure 6.4 – The Off-Set Cone Weave pattern.
Source: http://conepatterns.com.

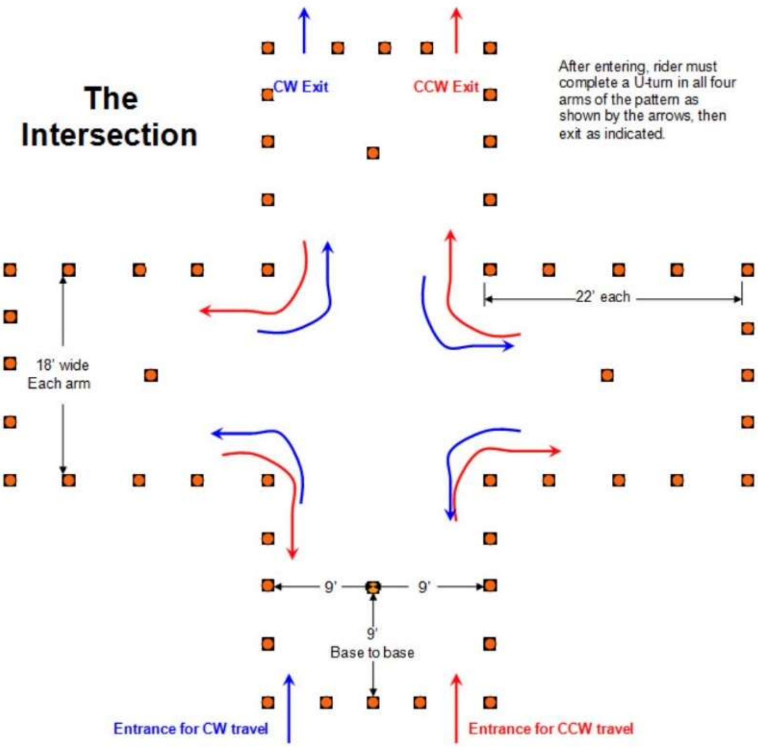

Figure 6.5 – The Intersection pattern.
Source: http://conepatterns.com.

Depending on the riders´ ability level, the dimensions of the exercises may be adjusted accordingly, or other more advanced exercises may be introduced, as shown in the patterns of Figures 6.6 and 6.7.

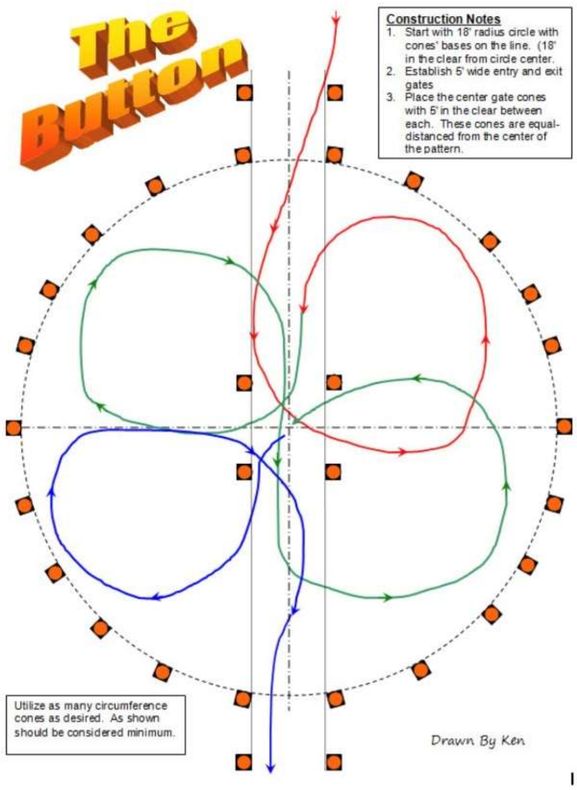

Figure 6.6 – The Button pattern.
Source: http://conepatterns.com.

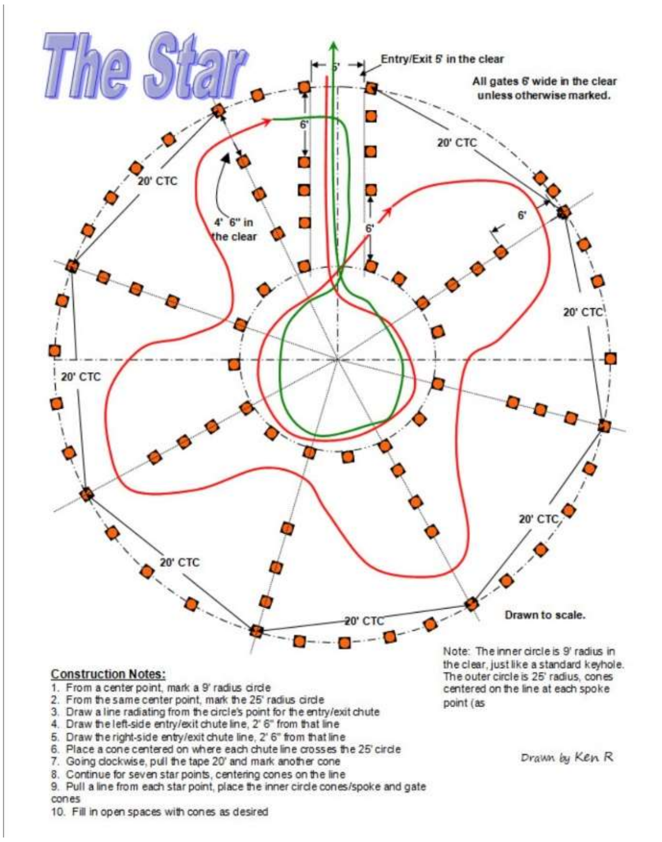

Figure 6.7 – The Star pattern.
Source: http://conepatterns.com.

7. Example of the course held outside the MTC

The My Way MS Preventive Riding Course is sometimes also held in other locations with adequate infrastructure, even in other cities, as in this example in the city of Paragominas, about 300 km from the state capital, Belém. In this case, the course was held for twelve riders, some of them with their regular pillions.

Figure 7.1 – The theoretical part for a group of riders with their pillions.
Source: Photograph by the author.

Figure 7.2 – Learning the motorcycle static balance.
Source: Photograph by the author.

Figure 7.3 – Learning how to lift a dropped motorcycle.
Source: Photograph by the author.

Figure 7.4 – Practicing clutch and throttle control.
Source: Photograph by the author.

Figure 7.5 – Running the slaloms.
Source: Photograph by the author.

Figure 7.6 – Practicing the intersection.
Source: Photograph by the author.

Figure 7.7 – Doing the off-set cone weave with a pillion.
Source: Photograph by the author.

Figure 7.8 – The 90-degree pull-out.
Source: Photograph by the author.

Figure 7.9 – Starting early in the 90-degree pull-out.
Source: Photograph by the author.

Figure 7.10 – Demonstrating the brake-and-swerve exercise.
Source: Photograph by the author.

Figure 7.11 – End of the course.
Source: Photograph by the author.

8. Conclusion

The My Way MS Preventive Riding Course was developed based on the author´s experience as a professor and researcher of Electrical Engineering during more than forty years, and as a more committed motorcyclist mainly for the last fourteen years. The importance of teaching the theory consistently before going to the practical training is emphasized in the course, since it has been verified that the participants make quicker progress when they understand why they are doing a specific exercise and the principles behind it.

The topics of the theoretical part are chosen according to the author´s knowledge acquired over many years of experience studying motorcycling and related topics, as well as traffic safety procedures. The exercises of the practical part are adapted from the author´s experience with other courses he has attended, seen in many training videos, and based on his experience practicing these drills himself and instructing other riders.

The course has been applied successfully to several groups of riders with different ages, riding experience, skills, and motorcycle types and sizes. The course has always been very well evaluated by all participants, and some small modifications have been suggested and implemented to improve the course.

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Competencies, Characteristics, Experiences, and Abilities Of Motorcycle Rider Education Instructors in the United States

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ABSTRACT

Motorcyclist Rider Education is an integral part of a systems approach to reducing injuries and fatalities in two and three-wheeled transportation. Instructors have an essential role within the system, influencing positive curricular student outcomes and impacting learning success (Baldi, Baer, & Cook, 2005). Previous research on motorcycle rider education emphasized examining instructor selection and development, stating that quality education relies on competent and qualified instructors (Daniello, Gabler, & Mehta, 2009). Instructor selection foundations require the necessary Competencies, Characteristics, Experiences, and Abilities (CCEA) (Ochs, 2005), emphasizing a need for skilled and qualified instructors. Emphasizing quality motorcyclist education relies on instructors who can connect with students in a high challenge, low threat environment (Caine & Caine, 1991).

This research analyzes Instructor Trainer's views of ranked CCEA by applying a quantitative study method, revisiting a survey conducted by Dr. Raymond J. Ochs of the Motorcycle Safety Foundation in 2005. The results show a remarkable unity of influential trainers' choices for candidate profiles compared to the previous research. The practical application of the findings may help re-align selection criteria for Instructor Candidates and trainers. Corrective measures can improve motorcycle rider education by considering the multiple human factors in other scholarly disciplines. Selecting Instructor Candidates and Instructor Trainers could benefit by focusing more on the collective curricular message, organizational message, and risk management message to support increased humanistic and cultural elements.

1.0 INTRODUCTION

The Instructor Trainer position became more valuable to the Rider Education community as the need to expand the instructor training beyond the curriculum developers like MSF between the 1970s and 1990s. As the number of motorcyclists grew, so did the number of crashes and fatalities, creating a need for more research, training, and expansion of rider education. The Motorcycle Safety Foundation (MSF) formalized the Instructor (RiderCoach) Trainer system by publishing the Chief Instructor Guide in 1981 to provide a framework for filling a gap in instructor training (MSF, 2005; Ochs, 2004).

1.1 Problem

Learning is attaining new knowledge, understanding, skills, attitudes, and behaviors. Building a structure to accommodate beginners with the safest methods using progressive and sequential steps is possible when integrated into a system, as in motorcyclist rider education. In most accelerated education scenarios, previous experiences are used as the basis for future learning (Knowles, 2019), allowing quicker understanding and achieving more impactful results.

A problem can exist when an instructor's statements or actions contradict professional or ethical practices or provide insubstantial information endangering the learner. Instructor Trainers have a moral obligation to fully integrate into the learning system a breadth and depth of knowledge, understanding, skill, attitude, and behavior congruent with the material they share. Instructors require the appropriate Competencies, Characteristics, Experiences, and Abilities (CCEA) necessary to ensure the system supports student learning.

1.2 Context and Literature Review

The Motorcycle Safety Foundation (MSF) was established in 1973 by the Motorcycle Industry Council (MIC) after a year as the Motorcycle Industry Council Safety and Education Foundation, Inc. The original MSF standardized curriculum was published in 1974 based on current knowledge called "The Beginning Rider Course." The Motorcycle Task Analysis (Motorcycle Safety Foundation, 1974) and Motorcycle

Instructional Objectives were published concurrently, providing a research-based analysis of the physical skill required to operate a motorcycle centered primarily on motor skill development.

There have been four iterations or versions of the novice Rider's Course under the MSF. In 1976 the original BRC was replaced with the Motorcycle Rider Course (MRC), a more comprehensive course enhanced by the Task Analysis, the Instructional Objectives from 1974, and the Photographic Analysis of Motorcycle Operator Control Analysis (Motorcycle Safety Foundation, 1976). Almost ten years later, the MRC: Riding Street Skills (RSS) was published in 1985, revising the curriculum and shortening the experience to 15 hours. In 2001 the MRC: RSS was enhanced again by the *Basic RiderCourse,* focusing on more modern adult learning techniques and rider risk management components (Buche, 2004).

In 2014 the current Basic *RiderCourse* updated (BRCu) (MSF, 2014) was fielded with a greater focus on the rider's behavioral component. The latest version improves the system with more in-depth adult learning enhancements, including methodology to help students view their behaviors through the light of cognitive dissonance, using subtle behavioral-based methods. Since introducing the latest MSF curriculum, some programs have trended away from accepting the substantial leap forward in the content, reverting backward towards a didactic, motor skill concentrated development. The reversion creates a methodological shortcoming noted as disadvantageous in much of the historical research.

In the last 50 years, continued transportation and environmental changes have increased rider education's regulatory and societal requirements. As requirements for instructors with more depth and breadth in rider education knowledge increase, so should the Instructor Trainers' preparation and quality.

Instructors are the vital link between curriculum implementation and student outcomes. Instructor Trainers (IT) are part of a model necessary to ensure the content and knowledge are relayed appropriately and successfully. Since the MSF's inception, the varying duties of ITs have grown in scope. The Chief Instructor, as initially known, grew into a position responsible for solidifying teaching skills, curriculum knowledge, administrative acumen, public relations, quality assurance, and cultural awareness. Instructor Trainers' impact on future instructors and students is significant, requiring trainers to be highly effective in each of the above areas. Making critical, informed decisions, like ranking the Characteristics, Competencies, Experiences, and Abilities (CCEA), indicates the skill and character attributes required to be an Instructor Trainer and strongly affects rider education programs.

1.3 Purpose

In 2005 Dr. Raymond J. Ochs of the MSF surveyed Instructor Trainers to elicit their views on CCEA, establishing the initial list of perceived skill sets and experiences deemed valuable for professional development. In the 15 years since the previous research, implementing an updated curriculum allowed more significant focus on the behavioral aspects of riding. The newer curriculum was substantial as it integrated more behavioral factors, a change from previous versions that predominantly focused on motor skill development. The updates also allowed the integration of professional development for instructors emphasizing portions of the CCEA.

Revisiting the original study is necessary to see if the perception of ITs has changed to align with the new curriculum's intent. Educational methodologies in line with adult accelerated learning have become more contemporary as some of the older practices of rider education associated with the more senior platform type instruction have proven less effective. The common adages depicted in seminal education literature, "*Telling Ain't Training*" (Stolovich & Keeps, 2011) and "*You Haven't Taught Until They Have Learned*" (Nater & Gallimore, 2010), are more accepted in coaching circles.

By gaining a current view of Instructor Trainer's perceptions, the results can help better understand trainers' challenges and needs associated with selecting candidates for Instructor Trainers and Instructor Candidates as a precursor to becoming future Instructor Trainers. The input from Instructor Trainers allows a more precise awareness of the day-to-day actions and conditions of rider education at the local, state, and national levels. The documented behaviors and perceptions of Instructor Trainers can be meaningful as they may represent a model of a larger culture (Green, 2021).

1.4 Research Questions

In the examination of the Competencies, Characteristics, Experiences, and Abilities of Instructor Trainers, the following questions are asked of the results:

RQ1: What are the current most critical Competencies, Characteristics, Experiences, and Abilities for Instructor Candidates as perceived by Instructor Trainers in the United States?

RQ2: What are the current least critical Competencies, Characteristics, Experiences, and Abilities for Instructor Candidates as perceived by Instructor Trainers in the United States?

RQ3: What are the differences between the current (2020) and previous (2005) Competencies, Characteristics, Experiences, and Abilities of Instructor Candidates as perceived by Instructor Trainers in the United States?

1.5 Follow-up Post Survey Questions to the Population

The following questions were used to determine the reasons for participation and non-participation of the population after the 2020 survey:

PSQ1: Why did you NOT participate in the CCEA research?

PSQ2: Why DID you participate in the CCEA research?

PSQ3: Are you interested in the results of the research?

2. METHOD

The original list of core competencies and abilities arose from reviewing objectives and activities associated with Instructor Trainer certification processes and was combined with an index built from a 2005 trainer questionnaire (Ochs, 2005). The outcome was a list of 40 CCEAs used as the starting point for the previous and current research.

Using forms and methods specified in the 2005 research by Dr. Ochs, only changing dates and contact information, a request for participation was provided by email to 186 of the 210 active Instructor Trainers certified by the Motorcycle Safety Foundation. The solicitation advertised that participation was optional and considered a professional development learning experience.

The first form, consisting of two pages (see Appendix A), asked to delineate the 40 randomized selections of CCEAs with instructions to rate their importance on a scale of 1 [most important] to 5 [least important]. The second form, consisting of one page (see Appendix B), allowed the respondent to rank the 40 CCEAs in chronological order from 1-40, where one (1) is the most important and 40 is the least important. A descriptive data analysis used rank order scaling with a weighted relative frequency of forty potential answers against the 34 individually ordered responses.

Each of the 40 CCEAs is codified and aligned into the five areas 1) Personal, 2) Rider, 3) RiderCoach: Curriculum, 4) RiderCoach Trainer: Curriculum, and 5) Professional associated with MSF literature and curricular documents (See Appendix C). The five areas can also be described using the physical, social, mental/perceptual, and emotional rider sub-tasks associated with being Motorcycle Rider Education Instructors (See Appendix E).

Additionally, a post-research survey within the same community of 186 active Instructor Trainers about survey participation yielded some noteworthy responses adding some context to the data captured. More importantly, the questions may highlight known social and cultural representation issues and how perceived impressions affect answers within a select group.

2.1 Participants

At the time of this survey, there were over 5000 certified Motorcycle Safety Foundation Instructors, referred to as RiderCoaches. Within the community, there was a sub-population of 210 “active” Instructor Trainers, also known as RiderCoach Trainers. 189 Instructor Trainers were reachable through electronic mail or telephone. This became the researched population, and no other constraints were imposed upon the group.

Of the population, 34 respondents participated, becoming the sample and submitting their CCEA results, creating a response rate of 17.9 percent. A compilation of the responses collected was then analyzed to determine the overall rank order of each CCEA in aggregate (See Appendix D).

A total of 44 respondents participated in a follow-up survey by answering questions to clarify their reasons for participating in the CCEA survey. The secondary sample had a response rate calculated at 25.3 percent.

It is also essential to know the participation in the 2005 study. At the time of the 2005 survey, there were over 7000 certified Motorcycle Safety Foundation RiderCoaches. Within the population, there was a sub-population of 215 “active” Instructor Trainers, also known as RiderCoach Trainers. The 2005 sample included 32 respondents and a response rate of 14.9 percent.

2.2 Demographics

The average participant is a middle-aged white male with a bachelor’s degree with over 35 years of motorcycling experience, 20 years of instructor experience, and 15 years of Instructor Trainer experience.

The oldest respondent was 77 years old, and the youngest was 28 years old. Eighty percent of the respondents were male and 20 percent female. 85.8 percent identified as white, 8.6 percent preferred not to share, 2.8 percent Hispanic, and 2.8 percent Black or African American.

The Instructor Trainer with the most motorcycle riding experience had been doing so for 60 years. The trainer with the most instructor experience had 48 years of participation, and the trainer with the most Instructor Trainer experience had 41 years. The Instructor Trainer with the least motorcycling experience had been riding for nine years. The Instructor Trainer with the least instructor experience had nine years as an instructor and two years as an Instructor Trainer.

3. RESULTS

A descriptive data analysis used rank order scaling with a weighted relative frequency of the forty potential answers against the 34 individually ordered responses. Appendix D shows the CCEA descriptions ranked from the most important to the least essential CCEAs identified through data collection and rank ordering by the sample respondents. The order helps to understand the perception of CCEA considered most critical to least necessary in educating new instructors or trainers as viewed by current Instructor Trainers. It is appropriate to note that there were no definitions provided for the CCEAs, but they would ostensibly be recognizable in the motorcycle rider education context.

3.1 CCEA Rankings

The results are centered on the perceptions of the respondents as scaled and weighted in total amongst the sample population. Presented is a cumulative look at the experiences and perceived notions, giving an appealing look into the community and culture. Compared to the previous study, there are only slight variations from the initial investigation, and the current rank shows very little difference in the list's top five and bottom five.

3.1.1 Research Question 1: Most Critical CCEA

The most critical CCEA recommended was "Understand teaching/learning dynamics," scoring slightly above "Possess character, competence, and leadership skills." Teaching and learning dynamics are associated with the Professional Category of the literature alignment and the Cognitive area of the 4 Riding Subtasks. The competency gained four positions. In contrast, the personal attributes of character, competence, and leadership skills fell from their previous ranking. Of note, "Evaluate and Coach Effectively" fell to position six.

The five most critical CCEAs in order are 1) Understand teaching/learning dynamics, 2) Possess character, competence, and leadership skills, 3) Understand safety and risk management principles, 4) Understand motor skills principles, and 5) Ability to teach others to evaluate and coach.

3.1.2 Research Question 2: Least Critical CCEA

The least critical CCEA recommended was "Have completed a track course or school," scoring again as the least necessary experience for being an Instructor Trainer. The bottom five CCEAs were the same, only discriminated by a change in the order of "Design Ranges" and "Possess motorcycle maintenance skills."

The five least critical CCEAs in order are 40) Have completed a track course or school, 39) Affiliate with motorcycle organizations, 38) Possess motorcycle maintenance skills, 37) Design ranges, and 36) Be adept at public relations.

3.1.3 Research Question 3: Differences from 2005 -2020

In aggregate, there was very little difference between the 2005 survey by Dr. Ochs and this survey, potentially showing that overall perceptions of Instructor Trainers have not changed in the subsequent 15 years. 22.5 percent of the answers did not change, and 87.5 percent did not change more than five places. Of note, "Conduct Skill Test Proficiently" decreased in rank by nine positions from 17th to 26th. "Screen Candidates" declined in rank by 11 places, from the 19th to the 30th position. The one increase of significance was "Understand MSF Rider Education Training Systems," which Increased class by 14 positions from 31st to 17$^{th.}$ (See Appendix D).

3.2 Post Research Survey

The post-research survey was designed to complement the study with the "why" of respondent participation or non-participation. By asking the post-survey questions, it was possible to get a qualitative feel for the feedback. Instead, the responses raised more questions than they answered.

The post-survey questions were sent to the same 189 Instructor Trainers as the original research questions. 44 ITs responded, giving a larger sample than the research. The 44 respondents were 25.3 percent of the population; however, only 45.8 percent participated in the contemporary study. Of the other 54.2 percent responding not participating in the modern study, 30.7 percent stated they participated in the research when they did not. This number is significant considering the implications.

Overall, 96 percent stated they were interested in the research, with two percent being neutral and two percent giving no response. Six percent of the total respondents had participated in the 2005 research and wanted to see the recent results for comparison.

4. DISCUSSION

It is somewhat difficult to differentiate the importance of each CCEA without context or boundaries, as each has merit in value when it comes to being an Instructor Trainer or Instructor. Perhaps the aggregate collection is more meaningful as it clarifies how the culture approaches selecting what is valuable within the community. In *The Human Element* (2022), Nordgren and Schonthal describe individuals as each seeking emotional, functional, and social value when relating to the ideas in question. Most accept the concepts forming from a collaborative outcome by aggregating and weighing the responses.

Determining the collective opinion of Instructor Trainers serves as a baseline for understanding perceptions at large and how they may view the Competencies, Characteristics, Experiences, and Abilities of the Instructor Trainer community. Opinions are very diversified, creating striking tensions regarding the importance of CCEAs. For example, the most critical CCEA, "Understand teaching/learning dynamics," was only selected for a number one rating by three percent of the respondents. However, when weighing all responses, it appears as the top selection. On the opposite end of the spectrum, "Have completed a track course or school," there was a significant congruence where 56 percent agreed with the ranking. This example was the highest point of agreement within the survey, whereas most other agreements were 12 percent or less.

The overall ranking has not changed in the 15 years since the 2005 research creating more questions than answers. Has the mindset of Instructor Trainers remained the same, or are the notable variances become indicators of change? Is there significance in the social aspects of the community and the ability to interact with others when there are decreases in #5 ability to teach others to evaluate and coach (-3 positions) or #30 screening for appropriate candidates (-9 positions)? Has the value of the Rider Education community diminished when #24 handle a motorcycle as a rider (-5 positions), #20 conduct simulated practice activities properly (-5 positions), or #26 conduct skill test proficiently (-9 positions), all show decreases?

Moreover, post-research questions show that 30.7 percent stated they participated in the research when they did not. The number is vital as it puts into doubt the second most critical CCEA selected in the research survey. Although it is possible that there was some miscommunication, the potential is minor considering the group and the repetitive communications during the study. It is possible that after continued requests, there was a social aspect of being involved prompting the respondents to feel it necessary to provide input as if they were a part. This could highlight the social aspects of voicing as a member of a community when in fact, the action was not taken. A point of dissonance that could put in question all other information collected or merely an example of the Hawthorne effect.

5. CONCLUSION

The results show a remarkable congruence of influential trainers' choice for candidate profiles compared to the previous research. Despite a few variations, little has changed in the 15 years, providing some consistency in the philosophy of the respondent instructor sample. New variations in the study also highlight a potential change in critical aspects of the culture despite the overall consistency. The selection of Instructor Candidates and Instructor Trainers can continue to use the CCEAs as a baseline for various processes. Still, it could also be refreshed using contemporary research, literature, curricular messages, organizational messages, and risk management messages. The Characteristics, Competencies, Experiences, and Abilities from the 2005 study still serve Instructor Candidates and Instructor Trainers with significant humanistic, social, and cultural elements.

6. PRACTICAL APPLICATION

The practical application of the findings may help confirm or re-align the selection process or criteria for Instructor Candidates and Instructor Trainers. Corrective measures or realignment could improve motorcycle rider education by considering the multiple human factors elements in other scholarly disciplines or contemporary motorcycle rider education research.

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MSF RiderCoach Trainer 2020 Special Assignment
Competencies and Abilities of MSF Certified RiderCoach Trainers

(This form used with permission by Dr. Raymond J. Ochs)

If you have not done so already, please complete this optional assignment as a professional development learning experience. Once enough forms have been completed, we will provide the results. The first part of the activity is to complete the ratings on this sheet; the second part is to organize all 40 items in rank order on the following page.

Directions (1): Below are 40 competencies and abilities of RiderCoach Trainers. Evaluate the importance of each by circling the number that most nearly describes its importance. Circling a “5" for example, will indicate that you believe the item is very important for success. Circling a “1" will indicate that in your opinion the ability is much less important.

COMPETENCIES & ABILITIES		EVALUATION SCALE				
		Highest				Lowest
1.	Determine instructional objectives for the classroom.	5	4	3	2	1
2.	Determine instructional objectives for the range.	5	4	3	2	1
3.	Analyze and interpret written test scores.	5	4	3	2	1
4.	Analyze and interpret skill test scores.	5	4	3	2	1
5.	Diagnose problems and determine remedial activities.	5	4	3	2	1
6.	Construct efficient schedule.	5	4	3	2	1
7.	Screen candidates.	5	4	3	2	1
8.	Prepare lesson plans.	5	4	3	2	1
9.	Collaborate with program administrators.	5	4	3	2	1
10.	Use instructional aids well.	5	4	3	2	1
11.	Design ranges.	5	4	3	2	1
12.	Ability to teach others to evaluate and coach.	5	4	3	2	1
13.	Know motorcycle research.	5	4	3	2	1
14.	Know motorcycle dynamics.	5	4	3	2	1
15.	Understand teaching/learning dynamics.	5	4	3	2	1
16.	Understand motor skills principles.	5	4	3	2	1
17.	Understand safety and risk management principles.	5	4	3	2	1
18.	Facilitate group activities.	5	4	3	2	1
19.	Evaluate and coach effectively.	5	4	3	2	1
20.	Use RCG/RCTG effectively.	5	4	3	2	1

21.	Use range cards effectively.	5	4	3	2	1
22.	Conduct peer teaching effectively.	5	4	3	2	1
23.	Schedule peer and student teaching effectively.	5	4	3	2	1
24.	Conduct quality assurance effectively.	5	4	3	2	1
25.	Possess character, competence, and leadership skills.	5	4	3	2	1
26.	Conduct skill test proficiently.	5	4	3	2	1
27.	Conduct simulated practice activities properly.	5	4	3	2	1
28.	Be adept at public relations.	5	4	3	2	1
29.	Possess motorcycle maintenance skills.	5	4	3	2	1
30.	Make and apply safe riding decisions.	5	4	3	2	1
31.	Keep records accurately.	5	4	3	2	1
32.	Wear full protective attire when riding.	5	4	3	2	1
33.	Wear an appropriate helmet when riding.	5	4	3	2	1
34.	Handle a motorcycle as a rider.	5	4	3	2	1
35.	Maintain professional development.	5	4	3	2	1
36.	Affiliate with motorcycle organizations.	5	4	3	2	1
37.	Possess CPR/First Aid skills.	5	4	3	2	1
38.	Maintain good human relationships.	5	4	3	2	1
39.	Understand MSF RETS.	5	4	3	2	1
40.	Have completed a track course or school.	5	4	3	2	1

Directions (2): Now comes the fun part! Rank each of the forty items from most important to least important. A good way to do this is to sort out all the "5" ratings first and rank them, all the "4" ratings and rank them, and so on. The goal is to have all 40 items ranked from most important to least important. Use the table on the next page to put the ability and competency number next to your ranking. Then scan or take a picture and send to don.green@riderchoices.com or fax to (845) 610-5262.

Name ____ RCT # ____________________________

Rank Position of the 40 RCT Competencies and Abilities

Ranking (most to least important)	**Competency and Ability #**
1	
2	
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Personal	Rider	RiderCoach: Curriculum	RiderCoach Trainer: Curriculum	Professional
Possess character, competence, and leadership skills	Wear an appropriate helmet when riding	Evaluate and coach effectively	Ability to teach others to evaluate and coach	Understand safety and risk management principles
Maintain good human relationships	Make and apply safe riding decisions	Diagnose problems and determine remedial activities	Use RCG/RCTG effectively	Understand teaching/learning dynamics
	Wear full protective attire when riding	Use range cards effectively	Conduct peer teaching effectively	Understand motor skills principles
	Handle a motorcycle as a rider	Facilitate group activities	Screen candidates	Maintain professional development
	Know motorcycle dynamics	Conduct simulated practice activities properly	Conduct quality assurance effectively	Determine instructional objectives for the range
	Possess motorcycle maintenance skills	Conduct skill test proficiently	Schedule peer and student teaching effectively	Determine instructional objectives for the classroom
	Affiliate with motorcycle organizations	Use instructional aids well	Construct efficient schedule	Collaborate with program administrators
	Have completed a track course or school	Keep records accurately		Prepare lesson plans
				Understand MSF RETS
				Analyze and interpret skill test scores
				Analyze and interpret written test scores
				Know motorcycle research
				Possess CPR/First Aid skills
				Be adept at public relations
				Design ranges

Results: Competencies, Characteristics, Experiences, and Abilities (CCEA) Ranked Most Important to Least Important				
Rank (2020)	Rank (2005)	Change	Question	CCEA
1.	5.	4	15.	Understand teaching/learning dynamics.
2.	1.	-1	25.	Possess character, competence, and leadership skills.
3.	4.	1	17.	Understand safety and risk management principles.
4.	6.	2	16.	Understand motor skills principles.
5.	2.	-3	12.	Ability to teach others to evaluate and coach.
6.	3.	3	19.	Evaluate and coach effectively.
7.	8.	1	20.	Use RCG/RCTG effectively.
8.	12.	4	38.	Maintain good human relationships.
9.	7.	-2	5.	Diagnose problems and determine remedial activities.
10.	14.	4	30.	Make and apply safe riding decisions.
11.	11.	0	18.	Facilitate group activities.
12.	10.	-2	22.	Conduct peer teaching effectively.
13.*	9.	-4	21.	Use range cards effectively.
14.*	20.	6	35.	Maintain professional development.
15.	13.	-2	33.	Wear an appropriate helmet when riding.
16.	16.	0	32.	Wear full protective attire when riding.
17.	31.	14	39.	Understand MSF RETS.
18.*	24	6	23.	Use instructional aids well.
19.*	22.	3	10.	Schedule peer and student teaching effectively.
20.	15.	-5	27.	Conduct simulated practice activities properly.
21.	25.	4	2.	Determine instructional objectives for the range.
22.	26.	4	1.	Determine instructional objectives for the classroom.
23.	18*	-5	34.	Handle a motorcycle as a rider.
24.	21.	-3	24.	Conduct quality assurance effectively.
25.	23.	-2	6.	Construct efficient schedule.
26.	17.	-9	26.	Conduct skill test proficiently.
27.	28.	1	31.	Keep records accurately.
28.	27.	-1	9.	Collaborate with program administrators.
29.	30.	1	8.	Prepare lesson plans.
30.	19*	-11	7.	Screen candidates.
31.	29.	-2	14.	Know motorcycle dynamics.
32.	32.	0	4.	Analyze and interpret skill test scores.
33.	33.	0	3.	Analyze and interpret written test scores.
34.	34.	0	13.	Know motorcycle research.
35.	35.	0	37.	Possess CPR/First Aid skills.
36.	36.	0	28.	Be adept at public relations.
37.	38.	1	11.	Design ranges.
38.	37.	-1	29.	Possess motorcycle maintenance skills.
39.	39.	0	36.	Affiliate with motorcycle organizations.
40.	40.	0	40.	Have completed a track course or school.
				* Indicates no statistical difference from companion CCEA.

Cognitive	Social	Emotional	Physical
Make and apply safe riding decisions	Possess character, competence, and leadership skills	Evaluate and coach effectively	Understand motor skills principles
Construct efficient schedule	Conduct peer teaching effectively	Diagnose problems and determine remedial activities	Conduct simulated practice activities properly
Understand safety and risk management principles	Screen candidates	Use range cards effectively	Have completed a track course or school
Understand teaching/learning dynamics	Be adept at public relations	Conduct skill test proficiently	Handle a motorcycle as a rider
Analyze and interpret written test scores	Affiliate with motorcycle organizations		Use instructional aids well
Maintain professional development	Collaborate with program administrators		Design ranges
Determine instructional objectives for the range	Maintain good human relationships		Wear full protective attire when riding
Determine instructional objectives for the classroom	Facilitate group activities		Wear an appropriate helmet when riding
Conduct quality assurance effectively	Ability to teach others to evaluate and coach		Know motorcycle dynamics
Prepare lesson plans	Schedule peer and student teaching effectively		Possess motorcycle maintenance skills
Understand MSF RETS			
Analyze and interpret skill test scores			
Know motorcycle research			
Possess CPR/First Aid skills			
Keep records accurately			
Use RCG/RCTG effectively			

Anti-lock Braking System Control for Two-Wheeled Vehicles using Deep Reinforcement Learning

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ABS controllers are historically based on heuristics, and require high manual calibration effort on the vehicle. Current research focuses predominantly on model based approaches, that are at best as good as their underlying model. In this work, we propose a data driven slip controller for two wheeled vehicles on the example of an anti-lock braking system (ABS). For this purpose, we formulate the problem as a Partially Observable Markov Decision Process (POMDP), deriving the action and observation space from sensor equipment, in production motorcycles are typically equipped with. Special focusing is taken on the discussion of the formulation of the reward function, as it is a crucial design choice for finding a good control policy. The resulting POMDP is implemented in a high fidelity dynamics simulator and solved approximately, using a recurrent soft actor critic deep reinforcement learning approach. The ABS problem is highly nonlinear and inherently partial observable, as the control variable - the slip - is not directly measurable. In order to solve this problem, we employ a long short-term memory (LSTM) layer in the deep neural net, giving the agent the ability to learn a latent representation of the observation history. A study with a variety of road conditions and rider inputs shows that a high control performance can be achieved using this deep reinforcement learning approach for slip control in motorcycles. It furthermore is demonstrated, that an observation space consisting only of the wheel speeds and accelerations at the front and rear wheel is sufficient for solving the ABS control problem. In addition, the agent is able to mitigate a lift-up of the rear wheel, even though it was not explicitly considered in the design of the POMDP, thereby solving a second major instability mode in motorcycle dynamics.

Introduction

All major motorcycle markets in the world are planning to introduce or already have introduced governmental requirements for anti-lock braking systems (ABS) in two wheeled vehicles above 125 cc, in order to increase the safety on motorcycles. The current in-production systems rely on heuristic control strategies, that come with the cost of a high manual calibration effort on the vehicle, usually carried out by specialized calibration engineers. Accordingly, the demand for an easily tuneable controller is rising, in order to reduce the costs associated with engineering services.

A multitude of approaches has been applied to the problem of wheel slip control. A comprehensive survey can be found in. [1] They conclude, that Model Predictive Control (MPC) yields the highest potential, albeit with a cost in calibration effort. They also state, that reinforcement and deep learning are “a weak-investigated direction and in the starting point of research in WSC[1].”

While the performance of heuristic approaches depends majorly on their complexity, as well as the proficiency of the calibration engineer, model based approaches are limited by the fidelity of the used model and the identification of the model parameters. [2] This can lead to costs associated with engineering services, that can be prohibitive especially in low-volume projects.

In this paper we discuss the formulation of the ABS control problem as a Markov decision process and try to approximately solve it by use of a soft actor critic deep reinforcement learning algorithm, in order to tackle the aforementioned problems.

Anti-lock Braking System

The Anti-lock Braking System (ABS) is an active safety system present in modern vehicles, that prevents the wheels from locking up during braking in order to ensure the controllability of the vehicle while maximizing braking performance.

The slip λ of a tire is defined as

$$\lambda = (v_U - v_F)/v_f \qquad (1)$$

where v_f is the vehicles absolute velocity and v_U the circumferential velocity of the wheel.

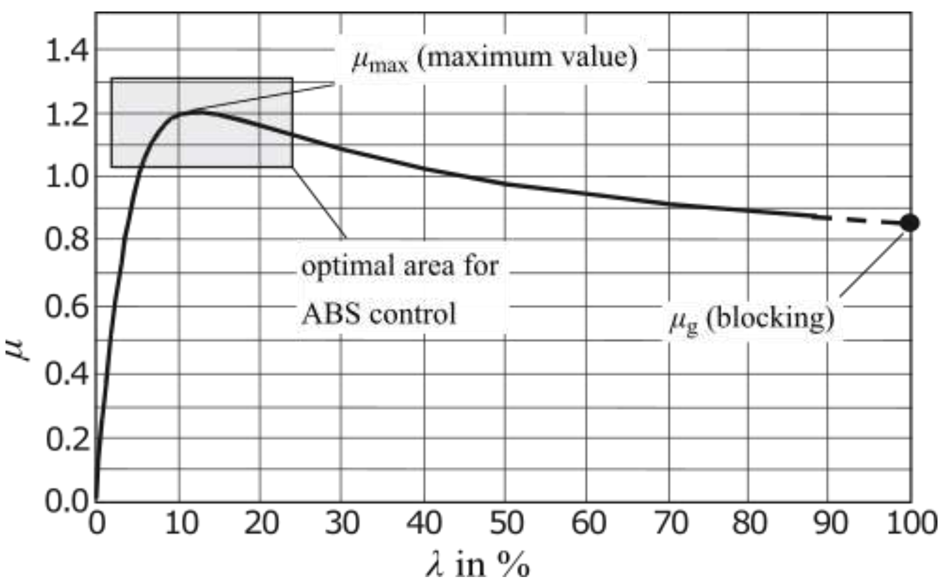

Figure 1: Example μ-λ-curve with optimal area for ABS control[2] [4]

[1] WSC: Wheel Slip Control

[2] Note that contrary to the rest of this study, the brake slip is defined as positive here.

Figure 1 shows an exemplary relation between the slip λ and the friction coefficient μ. Typically, the level of adhesion — and thereby the braking force — increases up to a maximum as the brake pressure — and thus the slip — rises. At this peak the highest deceleration can be generated and is therefore the optimal area for ABS control.

A locked wheel cannot transfer significant lateral forces anymore and thus the vehicle becomes uncontrollable [6]. Even in straight line riding, a loss of the ability to transfer lateral forces leads to an imminent crash in a motorcycle because of the semi stable nature of motorcycle dynamics [4].

Due to the comparably high center of gravity, combined with a short wheelbase, motorcycles are prone to a lift-up of the rear wheel. In order to mitigate this, the ABS controller has to reduce the brake pressure at the front wheel. [10] In motorcycles, the mitigation of a rear wheel lift-up is usually considered as a part of the modern ABS.

A lot of approaches in ABS design call for an estimation of the slip. In order to estimate the slip, the speed over ground of the vehicle has to be measured or estimated. If the estimation is suspected to be bad, a wheel can be intentionally under-braked in order to obtain a new reference speed. While this is viable in a four wheeled vehicle, this approach is a lot more punishing in two wheeled vehicles. This is worsened by the fact, that the rear wheel barely has any ground contact in motorcycles in high friction-ratio scenarios, as the wheelbase is short and the center of gravity is high.

Reinforcement learning

Reinforcement learning is a subfield of machine learning. In reinforcement learning, an agent learns a policy $\pi(S)$, that maps states S to actions A. The objective of reinforcement learning is to find an optimal policy, that maximizes the cumulative sum of a scalar reward signal R by directly interacting with the environment. In deep reinforcement learning the policy-function $\pi(S)$ is approximated by a deep neural net. [5]

The so-called Markov decision process (MDP) is the mathematically idealized form of the reinforcement learning problem.

Figure 2 shows a depiction of an MDP. The agent receives a representation of the environments state S_t on which's basis it selects an action A_t. The agent then receives a scalar reward R_{t+1} and the next state S_{t+1}. The agents objective is to maximize the expected value of the cumulative sum of the future rewards. [5]

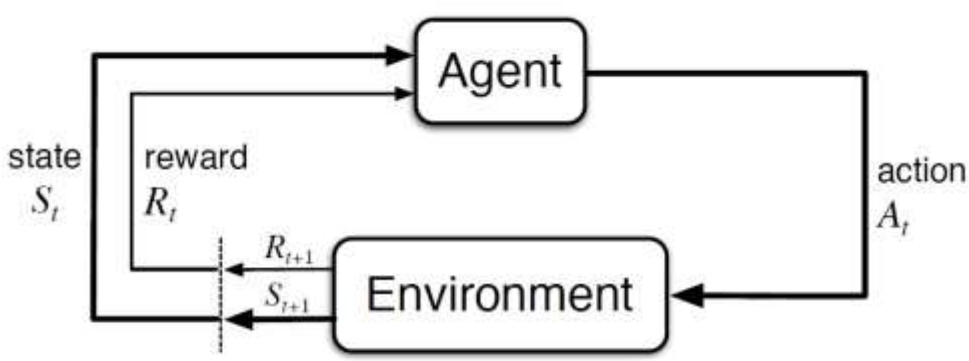

Figure 2: The agent-environment interaction in a Markov decision process [5]

In order to value immediate rewards higher than delayed rewards, a discount factor γ can be introduced. The discounted return G_t is then given by

$$G_t = \sum_{k=0}^{\infty} \gamma^k R_{t+k+1} \qquad (2)$$

The agents objective is now to maximize the expected discounted return G_t. [5]

A partially observable Markov decision process (POMDP) is a generalization of the MDP. In a POMDP, the agent cannot observe the state of an MDP directly. Therefore, the policy function $\pi(O)$ maps observations O — in contrast to the whole state S — to actions A. [5]

Related work

Radac et al. [2] successfully solve the slip control problem on a laboratory setup using neural batch fitted Q-Learning. The setup consists of two wheels touching each other, of which the lower wheel acts as an accelerator and the upper wheel is braked.

Mantripragada and Kumar [11] have recently shown, that the Proximal policy optimization algorithm produces policies, that are viable for the ABS control of a 7 DOF, one-track model. By randomly sampling the parameters of the Pacejka magic formula [12], they show, that a policy produced by a deep reinforcement learning framework can handle a variety of different tires.

Both the authors of [2] and [11] design the state space in such a way, that it is fully state observable. Most notably, they assume that the velocity over ground (the speed of the lower wheel in their setup) is measurable. This does not hold true in real ABS applications.

Drechsler et al. [7] show, that actor-critic reinforcement learning is a feasible approach for slip control on the example of traction control.

Jaritz et al. [8] use an Asynchronous Actor Critic (A3C) framework in order to teach an agent to control a car at a racing track.

Problem formulation and scope

In the current research phase only straight line ABS is considered.

The WSC problem is inherently a partially observable problem, as the control variable — the slip λ — is not directly measurable. In the following, the POMDP is defined.

Observation space

The observation space is constrained by the sensors typically found in series motorcycles. Motorcycles in the high-end market are usually equipped with up to 4 pressure sensors at the master and caliper cylinders at the front and rear wheel respectively. In the mid- and low-end markets, less to none pressure sensors are used, and instead a model estimates the pressures at the different brake calipers. While including the pressure sensors in the observation space has been considered initially, we found that they are not necessary using this approach.

In addition, the ABS is often equipped with a 6D inertial measurement unit (IMU). Because this study focuses on straight-line ABS, only the longitudinal acceleration a_x is taken into account.

Furthermore, the wheel speeds as well as the wheel accelerations are universally available on ABS equipped bikes.[3]

Thus, the observation space is defined as $\Omega = \{\omega_{W,f}, \omega_{W,r}, \dot{\omega}_{W,f}, \dot{\omega}_{W,r}, a_x\}$, where

- $\omega_{W,f/r}$: Wheel speed front/rear.
- $\dot{\omega}_{W,f/r}$: Wheel acceleration front/rear.
- a_x: Longitudinal acceleration (IMU).

Action space

The agent's action space is a continuous vector with two elements: $A = \{\Delta p_f, \Delta p_r\}, \Delta p \in [-1,1]$ MPa, allowing it to change the pressure at the wheel - front and rear - by a value in between -1 and 1 MPa. It cannot raise the pressure above the master cylinder pressure though.

Reward

Given the μ-λ-curve in figure 1, where the maximum friction coefficient also lies in the optimal area for ABS control, the most naive approach is to just define the deceleration at any given time step as a reward signal, as the deceleration is highest in this area. Unfortunately this leads to poor results, as the environment has an integrating behavior. Since the objective is to maximize the cumulative sum of the reward signal, braking with half the deceleration will double the length of one episode, resulting in the same cumulative sum. Because of this, a large fixed amount of reward is granted at the end of each episode. Together with the discount factor, this incentivizes the agent to finish the episode as fast as possible.

Thus, the reward signal is defined as follows:

$$R(t) = \begin{cases} 0 & \text{if } \lambda < -0.99 \\ 100 & \text{if episode done} \\ -a_x(t) & \text{else} \end{cases} \quad (3)$$

[3] There are one-channel ABS controllers on the market, only acting at the front wheel. Those are not considered in this study.

Implementation details

Simulation setup

The training and evaluation is performed in the high fidelity motorcycle simulation environment BikeSim by Mechanical Simulation. The tire model used is shown in figure 3.

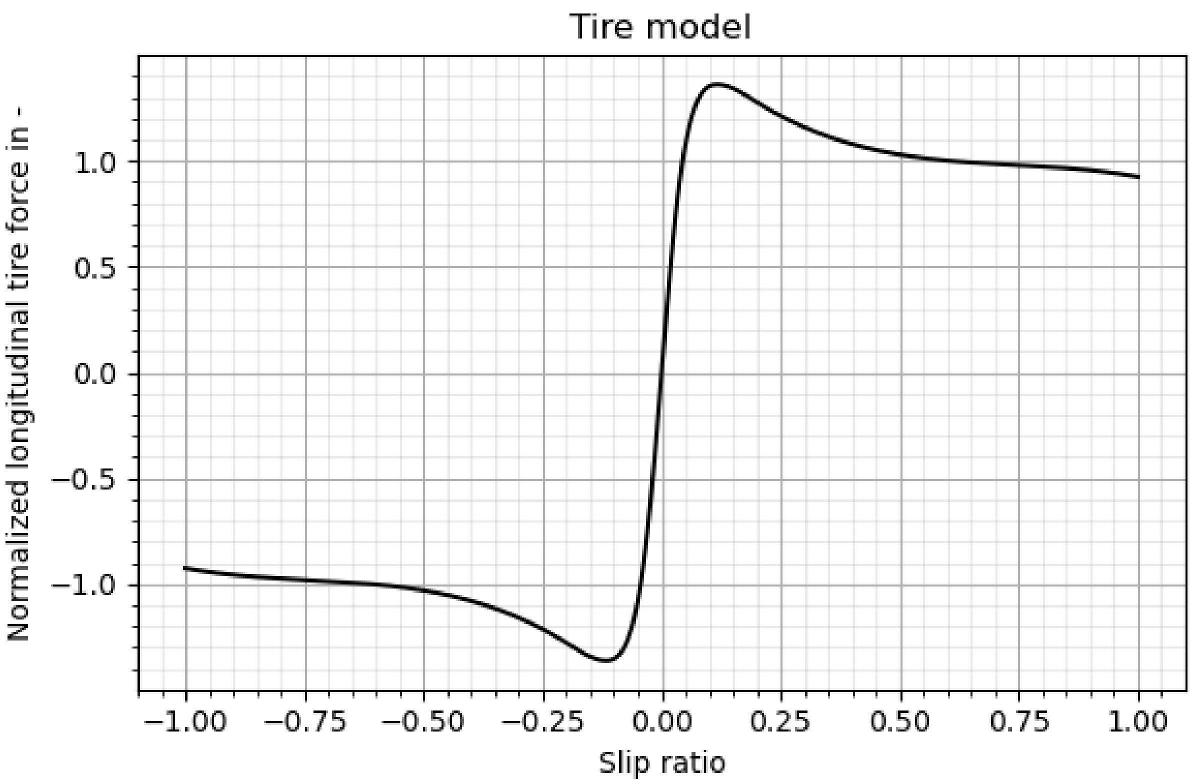

Figure 3: Tire model used in BikeSim

An episode consists of a full brake until standstill in purely longitudinal motion. For each episode the following variables are drawn uniformly random from a predefined range:

Table 1: Randomly sampled simulation parameters.

Parameter	Min	Max	Unit
Friction coefficient	0.5	1.0	-
Brake lever force front	0	400	N
Brake lever force rear	0	400	N
Brake lever force gradient front	400	20000	N/s
Brake lever force gradient rear	400	10000	N/s
Initial speed	80	120	km/h

Algorithm

Due to its impressive results, we use the soft-actor critic algorithm, first described by Haarnoja et al. [3]. It handles the exploration-exploitation dilemma by simultaneously maximizing the expected (discounted) return as well as entropy.[4]

In order to tackle the aforementioned problem of partial observability, we introduce a LSTM layer into our value- and policy networks, giving the agent the possibility to learn a latent representation of the belief state.

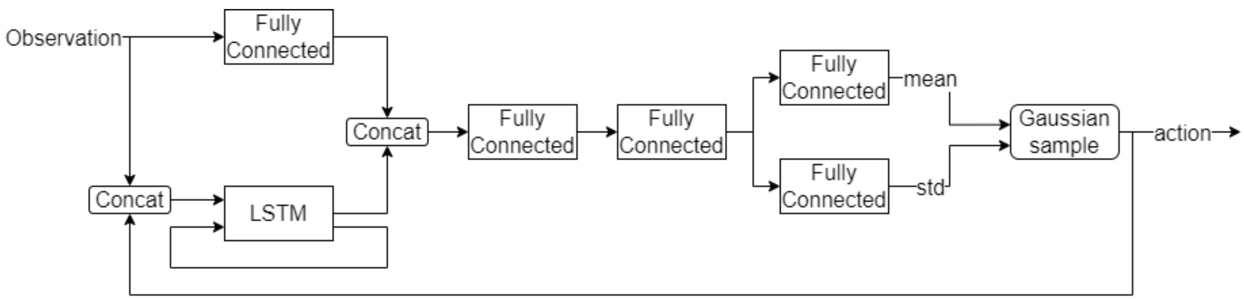

Figure 4: Policy network architecture

Figure 4 shows a schematic of the used policy network. It consists of a fully connected branch and a LSTM branch, that are then concatenated and fed into two more fully connected layers. The output is fed into a fully connected layer each in order to output a mean and standard deviation of a Gaussian distribution, that is then sampled in order to obtain the action. All hidden layers have the same dimension. The same basic architecture is used for the value networks as well, albeit with only one output for the state-action-value. We found that the algorithm is very robust against changes of the hyperparameters.

Results

In the following, some exemplary training and evaluation results are given.

Training

Every twenty episodes we run an evaluation episode with the following fixed parameters, in order to track the training performance.

Table 2: Parameters for the evaluation episodes

Parameter	value
Friction coefficient	0.7
Brake lever force front	300 N
Brake lever force rear	300 N

[4] The formal introduction of deep reinforcement learning algorithms is out of the scope of this work. The spinning up documentation by OpenAI[9] is an excellent starting point for the interested reader.

Brake lever force gradient front	5000 N/s
Brake lever force gradient rear	500 N/s
Initial speed	80 km/h

These evaluation episodes are not fed into the replay memory and are thus not trained on. We record the braking distance as well as the proportion of time any wheel is below a slip of -0.8, which is considered a locked wheel.

In figure 5 a typical write out of those evaluation runs during training can be seen.

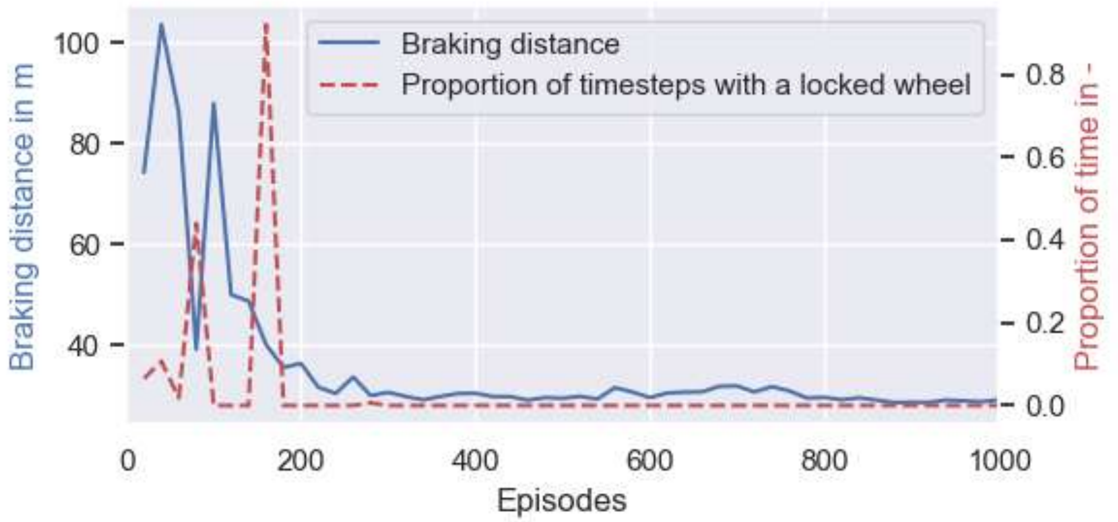

Figure 5: Write out of the braking distance and the proportion of time any wheel is locked of evaluation runs during training

After roughly 200 episodes, the agent prevents any of the wheels from locking, albeit with suboptimal braking performance. At this point the agent associates that a wheel speed of 0 will result in 0 reward. This leads to a reduction in pressure at the end of episodes, when the wheel speeds approach 0. Given more agent-environment-interactions though the braking performance improves drastically, as can be seen in the next section.

Slip Control

Figure 6 is an exemplary run with a sudden friction coefficient change. The friction coefficient of the road drops from a 0.8 to a 0.4 and back up to a 0.8, as indicated by the gray line plot. As soon as the friction coefficient drops, the agent reduces the brake pressure in order to recapture the wheel and hold it in a stable condition. Similarly, the agent increases the brake pressure as soon as the friction coefficient increases to 0.8. Figure 7 shows the acceleration during a maneuver on a road with a constant friction coefficient of $\mu = 0.5$. Given the tire model used in figure 3, with a peak at a value of 1.4, the theoretical optimum in this environment is a deceleration of $1\text{g} \cdot 1.4 \cdot 0.5 = 0.7\text{g}$. Over a large portion of the environment, the agent reaches almost this theoretical optimum.

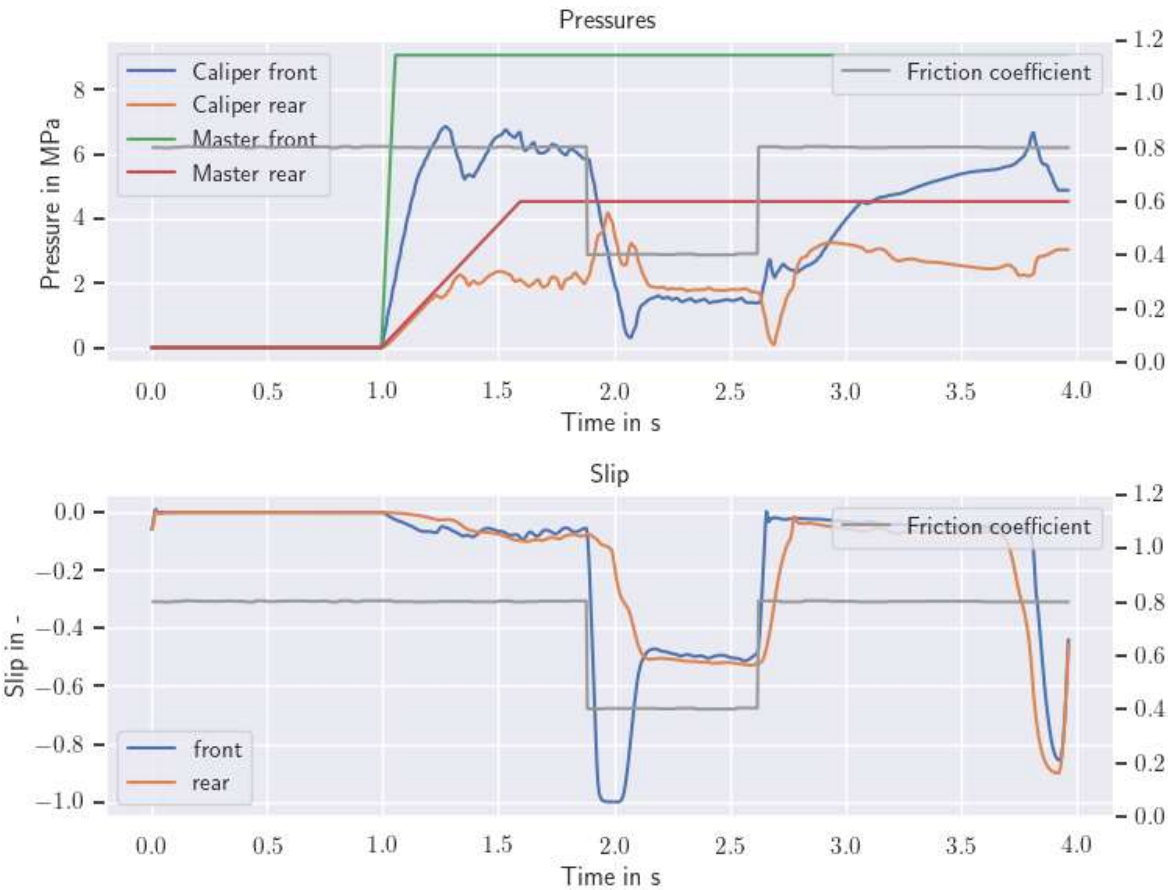

Figure 6: ABS Control on a road with a jump in the friction coefficient. Top: Pressures at the caliper and master cylinders; bottom: slip at the front and rear wheel; gray: road friction coefficient μ under the front wheel

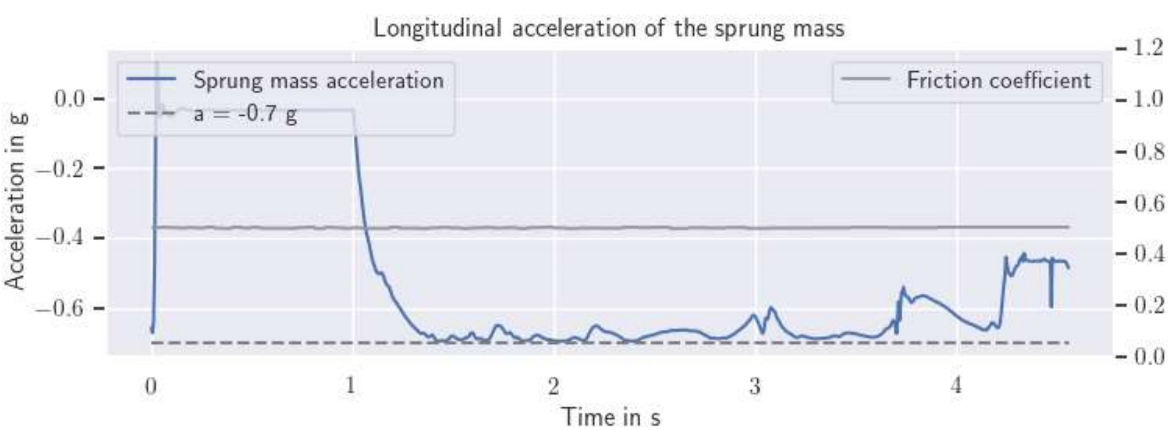

Figure 7: Acceleration of the sprung mass during ABS control on a road with a constant friction coefficient of 0.5; gray: road friction coefficient μ under the front wheel; gray, dashed: constant acceleration of -0.7

Rear wheel lift-up mitigation

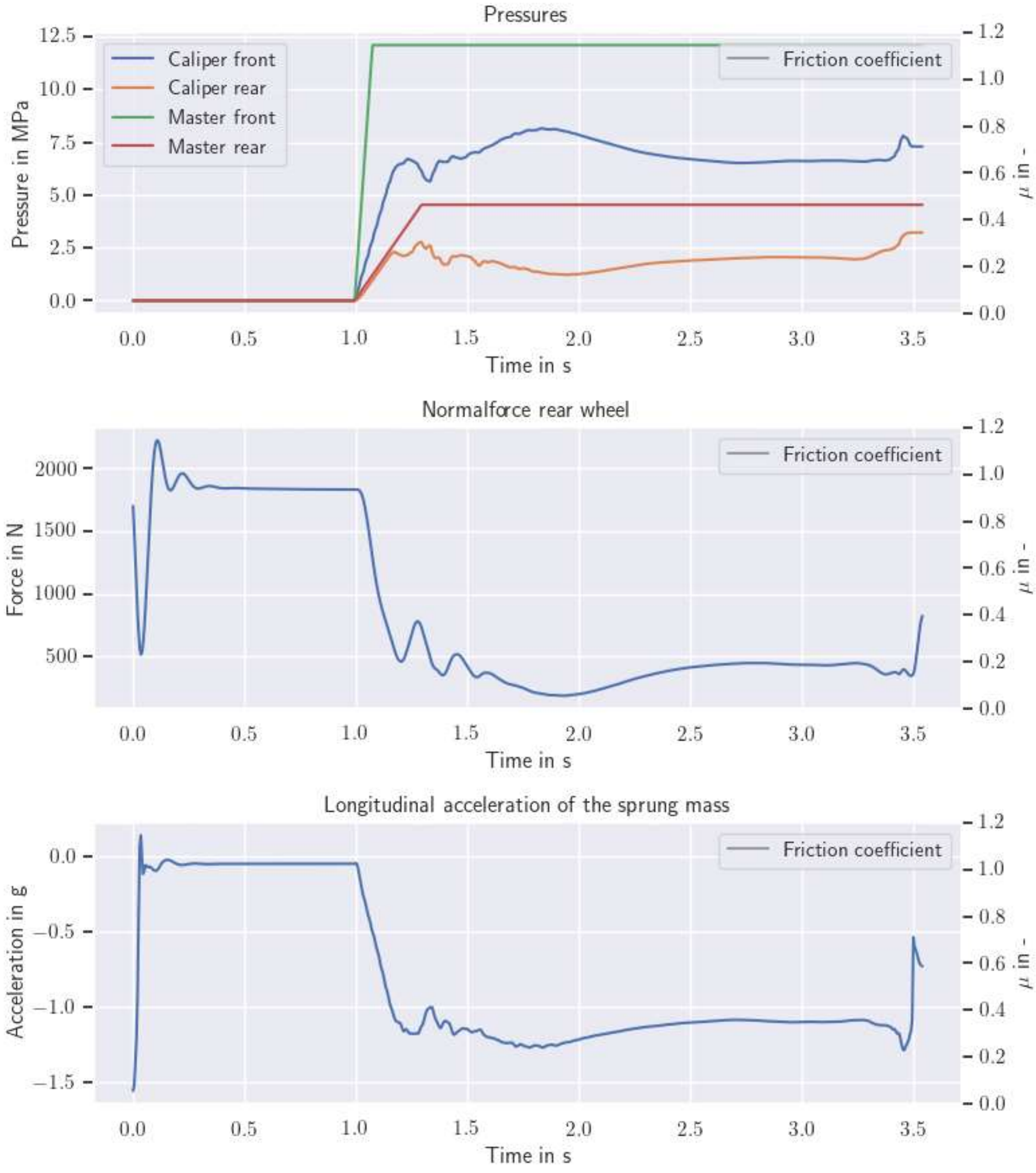

Figure 8: ABS Control on a road with a high friction coefficient of 1.2 in order to test the rear wheel lift-up mitigation. Top: Pressures at the caliper and master cylinders; middle: Normal force on the rear tire; bottom: acceleration of the sprung mass.; gray: road friction coefficient μ under the front wheel

As mentioned in the introduction, the mitigation of a lift-up of the rear wheel is traditionally part of the ABS controller in motorcycles. Even though a rear wheel lift-up mitigation was not considered in the formulation of the POMDP, the agent learned to successfully mitigate a lift-up of the rear wheel. The reasoning we suppose is that the agent cannot gain any more reward, if the episode ends prematurely due to the lift-up.

Figure 8 shows brake pressures as well as the normal force at the rear tire for an episode, that is deliberately chosen to provoke a lift-up of the rear wheel. The road has a friction coefficient of 1.2 and the rider is applying 400 N and 300 N of brake lever force at the front and rear brake respectively.[5] The agent successfully mitigates a lift-up by reducing the pressure at the front caliper, while reaching a very high deceleration. This can be seen by the small positive normal force as well as the high negative acceleration in figure 8.

Without the IMU

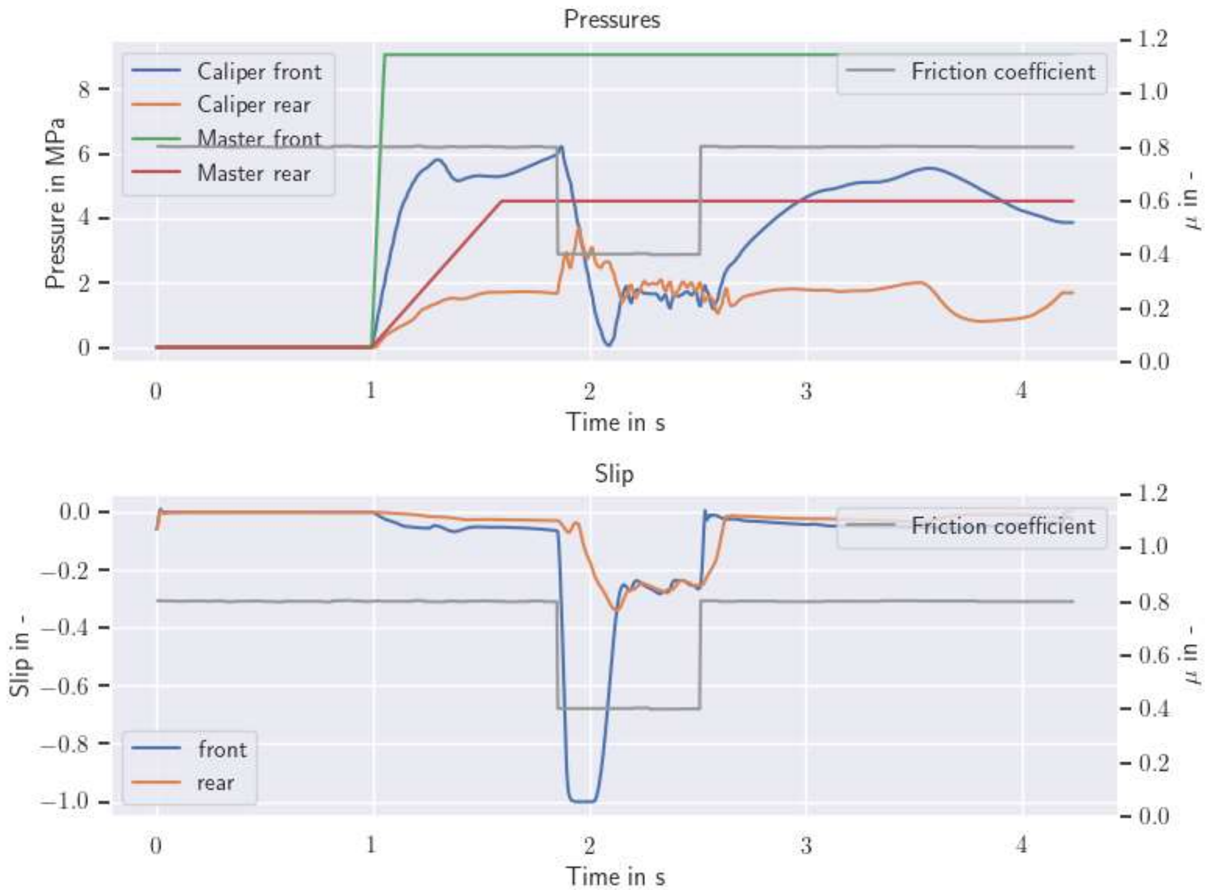

Figure 9: ABS Control with only wheel speeds and wheel accelerations in the observation space

Figure 9 shows a run without the IMU in the observation space. In this case the agent also keeps the wheels from locking, and the overall performance is very similar to the run with the IMU. Without the IMU, the agent reaches a mean deceleration of 0.54 g, compared to 0.58 g with the IMU, leading to a braking distance that is 3.09 m longer.

[5] The agent also mitigates a lift-up if the rear brake is not applied.

Summary and conclusions

In this research study we presented a method for generating an ABS controller using deep reinforcement learning. The MDP was formulated and solved approximately using a Soft Actor Critic algorithm with recurrence in simulation. While the primary motivation for this research is to reduce calibration effort, the results shown promise possible performance improvements as well. The ABS controller performs almost optimally in the slip control case and achieves good results in mitigating a lift-up of the rear wheel.

In contrast to related work, we did not call for the vehicle speed over ground in our state space definition, since it is difficult to estimate, especially in two-wheeled vehicles.

It could also be shown, that the approach is feasible for solving the ABS problem even without an IMU, albeit with slightly worse performance. This shows the flexibility in using a data driven approach for wheel slip control.

In order to assess the viability of the approach on real vehicles, further research is necessary. Namely, in this research we used ideal sensor data from the simulation, and it is not trivial that the same findings hold true with real and noisy sensor data. Similarly, in real applications the agent needs to be robust against transmission delays.

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BMW GROUP

BMW MOTORRAD

BMW'S HOLISTIC VIEW ON MOTORCYCLE SAFETY

Dennis Gerber, Ulrich Zoelch

MOTORCYCLE RIDERS ARE VULNERABLE ROAD USERS.

The BMW Group's safety strategy stands for an collaborative approach between motorcycle and passenger cars.

BMW Motorrad Safety Strategy

Reduction of riding errors and risks via:

- Technology
- Rider safety training
- Personal protective equipment (rider gear)

BMW Automotive Safety Strategy

Protection of Motorcycle riders:

- Accidentology including motorcycle scenarios
- Research on effectiveness of active safety systems
- Implementation of active safety systems in cars considering motorcycle specific characteristics

The BMW Group's safety strategy is an overarching safety approach which takes the interaction of passenger cars and motorcycles into account (joint working groups, combined validation and test events, development and adoption of systems).

BMW MOTORCYCLES ARE PREMIUM PRODUCTS EQUIPPED WITH STATE-OF-THE-ART SAFETY SYSTEMS.

Safe Driving

Rider safety training:	Rider Camps (driving licence training), Safety Training, "Ride Again" Training

Crash Avoidance

DRL:	Daytime Running Light
ABS (Pro):	Anti-lock Braking System (Professional)
DTC:	Dynamic Traction Control
ASC:	Automated Stability Control
ESA:	Electronic Suspension Adjustment (with damping and preload adjustment)
TPM:	Tire Pressure Monitor
Riding modes:	Road, Rain, … (e.g. adjusted throttle response to difficult road conditions)
Navigation System:	Safe navigation and less driver distraction
Active Cruise Control:	Keeps safe distance to vehicles ahead
Side View Assist:	Blind Spot Detection
Dynamic brake light:	Detects hard deceleration and warns following vehicles

Crash Protection

Personal Protective Equipment:	Rider Crash-Protection (Helmet, suits, boots, gloves …)

Post-Crash

eCall:	Automated emergency call, exclusive for BMW Motorrad

- BMW Motorrad TOP development goals: Rideability, controllability and best ergonomics.
- Constant development of new premium safety systems.

MOTORCYCLE SAFETY: ACCIDENT RESEARCH FINDINGS.

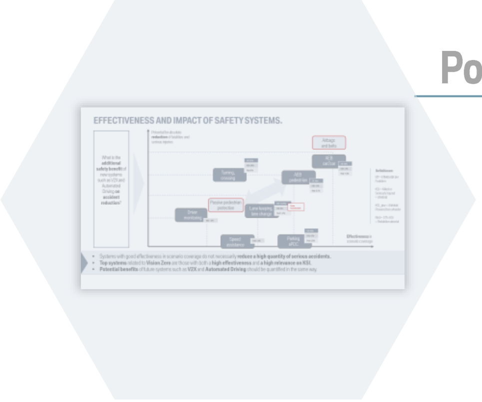
Research on Motorcycle accidents

Riding accidents:
Main cause is loss of control over the motorcycle.
Collision type accidents:
In approx. 80% the opponent is a passenger car.

Influence of the car - accident scenarios from MUSE project, GIDAS, CMC

Influence of the rider

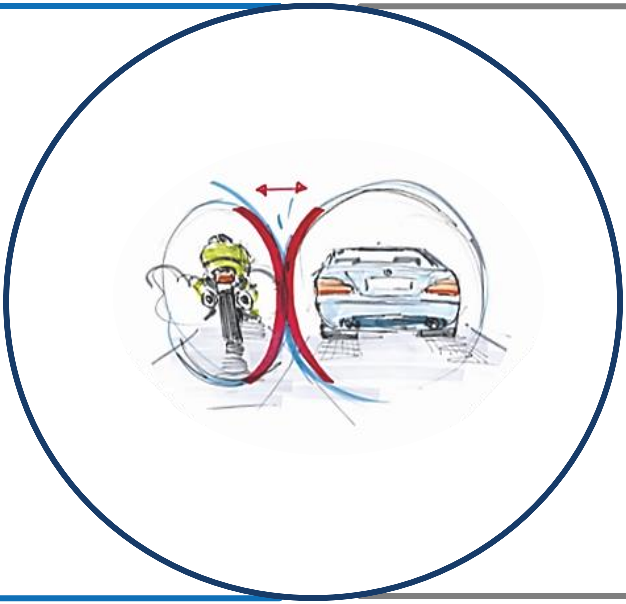
‚Riders are not the same as drivers'.
1) ‚High risk riders': They go to the limits of riding dynamics and vehicle technology on public roads.
→Not reachable by legal and consumer test ratings
2) Safety oriented riders:
- Riding skills are crucial
- Technical systems need to be controlled in order to benefit
→Certified rider safety trainings



Potential und Effectiveness

- Improving riding skills through continuous rider trainings is the foundation to avoid all types of motorcycle accidents.
- Active safety systems in passenger cars do have a high potential to reduce collision accidents.

MOTORCYCLE SAFETY AND MOTORCYCLE RIDER PROTECTION.



Motorcycle Safety

Goal: To maximize real world safety
- in addition to legal and consumer test ratings
- related to Automated Driving

Motorcycle Rider Protection

- BMW Motorrad holds responsibility for Motorcycle Safety.
- BMW Vehicle Safety holds responsibility for Vehicular Safety, NCAP and Motorcycle Rider Protection.
- At BMW Group both departments are working hand in hand in order to enhance road safety.

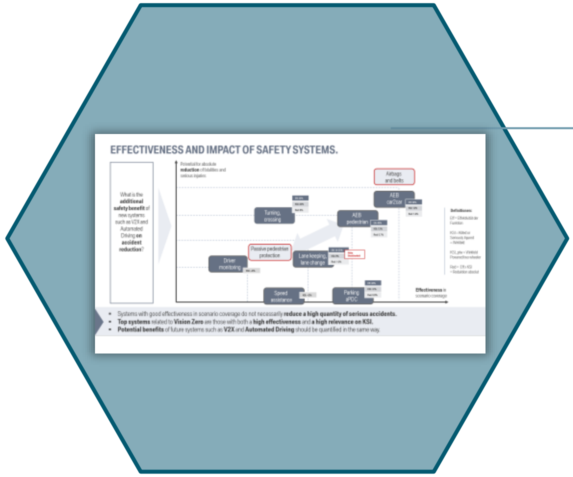
MOTORCYCLE RIDER PROTECTION: ACCIDENT RESEARCH SHOWS THE NEED FOR ACTIVE SAFETY SYSTEMS IN PASSENGER CARS.

Accident research on motorcycle accidents

Influence of the car - accident scenarios from the projects MUSE, GIDAS, CMC

Ranking of severe collision type accidents:
In most cases the accident is caused by the car driver.
1) Crossing traffic
2) Left turn/ farside turn

Influence of the rider



Potential und Effectiveness

Active safety functions
show a high potential
at crossing and turning scenarios.

MUSE: Motorbike Users Safety Enhancement
GIDAS: German in-Depth Accident Study
CMC: Connected Motorcycle Consortium

- More than half of the collision accidents with vehicles occur at junctions, in vast majority the car driver is the main causer.
- BMW sees the highest potential for mitigation of severe accidents in active safety systems in cars for crossing and turning.

ACCIDENT RESEARCH BASED ON EUROPEAN DATABASES SHOWS THE MAIN TYPES OF ACCIDENTS.

CMFtap
Use Case

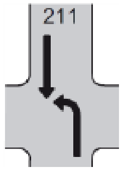
CMC
Use Case

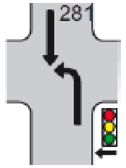
CMR
Use Case

TAP
Use Case

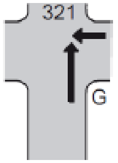
Results from MUSE Project

1) Left Turn Across Path – Opposite Direction 16,03%, U-Types 211, 281...............

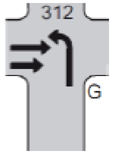




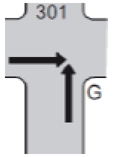
2) Straight Crossing Path – Right Direction 12,84%, U-Type 321........



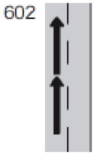
3) Left Turn Across Path – Left Direction 11,29%, U-Types 302, 312....................

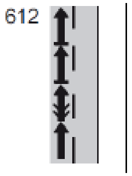


4) Straight Crossing Path – Left Direction 5,83%, U-Type 301.............

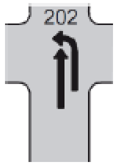


5) Follow-Up Driving 5,77%: U-Types 602, 612, 603 ....





6) Left Turn Across Path – Same Direction 5,01%: U-Types 202, 721,



CMFtap: Car to Motorcyclist Front - turn across path
CMC: Car to Motorcyclist Crossing
CMR: Car to Motorcyclist Rear
TAP: Turn Across Path

- Source: https://www.utacceram.com/testing-expertise/safety/active/muse-project
- The sum is 71% (due to weighting), the respective proportion of collision accidents is therefore 1.4 times higher
- KSI: Killed or seriously injured type accidents quantified

- The most frequent collision accident types are left turn and turning/crossing.

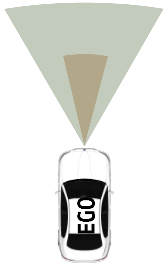
DETECTION PERFORMANCE OF BMW'S ONBOARD-SENSOR SYSTEMS ON MOTORCYCLES.

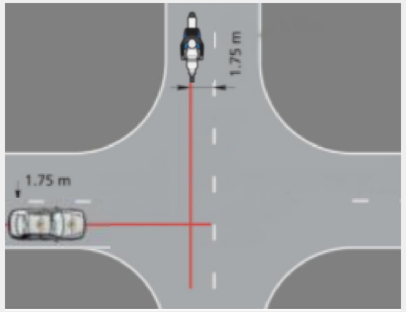
Motivation

- Validation of passenger car onboard-sensor systems regarding the detection performance on real motorcycles in addition to surrogates.

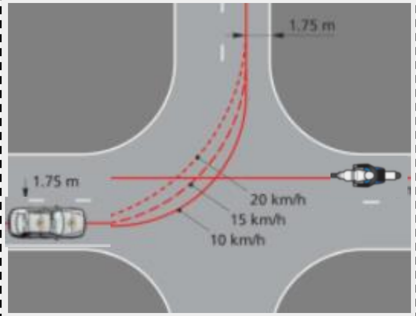
Test setup

- Several Tests were carried out in relevant scenarios for active safety functions with various vehicle configurations and different types of motorcycles.

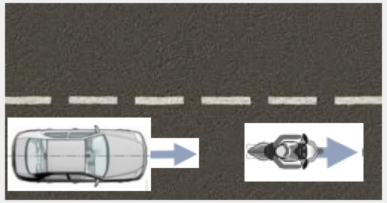




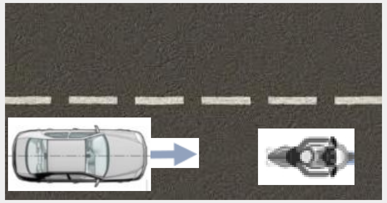
Car to Motorcyclist Crossing



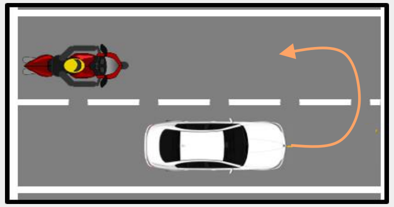
Car to Motorcyclist Front – turn across path



Car to Motorcyclist rear – moving powered two-wheeler



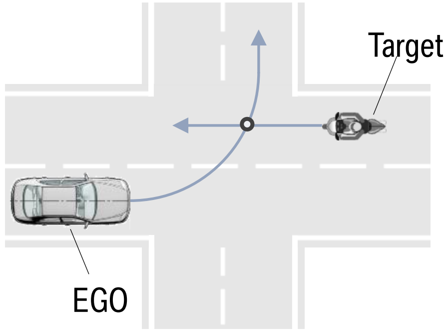
Car to Motorcyclist rear – stationary powered two wheeler



Turn Across Path – same direction

BMW's active safety systems are developed to detect real motorcycles and scooters.

LEFT TURN ACCIDENTS INVOLVING MOTORCYCLES AND CARS: ACCIDENT DATA ANALYSIS AND BMW ACTIVE SAFETY FUNCTION.



Front collision warning and braking function for turning with oncoming traffic
- Active safety function for turning situations in case of oncoming traffic
- The function reacts on oncoming motorcycles and cars up to 100 kph
- Basic configuration in the latest generation of BMW ADAS systems launched 2021

Data basis GIDAS Germany:
- Data freeze 7/2020
- Passenger cars (M1/N1) and motorcycles (> 125ccm) involved
- Accidents causing severe and fatal injuries (KSI)

Motorcycle target speed [km/h]

EGO-vehicle speed [km/h]	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	120
0	0,00%	0,00%	1,05%	1,05%	0,00%	2,11%	0,00%	0,00%	2,11%	0,00%	1,05%	0,00%	0,00%	0,00%	0,00%	0,00%
5	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	1,05%	1,05%	1,05%	1,05%	0,00%	1,05%	0,00%	0,00%	1,05%	1,05%
10	0,00%	0,00%	1,05%	0,00%	1,05%	1,05%	0,00%	0,00%	0,00%	1,05%	1,05%	0,00%	1,05%	1,05%	0,00%	0,00%
15	0,00%	1,05%	2,11%	2,11%	6,32%	3,16%	2,11%	0,00%	1,05%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
20	0,00%	0,00%	3,16%	0,00%	3,16%	2,11%	1,05%	0,00%	0,00%	1,05%	1,05%	0,00%	0,00%	1,05%	0,00%	0,00%
25	1,05%	1,05%	1,05%	2,11%	2,11%	1,05%	1,05%	1,05%	1,05%	1,05%	0,00%	1,05%	0,00%	0,00%	1,05%	0,00%
30	1,05%	1,05%	0,00%	0,00%	4,21%	3,16%	0,00%	0,00%	2,11%	0,00%	2,11%	0,00%	1,05%	0,00%	1,05%	1,05%
35	0,00%	0,00%	2,11%	1,05%	3,16%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
40	1,05%	0,00%	0,00%	0,00%	0,00%	1,05%	0,00%	1,05%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	1,05%	0,00%
45	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	2,11%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
50	0,00%	0,00%	0,00%	0,00%	1,05%	0,00%	1,05%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
55	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	1,05%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%

Euro NCAP 2023*

Extended System

*) Euro NCAP AEB CMFtap:
Automated Emergency Brake
Car to Motorcyclist Front turn across path

- There is a significant amount of severe accidents involving motorcycles oncoming with velocities up to 100 kph.
- The BMW active system is capable to cover >40% more of severe accidents compared to the related Euro NCAP test scenario.

BMW LEFT TURN WARNING INCLUDING AUTOMATED BRAKE ACTIVATION CAR TO MOTORCYCLIST FRONT - TURN ACROSS PATH USE CASE.

BMW GROUP

BMW MOTORRAD

THANK YOU

MAKE LIFE A RIDE

03/10/22
GERBER, ZOELCH

CURRENT AND NEAR FUTURE CHALLENGES FOR THE PTW COMMUNITY IN EUROPE: FEMA – FIM EUROPE CONSIDERATIONS

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Abstract

In 2014, FEMA and FIM Europe started to investigate where their views could meet on recent and future PTW related issues. To this purpose a Working Group was initiated with members from FIM Europe and FEMA. The Working Group has identified four areas that are addressed by position papers. The areas are: A. Vehicle technology, B. Road infrastructure, C. PTW rider and D. Mobility aspects. Except safety issues for the PTW riders, the WG considers the new challenges of environmental protection and energy sources that have become an important issue for the coming decade and beyond.

Keywords: Powered Two Wheelers (PTW), PTW future challlenges, FEMA-FIM position papers

1. Introduction

In 2014, FEMA and FIM Europe started to investigate where their views could meet on recent and future PTW related issues, and the results of these discussions were laid down on several joint position papers. This was done in the FIM-FEMA Working Group that exists of delegates from both federations. The first set was published in 2015 and since then they are revised every two years by this working group.

2. Methods

The Working Group has identified four areas that are addressed by position papers. The areas are: A. Vehicle technology, B. Road infrastructure, C. PTW rider and D. Mobility aspects. Its paper provides a general description of the addressed issue, followed by the definition of the problem or the benefits for the PTW community and lastly there is a section with recommendations for improvement.

In the "Vehicle technology" area, the topics of Intelligent Speed Assistance (ISAs), Personal Light Electric Vehicles (PLEVs), Advanced Driver Assistance Systems (ADAS), Advanced Rider Assistance Systems (ARAS) on Powered Two-Wheelers, Powered Two-Wheelers and the environment, and Repair and Maintenance Information (RMI) have been identified as urgent ones. "Road infrastructure" includes the topics: Powered Two-Wheelers high risk spot and network safety management, Powered Two-Wheelers safe infrastructure, Road restraint systems and Traffic calming devices. The remaining area, C and D, are discussed in the topics Initial training and licensing (C), Powered Two-Wheelers Safe Systems (D), and Powered Two-Wheelers and mobility (D).

All area topics are descripted in detail in the following sections.

3. Vehicle Technology

3.1. Intelligent Speed Assistance (ISA)

From 2022 new cars will be fitted with an intelligent speed assistant (ISAs) system. This system will alert drivers in a haptic way when they are speeding. Motorcyclists need to be aware of a possible introduction for PTWs too.

The working of ISA is that a vehicle is fitted with a camera that recognizes traffic signs and/or a database of traffic signs locations connected to a satellite receiver. When this system notices that a vehicle is speeding, either the engine power is temporarily limited (intelligent speed adaptation or ISAd) and/or the driver is warned by a visual or acoustic signal or in a haptic way (intelligent speed assistance or ISAs). In present schemes, the driver is always able to override the system and it is always possible to switch it off.

Speed is a complex factor. According to the International Transport Forum (ITF) [1], it can influence the crash process at three different stages:

- At the driving phase, the driver can be in a situation that he cannot react or act on time.
- At the emergency phase, inappropriate speed can prevent the driver from efficiently regulating the vehicle direction and decelerate properly to compensate for a delicate situation.
- At the collision phase, speed can drastically increase the crash severity due to the kinetic energy dissipated during the crash. ISA is expected to reduce collisions by 30% and fatalities by 20% by mass installation in vehicles [2]. It also helps drivers and riders to avoid speeding tickets and focus more on the road instead of the speedometer.

Table 1. *Intelligent Speed Assistance (ISA) considerations*

ISAs or ISAd for PTWs
➢ PTWs have different dynamics than cars. Full control of speed is essential for the control of PTWs and the direction in which it goes. A system that prohibits acceleration (ISAd) is dangerous for motorcyclists due to reduced active safety and therefore not acceptable. ➢ ISAs for PTWs should only be implemented when it is beneficial for road safety. ➢ This leaves the question open if ISAs that only requires more effort from the rider to accelerate (through a greater resistance of the throttle) when he/she is speeding or going to speed is acceptable. We think that this is too dangerous and therefore not acceptable. ➢ Any form of ISAs should only be implemented when it is tested thoroughly first and these tests prove that there is no extra risk for the rider. ➢ Installation of an ISAs device should not come at high costs and should not be heavy. ➢ Any kind of ISAs should be overridable and the rider must be able to switch it off. ➢ ISA systems should be designed and fitted in a standardized way and work in the same way on all PTWs.

3.2. Personal Light Electric Vehicles (PLEVs)

Worldwide, especially in the cities, a growing number of people are using personal light electric vehicles (PLEVs), to move on the streets; e.g. electrically powered step type “scooters” and other devices such as Segways, monocycles and powered skateboards. Bicycles, fully electric or with electric pedal assistance, are also becoming more common. Some of the bicycles have at least as much power as a L1e-B moped, and an electric kick-scooter has been seen on the road doing over 80kph. Users may choose to use them in pedestrian, cycle or vehicular space on the street. Most of these vehicles are currently not subject to any form of registration, or any other regulation usually associated with the use of vehicles such as type approval, driver training and licensing, third party insurance and the use of protective equipment. Only some of the applicable regulation is made at EU level and may be subject to variations of implementation by Member States. In some cities a significant number of injuries are being sustained by the users of these vehicles.

It is not within the remit of FEMA or FIM to presume to specify what regulations should be applied to the manufacture and the use of vehicles which are not mopeds or motorcycles. However, we do have concerns about their use since their users fall, as motorcyclists do, into the category of vulnerable road users.

Table 2. *Personal Light Electric Vehicles (PLEVs) considerations*

Personal Light Electric Vehicles (PLEVs)	
Considerations	➢ Collision and injury data relating to these vehicles must be collated separately from that relating to motorcycles, mopeds, or bicycles. This is a major concern for us as we do not want to have the collision data for powered two-wheelers (PTWs) skewed by the inclusion of powered vehicles which are not subject to the same regulations. ➢ Consideration must be given as to what regulation, if any, should apply to these personal light electric vehicles. ➢ We propose to create a separate category for PLEVs to distinguish them from bicycles, electric assisted bicycles, mopeds, motorcycles, and other L-category vehicles.
Vehicle demands or test specifications should include	➢ The possibility of specific vehicle categorisation ➢ Maximum allowable speed ➢ Braking capability ➢ Lights ➢ Provisions for audibility of the vehicle ➢ Cyber security, where applicable

3.3. Advanced Driver Assistance Systems (ADAS)

Advanced Driver Assistance Systems (ADAS) cover a wide range of systems and applications and provide personal assistance to drivers. In this context we mean ADAS for cars. ADAS can draw attention to approaching traffic and stationery or slow-moving vehicles, signal road users in the drivers' blind spot and provide prior knowledge of the traffic situation ahead. Some systems actively interfere by braking, by applying additional braking force or interfering with the steering or speed of the vehicle. In a number of situations and in certain circumstances, ADAS can completely take over the task of the driver. ADAS can work autonomously or in connection with other vehicles (V2V) or with the infrastructure (V2I/I2V).

The effects of ADAS on powered two-wheelers (PTWs) are considered the following:

- Riders can benefit from ADAS by better visibility, especially in combination with V2V connectivity like developed by the Connected Motorcycle Consortium (CMC) of which FIM Europe and FEMA are supporters. ADAS devices can also prevent accidents where drivers are not aware of motorcyclists, especially in situations where a car is crossing the lane of oncoming traffic, or when a car driver's vision is obscured at crossings.
- In the transition period when many PTWs belong to a declining number of non-automated and non-connected vehicles, this can cause risks if ADAS devices in cars assume connectivity and digital visibility.
- ADAS can lead to an overflow of information, thus leading to distraction and diversion.

Table 3. *Advanced Driver Assistance Systems (ADAS) considerations*

Conditions for ADAS to be safe and acceptable for PTWs
➢ PTWs differ from other non-connected road users like bicycles and pedestrians in speed and acceleration. ADAS devices must be developed with all kinds of vulnerable and non-connected road users in mind, should always be tested with PTWs and must comply with UNECE regulations. ➢ ADAS devices must be developed and tested with non-ADAS equipped road users in mind. ➢ Optional retrofitting of devices, such as beacons, on motorcycles must be possible and allowed to enhance (digital) conspicuity

3.4. Advanced Rider Assistance Systems (ARAS)

ARAS covers a wide range of systems and applications that provide personal assistance to riders. ARAS can draw attention to approaching traffic, signal road users in the riders' blind spot, assist the rider in directing his attention to relevant information, provide prior knowledge of the next traffic situation, warn the rider of obstacles in his path. ARAS can work autonomously or in connection with other vehicles (V2V) or infrastructure (V2I/I2V). In this case it is a Connected ITS (C-ITS) device.

Effects of ARAS on PTWs can be:

- Existing vehicle safety systems, such as ABS, lean ABS (or cornering ABS) and traction control, have already proved beneficial to motorcycle road safety. Other devices can be just as beneficial if the rider is allowed a full control of the throttle, both deceleration and acceleration, braking and steering.
- Systems can give warnings to riders about speed limits, oncoming curves, traffic jams ahead, damaged roads etc. However, this can also result in information overload. Special attention is needed for fully functional human machine interfaces (HMIs) that filter the needed information and cause no danger by their design.
- The situation may occur where many PTWs belong to a declining number of non-automated and non-connected vehicles, which can cause risks if ITS devices of other vehicles assume connectivity and digital visibility.

Table 4. *Advanced Rider Assistance Systems (ARAS) considerations*

Conditions for ARAS to be safe and acceptable for PTWs
➢ ARAS devices for PTWs must not take over the control of throttle and steering from the rider with present technology. ➢ Mandatory devices must be tested on benefits for comfort and road safety and should not be implemented unless it is certain that they do not affect safety in a negative way. ➢ Roads should always remain accessible for vehicles that are not controlled by electronic systems, and are not connected with other vehicles and/or infrastructure. ➢ Retrofitting of devices that connect PTW with other vehicles and/or infrastructure should be possible and allowed, but should not be mandatory. ➢ Data must be secure, controlled by the vehicle owner and privacy should be guaranteed.

3.5. PTWs and the environment

The European Union has laid down several goals to decrease the emission of especially CO_2, PM, and NOx. National and local authorities are also trying to reduce CO2, PM, and NOx emissions. Some have already banned or are planning to ban older vehicles, including PTWs, or demand high tolls to enter cities, e.g., Paris and London. Furthermore, taxation schemes are being developed that are based on fuel consumption, exhaust emissions and sound. These developments demand an appropriate answer from the motorcycle industry and motorcyclists to preserve a role in future mobility schemes.

There is an evident contribution of PTWs to a cleaner environment. PTWs are smaller and lighter than cars and therefore already contribute to less fuel consumption and less pollution. They also need less space in traffic and parking, which also contributes to a better flow in traffic and thus less pollution. Because PTWs can keep moving where cars are stuck in traffic jams, they use less fuel and pollute less. Motorcycles have become much cleaner in the last decades and have become even cleaner with the implementation of the Euro 5 emission limits in 2020. Less energy and material are needed to produce and scrap PTWs compared to cars, because PTWs are smaller than cars and much less material and energy is used to make them. Electric PTWs for urban use are much cheaper than electric cars, with swappable batteries as agreed by the PTW manufacturers. The break-even for electric PTWs will be much lower.

Table 5. *PTWs and the environment protection considerations*

Actions to make PTWs cleaner
➢ PTW riders should be aware of the fuel consumption and emissions of their motorcycles and make a balanced choice when they purchase a new motorcycle. To be able to do this the manufacturers of motorcycles should provide motorcycles with consumer-information about fuel consumption, CO, NOx, and CO2 emissions. ➢ PTW riders should be aware that their behaviour affects the impact they have to their surroundings, especially the sound emissions, and therefore need to behave in a proper and social way. ➢ Manufacturers of PTWs should keep on developing cleaner PTWs by enhancing the environmental performance of internal combustion engines, and at the same time develop towards zero emission engines. ➢ Charging for electric PTWs should be encouraged by implementing simple and universal payment systems and creating secure and dedicated charging and parking facilities for PTWs. ➢ Development of a circular system to process old batteries is crucial.

3.6. Repair and Maintenance Information (RMI)

Repair and maintenance information (RMI) is information that is stored in electronic devices which are part of the vehicle. RMI can be accessed by universal or special connectors or on-line. RMI means all information required for diagnosis, servicing, inspection, periodic monitoring, repair, re-programming, or re-initialising of the vehicle, which the manufacturers provide for their authorised dealers and repairers, including all subsequent amendments and supplements to such information. This information includes all information required for fitting parts or equipment on vehicles.

RMI is vital for the functioning of the PTWs and therefore for the rider. Without access to the RMI, repair shops, roadside assistance services and owners of vehicles who, for whatever reasons, do their own maintenance and repairs, may not be able maintain and repair their vehicle. RMI stores a large amount of data on the vehicle itself. Such data can be accessed via an external device or might even be transmitted to the manufacturer wireless. Therefore, ownership of data and privacy are at stake. The rider needs to be able to perform repairs and maintenance where it is very hard or even not possible to have this done in a workshop.

Table 6. *Repair and maintenance information (RMI) considerations*

How to handle RMI
➢ Riders own the RMI and have the right to know what data is generated and how it is used. ➢ Riders must have the ultimate right to decide who has access to the RMI and what is being done with it. ➢ RMI should be accessible by the owner, or anyone who is delegated to this by the owner, by way of a standardized connector, at no extra cost. ➢ The access to RMI should be secured, especially against attacks from cyberspace. No unauthorized access to the data of the PTW or interference with the handling of the motorcycle must be possible through the RMI interface.

4. Road infrastructure

4.1. High risk spot and network safety management

To enhance PTW road safety, a safe road infrastructure is essential. This starts with a safe road design. However, accidents can occur, and infrastructure can be less safe than expected and desirable. Therefore, PTW high risk (or blackspot) management (HRSM/BSM) is an essential part of the site-specific traffic safety work done by the road authorities and concerns short road sections (< 0.5 km). Supplementary to this is network safety management (NSM) that concerns longer road sections (2-10 km). Both high risk spots management and network safety management concern all infrastructural aspects, but both HRSM/BSM and NSM lack standardised definitions and methods. Authorities must realise that roads should be safe for every road user and roads that are safe for PTW-riders are safe for every road user.

Table 7. *High risk spot and network safety management considerations*

High risk spot and network safety management	
High risk spot detection and registration	➢ Regular road inspections must be done with and include a PTW focus. ➢ Systematic accident data collection will reveal places and stretches of roads that are particularly PTW accident prone, needing further investigation and follow-up measures.
High risk spot safety management	➢ As PTW accidents are rare occurrences and spread over the road network it is virtually not possible to identify a high-risk spot simply by the number of accidents. Therefore, road authorities should adopt the British Critical Crash Rate Factor Method, or other systems that are aimed at identifying the high-risk spots, as these consider additional factors, including traffic volume, to assess risk. ➢ High risk spot management and network safety management should be part of the safety policy of the European Union and non-EU governments with special attention to vulnerable road users, including riders of powered two-wheelers. ➢ High risk spot management should include all public roads.

4.2. Safe infrastructure

Road infrastructure is developed with two-track vehicles in mind. The design of roads, the tests of roadside and median barriers, poles, road surfaces and everything else that is part of or next to a road is done from the perspective of car drivers. Powered two-wheelers (PTWs) are by their design different from cars and have different needs. PTWs are one-track vehicles and as such are more sensitive than cars to unevenness, slippery and polluted road surfaces, badly maintained or repaired road surfaces and poorly applied markings on the road. Motorcyclists have no protective cage like car drivers. Therefore, road restraint systems, curbs, poles, and other obstacles that may be beneficial, or just not dangerous to other road users, are often a hazard for motorcyclists and increase the injury risk in case of an accident. For further detail, see Road restriction systems position paper.

A better infrastructure can significantly enhance the PTW safety. Inadequate and/or badly maintained infrastructure are common factors of crashes in which PTWs are involved. Inadequate and/or badly maintained infrastructure is one of the main causes of severe injuries and deaths of motorcyclists, even when it is not the cause of the crash. Additional costs to improve road infrastructure standards to meet the, so far neglected, needs of vulnerable road users, including PTW riders, is by far outweighed by the benefit of saving lives on European roads. Funds, spent on infrastructure are not costs but investments in lives, life quality and in financial revenues.

Table 8. *Safe infrastructure considerations*

How infrastructure should be improved
➢ New standards should be adopted for roadside and median road restraint systems to make them less dangerous for PTW riders. ➢ All unnecessary objects along the road must be removed where possible, to create an obstacle free roadside and to provide free sight for all road users. Objects that cannot be removed should be shielded in a proper and safe way. ➢ The surface of the road should be free of unnecessary markings. Where markings are unavoidable they should be made of a material with the same skid resistance as the pavement, and the thickness of the material should be limited. This skid resistance should be maintained for as long as the marking exists. ➢ The road should be free of all raised lane separations that cannot be driven/ridden over, especially at roundabouts. ➢ Road layout, and the development, installation and maintenance of road infrastructure and road furniture should be designed with PTWs in mind. ➢ Paved roads should be free of debris, including grit. ➢ Roads must be fitted with frangible signposts.

4.3. Road Restraint Systems (RRS)

Road restraint systems (crash barriers) are usually developed for, and tested with, cars and trucks. Especially for these vehicles they can improve safety as they prevent them from hitting objects near the road or colliding with oncoming vehicles. However, by their design and features they can also create a hazard for powered twowheelers (PTWs). Motorcyclists have no protective cage like car drivers and motorcyclists have less chance of surviving a collision with a barrier than car drivers. Barriers must therefore only be installed when necessary and must be safe for motorcyclists. The cost of improving standards for roadside and median barriers to meet the needs of vulnerable road users, including riders of PTWs, is far less than the benefit of saving lives or prevent serious injuries on European roads. Road restraint systems must be safe for all road users.

Table 9. *Road Restraint Systems considerations*

How road restraint systems should be improved
➢ Road restraint systems, of whatever type, should only be installed where there is a real risk for a collision with an object or oncoming traffic and no other solution - like removing the objects - is possible. ➢ New, safe, types of barriers need to be developed after extensive research of collisions of PTWs with barriers. New standards for roadside and median barriers should be adopted to make them less dangerous for motorcyclists. The existing Technical Specification CEN/TS 17342:2019-10 should be further developed and turned into an EN standard. ➢ New standards must include protection against hitting unprotected posts and top-side protection for PTW riders. Discontinuous protection of posts only improves the safety of PTW-riders when the collision speed is very low. Therefore, only continuous protection of the posts should be allowed. ➢ No new cable barriers (i.e., wire rope fences) or other barriers with unprotected posts should be installed. When old unsafe barriers need to be replaced, they must be replaced by a safer barrier type. ➢ Whenever a barrier is installed, the distance from the road should be as large as possible to allow for evasive manoeuvres and maximum emergency braking in the event of a collision which might reduce the force of the collision impact with the barrier. ➢ Existing barriers in outer curves or other locations with heightened risk must be retrofitted with Motorcycle Protection Systems (MPS). ➢ Introduce a common European classification system for crash barriers, based on vulnerable road users (VRU) collision friendly features.

4.4. Traffic Calming Devices

Inappropriate speed is one of the most important causes of accidents, especially on urban roads or smaller roads in rural areas. Signs are often not enough to reduce speed and enforcement is either not possible or the costs are too high. For this reason, the road authorities often choose to install traffic calming devices. These can be optical (road markings), horizontal (road width restrictions/chicanes) or vertical (speed bumps/rumble strips). Speed bumps and similar calming devices must only be installed on roads with a lower speed limit.

Traffic calming devices can be dangerous for powered two-wheelers. PTWs are balancing vehicles, and a sudden vertical or lateral momentum can cause loss of balance. A sudden vertical momentum can be caused by excessive gradient or height of a speed bump, or vehicle speed that is too high under the circumstances but can be still within the limits. PTWs are single-track vehicles. This means, that they lose grip much easier than multi-track vehicles. Loss of grip can be caused by a slippery surface, but also by the sloping ends of a speed bump that does not cover the entire width of the road or by the sloping ends of cushion shaped, or rounded speed bumps. When a PTW does not approach a speed bump at an appropriate angle, the PTW can lose grip, or balance. This happens when a speed bump is installed in or near a bend, or when the speed bump has an abnormal shape. Horizontal calming devices can be dangerous when the shape is not in accordance with the current national regulations or the allowed speed, when the markings are not clear under all circumstances or are situated in a bend or in other place with inadequate view

Table 10. *Traffic calming devices considerations*

How to install traffic calming devices that are safe for PTWs
➢ Calming devices should always be designed and installed in a way that is in accordance with the current national regulations and the allowed speed.

➢ The calming devices should be well marked and signed and placed correctly, so they are visible for the road users under all circumstances. ➢ Calming devices should never be situated in or shortly behind a bend. ➢ The material of the calming devices should ensure enough grip under all circumstances, especially at wet roads. ➢ The gradient and height of a vertical calming device should never be greater than is strictly necessary. ➢ The vertical calming device or speed bump should never have a slope that runs lateral to the direction of an oncoming PTW, because this can lead to loss of balance.

5. PTW rider

5.1. Initial training and licensing

High quality, cost effective initial rider training is probably the most important measure for improving powered two-wheeler (PTW) safety. Every European citizen who wants to start riding a PTW should have an easy access to training and testing. The present EU 3rd Driving Licence Directive, DLD, focuses on the regulatory framework, for example which vehicles that can be used during the test, without considering the content of training and only comments the testing briefly. The directive ignores the very purpose of training and testing. The claimed present regulatory framework's positive effects on PTW safety are undocumented and questionable. An extensive evaluation in the EU is necessary. Today training and testing has become complicated and overly expensive which in some, especially Nordic, countries has resulted in significant percentage of fatal accidents by riders which didn't have a valid license. The requirement to repeat the same training or test three times during a stepped access doesn't encourage riders to start with a smaller motorcycle. A revision to favour the access and be gender neutral could be to reconsider the limits of the test bikes taking in consideration the arrival of new models on the market. The specific demands on test vehicles in combination with a focus on the manoeuvre tests in the final license examination are the reasons for unnecessary failures. The approval rate among women decreases with the higher demands from EU for test vehicles from A1 - A2 - A. A licence test bikes power should be ≤ 40 kW.

Table 11. *Initial training and licensing considerations*

How to improve initial rider training
➢ Initial rider training must teach the skills, knowledge and attitude needed to safely operate a PTW on public roads, not just the skills needed to pass a licence test. ➢ Initial rider training should arrive from the EU/FEMA/FIM/ACEM Initial Rider Training Programme and should be described in detail in an agreed, national curriculum for category A. ➢ The licence test is a quality assurance of the candidate's competence, meaning the minimum skills, knowledge and attitude needed to safely operate a motorcycle on public roads, and it is of great importance that the licence test is designed to do exactly that. ➢ Risk awareness and risk management should be part of the training and licence tests. ➢ The licence test should not expose candidates to peculiar exercises with little relevance to real-life safe riding, the consequence being that perfectly competent candidates may fail the test, while questionable candidates, who have "learned the tricks", may pass. ➢ All training, testing and demand for test vehicles should be gender neutral. ➢ A stepped access with only one practical and one theoretical test after a cost-effective training coached by trained instructors might encourage riders to start riding on smaller and less powerful bikes.

➢ Instructors and examiners should be practising riders and should have participated in an officially recognised instructors /examiner's training programme derived from the agreed, national curriculum for category A.

6. Mobility aspects

6.1. PTW Safe Systems

Safe systems are an approach to road safety management, based on the principle that our lives and health should not be compromised by our need to travel. Powered two-wheeler (PTW) safe systems are especially aimed at the needs of motorcyclists. Road safety is a human right of all road users. In the Lillehammer ITF/OECD conference in 2008, and repeated in the Motorcycle Workshop 2021, it was clarified that it is a fundamental PTW safety requirement that PTWs should have a place in overall transport policy and infrastructure policy management. This still hasn't happened. PTW-riders are often excluded in guidelines for construction and maintenance. As a result, infrastructure and road furniture aren't developed including the needs of PTW-riders. PTW-riders have no protective cage like motorists, thus accident prevention measures are even more important than injury reduction measures. Next to infrastructural issues there is need for improved basic and advanced training for motorcyclists, since the basic and advanced rider training is still focused on technical skills and less on risk awareness. Another aspect that needs attention is the development of ITS (Intelligent Transport Systems) for cars that should consider PTWs better.

Table 12. *Safe Systems considerations*

How PTW safe systems should be improved
➢ PTW-riders are road users with specific needs that must be taken into account in the Safe System Approach. ➢ Accident prevention measures are even more important than injury reduction measures. ➢ PTW-riders should be included in national guidelines for planning, constructing and maintaining roads and road infrastructure. ➢ Improving safety for motorcyclists implies setting up a continuous dialogue and co-operation between the stakeholders, including PTW riders, policy makers, researchers and PTW manufacturers. ➢ All measures need to be founded on evidence-based scientific research into driver and rider behaviour, and before-and-after evaluations should be conducted. ➢ Funding effective road safety activities. ➢ Launching public awareness campaigns for drivers and riders. ➢ Better training systems for riders with focus on risk awareness, risk avoidance and risk management. ➢ Make PTWs safer by the use of appropriate and tested intelligent transport systems. ➢ ITS developments for cars and trucks should always include PTW-riders and other road users. ➢ (C-)ITS devices for other vehicles should always be developed keeping in mind that PTW often are not equipped with (C-)ITS devices.

6.2. PTW and mobility

The current focus of the European mobility strategies is on public transport, cycling and walking. However, public transport will never reach everywhere in urban, suburban and rural areas. Cycling and walking are only possible for limited distances. Therefore, there will always be a need for individual motorised personal transport. We foresee a growing role for PTWs, especially motorcycles, instead of cars.

PTWs are cheaper to buy, easier to maintain and use less fuel than most combustion engine cars and trucks. Therefore, PTWs are often the only affordable form of personal motorized transport for many people, both in developed and in emerging countries. PTWs are an important - if not the only - means of personal motorized transport for many people commuting to work, thus escaping social exclusion.

PTWs can go to places which other vehicles can only reach with greater difficulty or with needing much more time. This makes PTW important vehicles in all areas for the police, emergency services, medical organisations, health care and other professionals. They provide the greatest flexibility of all means of personal transport, because:

- They are smaller than cars, so there is less congestion and less need for parking space.
- They have a larger range than (electric assisted) bicycles.
- As means of personal transport, PTWs provide personal freedom on where you want to go and when you want to do so.

PTWs use less room and therefore need less parking space and as a result of this fact motorcyclists save time and distance. Moreover, PTWs for use in urban areas can be easier and cheaper to electrify than cars.

Table 13. *PTW and mobility considerations*

How PTWs contribute to improved mobility
➢ Less congestion by allowing PTWs to use bus lanes where possible.
➢ Less congestion by acceptance of filtering through slow moving traffic and advanced stop lines for bicycles and PTWs.
➢ Less need of parking spaces by acceptance of parking of PTWs on pavements if not hindering pedestrians, users of mobility scooters, and cyclists.
➢ Less need of car parking spaces by creating safe and secure PTW parking spaces.
➢ Less congestion through privileged inner-city access for PTWs.
➢ Tax incentive schemes and awareness campaigns highlighting the advantages of PTWs.
➢ Less pollution and less emissions by using “greener” PTWs: less energy consuming by internal combustion engines with use of low-carbon fuels, fuel cell powered engines, battery powered electric engines.
➢ Make motorcycling safer by use of appropriate (connected) intelligent transport systems (C-ITS), improved rider training, safer infrastructure, and better awareness by other road users.

7. Conclusions

In a fast-changing world, the PTW community is confronted with new developments. Except several safety issues that still require attention, PTWs have to meet the new challenges of CO_2 neutrality that has become an important issue, especially since the British Government and the European Commission have announced that from 2035 all vehicles should have zero CO_2 tailpipe emission.

This paper presents the FEMA-FIM working group view on four thematic areas related to PTWs. For each area, a number of conclusions is summarized below:

A. Vehicle technology

- Any kind of ISAs should be overridable and the rider must be able to switch it off.

- A separate category for PLEVs should be created in order to distinguish them from bicycles, electric assisted bicycles, mopeds, motorcycles, and other L-category vehicles.
- ADAS devices must be developed with all kinds of vulnerable and non-connected road users in mind, should always be tested with PTWs and must comply with UNECE regulations.
- ARAS devices for PTWs must not take over the control of throttle and steering from the rider with present technology.
- Charging for electric PTWs should be encouraged by implementing simple and universal payment systems and creating secure and dedicated charging and parking facilities for PTWs.
- Riders own the RMI and have the right to know what data is generated and how it is used.

B. Road infrastructure

- High risk spot management should include all public roads and should be part of the safety policy of the European Union and non-EU governments with special attention to VRUs.
- Road layout and the development, installation and maintenance of road infrastructure and road restraint systems/road furniture/traffic calming devices should be designed with PTWs in mind.

C. PTW rider

- Initial rider training must teach the skills, knowledge and attitude needed to safely operate a PTW on public roads, not just the skills needed to pass a licence test.

D. Mobility

- PTW-riders are road users with specific needs that must be taken into account in the Safe System Approach.
- The use of PTWs can contribute to less congestion through privileged inner-city access for PTWs and to less need of car parking spaces by creating safe and secure PTW parking spaces and consequently to less pollution and less emissions.

Acknowledgements

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IFZ

14th International Motorcycle Conference

03/04 October 2022 in Cologne

Safety in Motion

Knowledge Translation practice to enhance motorcycle research impact

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Knowledge Translation practice to enhance motorcycle research impact

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Abstract

R&D on motorcycle safety spans multiple domains and sectors. Innovations like ABS show proven benefits. Meanwhile, training and licensing suffers from a lack of evidence-based implementation of best practice examples. Safe (re)design of infrastructure is not a universal priority. Car drivers and motorcyclists make the same mistakes they have for decades, with tragic consequences. Riders' concerns are marginalized in international research projects due to the complexity of accounting for their nimbleness. PTWs are often regarded as the sources of danger to be removed, in discussions of Vision Zero roadmaps, even as they are increasingly identified as important to future sustainable mobility.

As scientists, to have real impact on improving motorcycle safety, we need to look beyond the laboratory and increase our capacity for engaging and collaborating across levels and sectors of society: "The major areas of scientific breakthrough in the future are not going to be within disciplines or fields, they are going to be at the nexus between disciplines and research users" (Dr. Matthew Flinders, 2021).

Knowledge Translation (KT) is both scholarly discipline and practice, aimed to enhance uptake of research for real-world application and policy-change. Known also as planning for impact, KT is highly developed in health services research. Increasingly, KT and research impact plans are required in grant applications, to ensure accountability of public funds and reduction of research waste. Key to KT success is engagement and collaboration with knowledge users to ensure relevance and uptake of results, as is tailoring the information to target audiences and sharing through evidence-informed strategies.

This paper describes how KT principles, tools and practices might be applied to enhance impact of motorcycle safety research, through examples from current projects and collaborations. Our conclusions illustrate how KT practices can be applied to address research-to-application gaps to improve uptake and use of motorcycle safety research and synthesis of new knowledge for positive change. Learnings from engagement with diverse stakeholder groups and syntheses from current road safety discourse are summarized. Recommendations are provided from a synthesis of various data sources and current best practice paradigms.

1 Introduction

I came to motorcycle safety research 'by accident'. (Small joke here, since it is no longer considered acceptable practice to refer to road crashes as accidents [e.g. see 1]). I actually interviewed for a research position on rider training, but the grant specified a senior researcher, and I was still finishing my PhD in kinesiology. When I was offered instead a research fellowship to investigate human factors in PTW-rider interaction, I asked about possible opportunities beyond the 18-month contract, expressing my interest in mobilization results of motorcycle safety research for public use. In the 1980s, I obtained my Canadian motorcycle license in through a 33-hour theoretical and practical course offered by the British Columbia Safety Council. I still remember the lessons on hazard anticipation, common crash scenarios and mistakes made by drivers and riders, and strategies to avoid these, all still relevant today.

While pursuing my PhD at McGill University, I was introduced to the term, Knowledge Translation (KT). This was in relation to the engaged scholarship being done by lifestyle health researchers in partnership with First Nations communities around obesity and type II diabetes. When I asked the lead professor Dr. Enrique Garcia what it was all about, he said the main thing was to take a step back as researchers and listen to the needs of a community instead of a priori presuming to know what knowledge they should receive and how it should be used. Rather, develop trust through 2-way communication to work together towards creating evidence-based solutions – evidence from the research and evidence about the users and their contexts. This democratization of the research process to involve a community who had been historically marginalized and disenfranchised was very appealing to me. Intrigued, I began exploring and learning about KT. Two years ago, I finally had the opportunity to try putting it into practice, in the context of a Horizon 2020 project addressing future risks for vulnerable road users in mixed automated traffic.

So what is KT and how might it be relevant to motorcycle safety? It is a system of practices and area of scholarship devoted to mobilizing research results for practical application and social benefit. It is highly developed and implemented in, but not limited to, the health and social services sectors. Collaboration and engagement across stakeholders and sectors throughout a research project are fundamental principles of KT. As a human activity, motorcycling spans almost every sector of society. Indeed, the World Health Organization targets road traffic injuries as a major preventable public health concern, advocating the creation of partnerships to develop sustainable and effective solutions [2]. Parachute Canada is a charity dedicated to injury prevention which applies KT to its cutting-edge Vision Zero program, among other injury topics. They have recently produced a framework to guide collaboration and alignment across sectors "to become a stronger voice in creating safe, active, healthy and sustainable urban roads through influencing public policy dialogue and actions" [3 p. 6]. At a free online conference hosted by Research Impact Academy, one of the guest speakers, Dr. Matthew Flinders from the University of Sheffield's Department of Politics and International Relations, made a statement that really resonated as being both timely and apropos to the current challenges in applying research innovations to reducing road danger for vulnerable road users (VRUs).

"The major areas of scientific breakthrough in the future are not going to be within disciplines or fields, they are going to be at the nexus between disciplines and research users." [4]

There are scant examples in the peer-reviewed literature of KT applied to road safety research [e.g. 5, 6] although there are many organizations that are doing evidence-based promotion of motorcycle and road safety without calling it KT. I see the potential of KT, with established resources of tools, frameworks, research and community of practice, to address many of the gaps and challenges cited in the motorcycle safety literature and discussed in meetings and conferences.

I'm introducing this paper in a personal tone because, after all, motorcycle safety *is* personal and because I wish to start a new conversation. Besides, we've all read (and written) the same introductions citing all the statistics a hundred times. Nobody reading our research papers needs convincing that motorcycling is dangerous. People and entities in key positions, however, may need persuading that reducing danger to motorcyclists should be a priority. Those people and entities are probably not reading our papers. Even if they were, they may not understand them nor know what to do with the information. Worse, our research may not go far enough, may be asking the wrong questions (or be asking the right questions in the wrong ways), or may suffer from faulty research designs and non-rigorous methods. We have 140+ studies published from 1979 to 2010 evaluating the effectiveness of rider training and licensing, while the authors of a 2010 Cochrane systematic review concluded that, "Due to the poor quality of studies included in this review, we were unable to draw any conclusions about the effectiveness of rider training on crash rates, injurious or fatal, or offence rates." [7 p. 14]

Everyone interested in this field has personal opinions about motorcycling, and these inform approaches to developing safety interventions – for better or for worse! A problem I have noted is that where there is a lack of expertise, researchers, legislators and driving educators tend to fall back onto personal opinion and experience. This is lamentable since it appears to stem from an ignorance of the rigorous methods and current knowledge available in human experimental research, education and learning research, behaviour change and social science research. Motorcycling/scootering is a cross-cutting activity that spans every level of human functioning from primitive reflexes to legislative compliance. It is therefore imperative to identify and involve the necessary expertise and knowledge domains to achieve integrated, sustainable solutions, which fit the intended users and their contexts.

We have the GDE, self-declared as having no grounding in empirical evidence [8], We have multiple versions of lists of content items meant to stand as rider training programs. After 22+ years we are still lacking expertise and recognized, evidence-based guiding frameworks in how to apply, implement and evaluate effective rider training programs. We have police, crash investigators, engineers unwittingly reproducing victim-blaming paradigms in the approach of evaluating crash causation by assigning fault to individuals. We have motorcycle researchers scrambling to find funding, but the grant structure demands the creation of transient partnerships with no support to ensure they function effectively. Meanwhile the success criteria appear to rest solely in the creation of reports.

Is there any research being done on how motorcycle safety research can be put into practical use? Government funding bodies require deliverables which are made freely available, but is there any system in place for tracking their uptake and impact? Citation scores are not much use to a motorcyclist or scooterist lying in a hospital bed awaiting their new prosthetic leg. How many reports and studies have been published, and what has been the safety impact of all that research? Are we *missing* opportunities to improve MC safety? How do we identify barriers to the uptake of our findings? Facilitators? Do our institutional structures restrict or reward our efforts at collaboration and community engagement? Are we stuck in circular thought patterns and institutionalized inertia that make it difficult to shift out of first gear?

Do our research questions reflect the real needs and concerns of those who should benefit from the new knowledge? Do equipment and vehicle manufacturers find the most recent research accessible and useable? If not, why? Are civil engineers and infrastructure designers trained in the specific dangers to riders of PTWs? Are city and highway planners? Do policy makers understand the effectiveness of different interventions, from ADAS to behaviour change campaigns? Are motorcycles appropriately accounted for in the testing of automated driving functions for cars? Are motorcyclists being left out of discussions on interventions due stigmatization and victim blaming? Are there frameworks and evidence-informed approaches to deconstructing and addressing these issues? How do we improve access of safety knowledge to those who can benefit from it? Is it even the job of researchers to do so?

How do we address such issues and gaps? How do we influence those with influence and the power to remove road danger? How to we establish appropriate research questions, high quality, standardized data collection and rigorous and appropriate analysis methods? As experts in our respective fields, how do we address our own expertise gaps in these necessarily cross-disciplinary endeavours?

If I've now alienated you or drawn you in, got you agreeing or cursing me, I don't care. What I'd like is for us to start a new discussion about how we can move forward boldly, how we can leverage existing resources, frameworks, best practice approaches, expertise and ideas beyond our usual domains. Or how to create new funding, collaborative and thought leadership opportunities.

To my knowledge, there is no framework proposed or applied in motorcycle safety for how to address these gaps and complex issues. But we are in luck! Knowledge translation (KT) is an entire domain of scholarly research and practice dedicated to effective dissemination of research results to facilitate uptake of new knowledge to inform practice, policy and behaviour change. The aim of this paper is to introduce some of those approaches and resources. And to inspire us all to think out our familiar gearbox when it comes to removing and reducing danger to motorcyclists. This paper is intended to provide an introduction to KT, its principles and practices, and stimulate exploration of its application to road safety innovation in general and powered two-wheeler (PTW) safety specifically.

Some of the key aspects of KT are illustrated through examples of its ongoing application in the **Horizon** 2020 project SAFE-UP in the development of evidence-based training, education and awareness strategies for VRU safety in future (and current) automated traffic. In the project, pedestrian, cyclist and motorcyclist safety are considered, however this paper focuses on PTW riders. We discuss the potential for KT to address gaps in application of road safety research and innovation to improve impact on motorcycle safety. Recommendations are provided from a synthesis of various data sources and current best practice paradigms.

2 What is Knowledge translation?

Knowledge Translation is an umbrella term for the activities involved in moving research from the academic realm into practical use. This requires engagement with the people and organizations who can apply it for personal and social benefit. The practice of KT requires that researchers build capacity for social processes that our traditional training does not cover: identifying target audiences outside of academia, building and maintaining relationships with knowledge users, planning for the impact they would like to see and actively share their results in user centred messages and formats through accessible channels. The goals of knowledge translation differ depending on the stage of the research and its topic. For example, KT goals for early research may be simply to inform and generate interest, using strategies like infomations or podcasts for general audiences, and peer reviewed journals and conference presentations for other researchers. For more mature research or new interventions, the goals may be to inform better decision-making and policy formation, or to teach practitioners about new tools, technology and methods. The earliest often cited example of KT is the 1914 US initiative to disseminate knowledge from agricultural research to farmers [9].

Where does KT come from? From the 1990s in Canada and the US there was a growing recognition that research findings were not making their way into practice in a timely fashion. This being in conflict with mandates for evidence-based, cost–effective, and accountable health care, KT saw intense development in health and social services realms, led by national funding agencies [10]. Thus KT is aimed to bridge the 'knowledge-to-action' gap, where *action* encompasses the use of knowledge by policymakers, practitioners, patients, and the public. [11].

Depending on the region, the organization, the goals, and stage of research, different KT terms may be preferred. Knowledge translation, knowledge exchange, knowledge mobilization, implementation, research utilization, engaged scholarship, impact planning, knowledge transfer, technology transfer/commercialization are just a few of the 29 related terms identified [11]. KT differs from traditional more passive methods such as academic publication by being targeted, tailored and delivered to specific audiences through a variety of practices and processes, many of which are social.

Some of the core activities of KT include engaging with KUs for collaboration, knowledge exchange and synthesis; translating technical/academic outcomes to plain language summaries; synthesis of results with other existing evidence, often across sectors and knowledge domains; and co-creation and dissemination of new knowledge, policy, practice with stakeholder partners.

Key KT principles of KT
From CIHR [cite]

- ***Synthesis*** – integrating the evidence with a larger body of research, synthesising qualitative and quantitative evidence [cite]
- ***Dissemination*** – tailoring messages and delivery methods to target audiences.
- ***Exchange of knowledge*** between researchers and partners for mutual learning.
- ***Ethically-sound application of knowledge*** – must be consistent with ethical principles and norms, social values, as well as legal and other regulatory frameworks.

In 2000, the Canadian Institutes of Health Research (CIHR) published what has become one of the most widely quoted definitions of KT:

> *"Knowledge translation (KT) is defined as a dynamic and iterative process that includes synthesis, dissemination, exchange and ethically-sound application of knowledge to improve the health of Canadians, provide more effective health services and products and strengthen the health care system."* [12]

3 KT for road safety innovation

KT for road safety innovation is currently being applied in the H2020 research & innovation project SAFE-UP. The project aims to contribute to Vision Zero goals by proactively addressing new road safety challenges expected with increasing penetration of connected and automated vehicles (CAVs). In one of the project's five technical work packages (WP2), researchers have defined current safety-critical scenarios in the EU from new analyses of CARE and GIDAS databases [13]. These scenarios are used by other work packages to inform development of active and passive safety innovations. As well, the scenarios will provide the basis for simulated recreations of traffic conflicts to test the effects of the new safety systems, and to predict future safety critical scenarios between passenger cars and between cars and VRUs – pedestrians, cyclist and motorcyclists. WP3 is developing active safety systems to mitigate current and future risks, while WP4 is developing adaptable restraint systems for new car occupant seating positions.

SAFE-UP quick links
https://www.safe-up.eu/

- 2-page project description
- Work plan
- Resources
  - Task 2.1 Definition of safety-critical scenarios [Infographic]
  - Newsletters, presentations, early KT products
  - List of research reports
- LinkedIn
- Twitter

Work Package 6 – Training activities and awareness creation on future traffic scenarios

It is expected that all road users will increasingly find themselves in unfamiliar traffic interactions due to the evolving mix of automated and conventional driving functions. The safety implications will be particularly important for VRUs. Thus, the grant call mandated the inclusion of activities dedicated to creating updateable training, education and awareness raising (TE&A) schemes for all road users which match the pace of increasing implementation of automated driving functions. Further requirements specified that schemes address diversity and recognize that IT-illiteracy may increase VRU risk in environments with an increasing share of CAVs. KT as a framework to guide development of TE&A schemes was applied to meet these requirements, due to its iterative and flexible nature which can be applied to any research domain.

WP6 together with the UNIFI partner group, whose focus and expertise are motorcycle safety, drafted the following definition adapted from that of the CIHR [12]):

Knowledge Translation for Road Safety Innovation is the exchange, synthesis and evidence-based application of knowledge, derived across road safety sectors – through a complex system of interactions among researchers, and users to accelerate, facilitate, and update the implementation of road safety innovations in a safe, acceptable and timely manner, including public education and awareness of new traffic interactions and technology.*

'Users' encompasses anyone who can benefit from the knowledge, also including the public sector, and the community of road users. Researchers may be academic and industrial. This definition is intended to be applicable to road safety research and practice in a very broad sense and extendable beyond the project to contribute to the evolution of better road safety solutions.

Project outcomes targeted for translation into TE&A strategies

The main SAFE-UP outputs targeted for translation into TE&A strategies addressing VRU safety are derived from the following activities:

WP2: Future Safety-Critical Scenarios

- Identification of initial safety-critical scenarios based on existing crash data [13]
  - Analysis of GIDAS database years 2000 to 2020. Small (< 50 cc) and large (> 50 cc) motorcycle crashes with passenger cars were analyzed separately.
  - Analysis of CARE data from year 2018 for EU countries (UK excluded).
- Rider training needs definitions based on analysis of in-depth crash data and human causal factors [14].
  - Analysis of MAIDS database years 1999 to 2001.
  - Analysis of naturalistic driving data (NDD) from the 2BeSafe project.
- Future safety-critical scenarios identified through simulations (results pending at time of writing [15, 16].

WP3: Active safety systems presented in demonstrator cars:

- DEMO 2: Enhanced sensors for VRU detection under bad weather conditions.
- DEMO 3: VRU detection integrated with advanced collision avoidance functions.
- DEMO 4: Safety solutions based on C-ITS for timely warnings.

It is yet to be determined if the outcomes from the demos will have relevance for PTW safety, as the project is focussed more heavily on cyclists and pedestrians [13].

Additional data sources

Organizations, campaigns and initiatives promoting road safety for vulnerable road user modes

An online search was conducted to become familiar with 1) organizations: safety councils, advocacy groups, charities devoted to injury prevention, ministries, etc., 2) campaigns: e.g. Parachute Canada Vision Zero, WHO Streets for Life #Love30, 3) motorcycle training courses, KT and resources (e.g. IFZ – Institute for two-wheeled safety, MSF – Motorcycle Safety Foundation, Ride to Live).

Topics searched in peer reviewed and grey literature

Having previously acquired a solid background in PTW rider safety research topics, additional topics were searched to fill gaps in knowledge and develop a foundation in the multi-sectoral world of road safety, AV implementation and urban mobility. This led to searches for background on automated vehicles (AV) and trends in research and implementation; organizational health and safety; road user behaviour research; PTW crash statistics, scenarios and causalities, PTW rider training, behaviour change for road safety, history of road safety, and early years of private automobile implementation.

Online events & courses

The events listed in Table 1 were attended build capacity in KT and inform on the latest initiatives and discussions, as well as become familiar with some of the key players in road safety promotion for VRUs in the EU and worldwide.

Table 1 Online events and courses attended to inform KT activities.

Date	Event & link	Host	Description
June 2020	*LEARN! Key Principles for Traffic Safety & Mobility*	ETSC	(Webinar) Report on status of traffic safety and mobility education in EU nations; recommendations.
March 2021	*Knowledge Translation Professional Certificate*	SickKids® Learning Institute	Seven-day online course on theory and practice of KT in any research domain.
April 2021	*1st EU Road Safety Results Conference*	EC Mobility & Transport - Road Safety	Plenary sessions and breakout on Distraction.
June 2021	*The LEARN! Manual Webinar*	ETSC	New publication setting out eight steps to improved road safety education in schools.
June 2021	*Motorcyclists Safety Workshop: Riding in a Safe System*	ITF	Online – Opening plenary session.
Sept 2021	*Motorcyclists Safety Workshop: Riding in a Safe System*	ITF	Online – Closing plenary session.
Sept 2021	*Research Impact Summit*	RIA	Online conference – Two-days of interviews and networking sessions with leaders in KT, implementation, research impact assessment and knowledge mobilization.
April 2022	*There are no accidents* The Deadly Rise of Injury and Disaster—Who Profits and Who Pays the Price	Nader Radio Hour	Live radio taping. Discussion with author Jesse Singer on why the record breaking "accidental" death toll in the United States is not really an accident but predictable and preventable.
April 2022	*An interview with Jessie Singer*, author of There Are No Accidents	Parachute Canada	Webinar – Jessie Singer is a journalist who currently serves as Senior Strategist and Head Writer at Transportation Alternatives, the editor in chief of Reclaim Magazine, and the founding editor of the international Vision Zero Cities Journal.

LEARN! Leveraging Education to Advance Road safety Now! EC European Commission, ETSC European Transport Safety Council, ITF International Transport Forum, RIA Research Impact Academy.

4 KT planning for research dissemination and implementation to enhance impact

Figure 1 shows the CIHR's knowledge-to-action model which illustrates many of the essential components of KT practice. The central triangle indicates the translation of research into syntheses, products and tools that are tailored to target audiences. The outer cycle involves social processes, collaboration, co-creation, implementation, evaluation and creation of new research questions. Depicted as a cyclic process, KT is iterative, with flexibility for monitoring and adjusting backwards and forwards. The knowledge-to-action framework is one of many KT models – other models may be a selected for different goals or at stages of a KT plan.

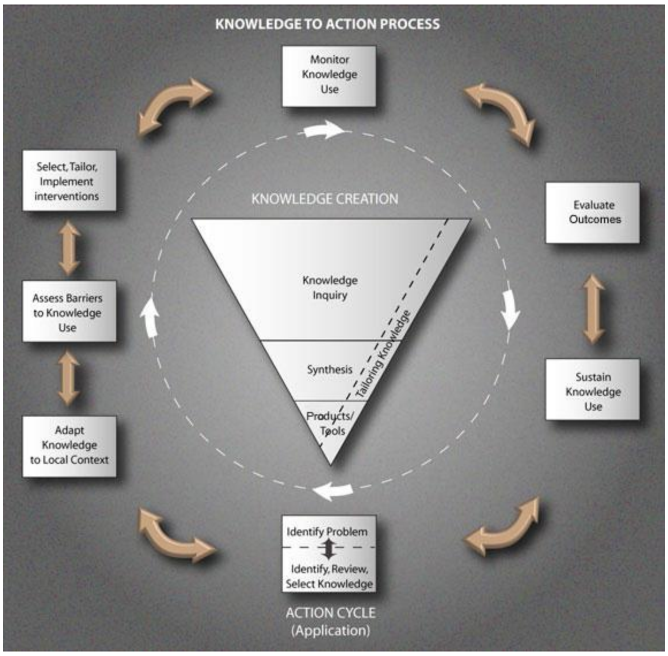

Figure 1The KT knowledge-to-action cycle – A model developed by the Canadian Institutes of Health Research (CIHR) [17].

The Knowledge Translation Planning Template© (KTPT©) [18], created by SickKids® Learning Institute, Toronto Hospital [18] was used as the underlying framework for WP6 activities. As there is no one size fits all approach to translating research, the KTPT is a planning tool that can be flexibly applied to any field or stage of research. It outlines 13 key components that need to be considered for an effective plan to disseminate research results. SickKids® Learning Institute also offers KT courses for researchers in any domain and complementary materials including eLearning modules *Introduction to Knowledge Translation* [19], *How to Prepare a Knowledge Translation Plan* [20] and *Using the Knowledge Translation Planning Template© - KT Planning Reference Guide* [21].

Key components in KT Planning
Source: KTPT©

1. Project Partners
2. Degree of Partner Engagement
3. Partner(s) Roles
4. KT Expertise on Team
5. Knowledge Users
6. Main Messages
7. KT Goals
8. KT Strategy(s)
9. KT Process
10. KT Evaluation
11. Resources
12. Budget Items
13. Plan implementation

Formation of an ad hoc Safety Partner Network

Fundamental to KT is identification of potential partners who can help ensure the success of the project. Inviting stakeholders to be a part of the process facilitates knowledge exchange. They may have specialised knowledge of specific KU groups to aid interpretation and tailoring of results. They may have communication channels that can be leveraged to increase dissemination and reach. They may wish to collaborate to co-created new evidence syntheses, knowledge products or interventions. Partner engagement promotes buy-in of project goals and uptake of the results.

With the aim to form an initial, scalable ad hoc network of safety partners and begin developing relationships early in the program (following best practice) [20], an online search was made before project initiation to identify potential partner organizations that might be interested in contributing to TE&A objectives or in using the outcomes in their own work.

Potential partners
Adapted from: KTPT©

- ❑ Researchers
- ❑ Practitioners/service providers
- ❑ Public
- ❑ Media
- ❑ Consumers
- ❑ Decision makers
- ❑ Policy makers/government
- ❑ Private sector/industry
- ❑ Research funders
- ❑ Volunteer road safety sector/NGO
- ❑ Other

The organizations engaged were chosen to represent a cross-section of entities knowledgeable and active in road traffic safety and positioned to have an impact on (current and) future VRU safety. As SAFE-UP aims address VRUs in general, advocacy groups included the International Federation of Pedestrians (IFP) and the European Cyclists' Federation (ECF), in addition to the Institute for two-wheeled safety (IFZ) and the Federation of European Motorcyclists' Associations (FEMA). Educational and licensing was addressed through the European Federation of Driving Schools Association (EFA), and the LEARN! (Leveraging Education to Advance Road safety Now!) initiative of the European Transport Safety Council (ETSC). POLIS - Cities network on transport innovation, ERTICO-ITS public-private partnerships in smart transport, also advisory board members for SAFE-UP were also engaged.

In the first half of the project, initial discussions with members of the Safety Partner Network provided knowledge on user needs, characteristics, priorities and concerns, as well as critiques on paradigms used for conceptualizing road danger and the loci of responsibility for VRU safety. "These data informed our paradigmatic approach and educational philosophy. They were further applied to determining relevance of results for specific KUs, and for creating guidelines on framing and delivering safety messages to ensure acceptance, usefulness, usability and accessibility" [22, p. 4] as summarized in [22] with full details reported in [23] and [24]. In later phases the SPN will be scaled up and engaged for possible co-creation and/or dissemination of knowledge products for testing, feedback and evaluation.

Description of applying the template is limited here to components 5 through 8, representing the core elements in translating and disseminating research results to target audiences.

Knowledge Users

Knowledge users (KUs) are any person or organization who needs to know about what was learned in the project, or who will value and apply the findings. It is helpful to think not only of end users, but also of who will be the *next* KUs.

For example, updated knowledge about the most common and dangerous crash scenarios and causal factors could be of interest to motorcyclists, legislators, driving and riding schools, infrastructure designers, CITS developers, city planners, safety councils, motorcyclists' associations, policy makers or vehicle manufacturers.

Potential KUs
Adapted from: KTPT©

- ❑ Researchers
- ❑ Road transport & safety Practitioners
- ❑ School boards, Educators
- ❑ Driving schools, instructors
- ❑ Public, Consumers
- ❑ Media
- ❑ Decision makers
- ❑ Policy makers, government
- ❑ Private sector, industry
- ❑ Research funders
- ❑ Charities, NGOs
- ❑ Other

Main messages

The first step in translating research evidence tailored to specific KU(s) is to craft a Main Message (MM) that is relevant, understandable and user centred.

Main messages (MMs) go beyond statements of data or findings to interpret what the research results *mean* to a specific target audience in a way that speaks to their needs and concerns. We can ask ourselves, why is the result important and what action should be taken as a result? Depending on the stage of the project, a MM can be about what we learned or what we *anticipate* learning.

When crafting main messages, we can think about distilling out of the Single Most Important Thing (SMIT) or Bottom-Line Actionable Message (BLAM) [18]. SMIT relates to what people should know (information level), BLAM suggests what people should do (implementation level), so which one applies depends on the stage or nature of the results. The MM could be different for different target audiences.

KT Goals

In determining knowledge translation goals, it is important to be clear about why we are communicating results. What do we hope to achieve by sharing them? In motorcycle safety research, it seems obvious that we want to improve the safety of motorcyclists, but what are the intermediary steps? Maybe we wish to stimulate more funding interest or speed up the implementation of CITS for communication between PTWs and larger vehicles, or influence policy such as mandating the installation of safer road barriers.

> **KT goals**
> *Adapted from: KTPT©*
>
> - ❑ Generate awareness, interest, buy-in
> - ❑ Impart knowledge, tools, skills
> - ❑ Generate public action or behaviour change*
> - ❑ Generate practice change*
> - ❑ Inform/improve decision-making
> - ❑ Inform research & researchers
> - ❑ Facilitate policy change
> - ❑ Facilitate commercialization/technology transfer*
> - ❑ Other
>
> **These KT goals will require separate implementation plans.*

KT Strategies

> *"Multifaceted/combined KT strategies are more effective than single strategies."* [20]

The conceptual logic underlying the distinctions and relationships among KT plan elements 5 through 8 provides needed clarity in research dissemination efforts. For example, improving rider safety is a goal, whereas rider training is one possible strategy to achieve this goal. Rather than jumping straight to training as a goal, or the best strategy, we are encouraged to think about how the evidence might be used in a variety of ways, by a variety of target audiences to have the best impact on rider safety. This could even lead to a more comprehensive, multi-pronged approach, which would have more chance of success as research shows "multifaceted/combined KT strategies are more effective than single strategies" [20]. Other strategies could be creation of toolkits for evidence-based support of community activism and rider advocacy, or educational materials for decision-makers or rider trainers.

Creating and implementing targeted dissemination strategies can require great time, money and effort. A strategy should not be chosen without evidence on its potential effectiveness for the targets and feasibility or fit the context of the intended users. Any practice or behaviour change goals require separate implementation plans [18], supported by the research on implementation science.

Table 2 provides an example of applying sections 5-8 of the KT template to the results from WP2 on initial (current) safety critical scenarios for car-to-PTW crashes in the EU. Figure 2 is a graphical summary of these results from the GIDAS analysis for large PTWs from [13].

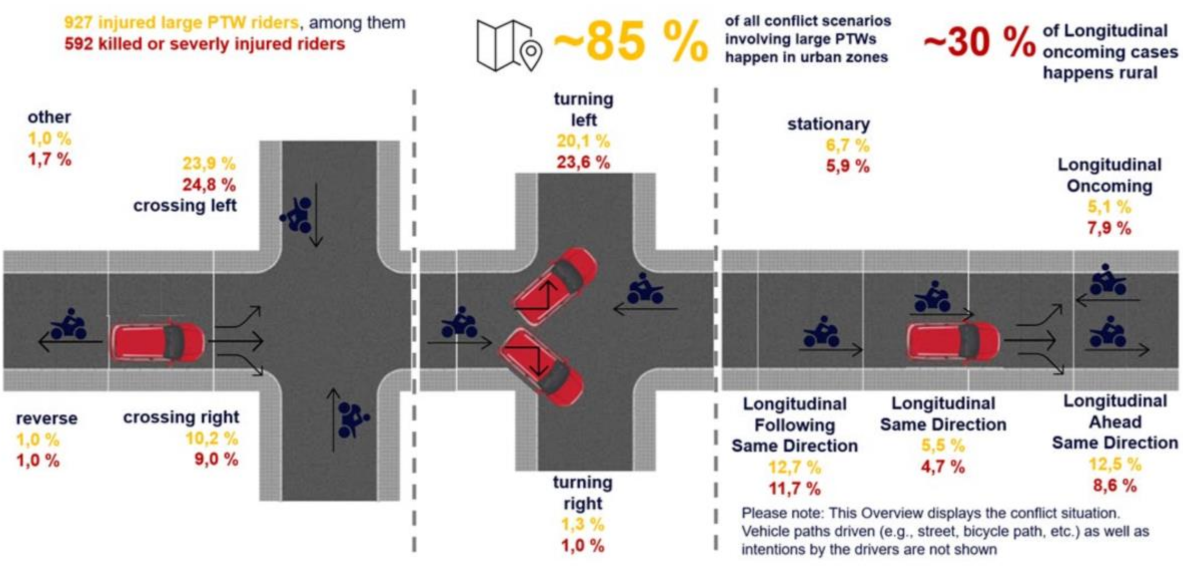

Figure 2 Overview of conflict scenarios for car-to-large PTW crashes. Source: [13]

Table 2 Translating SAFE-UP results for targeted dissemination.

Main message	KUs	KT Goals	KT Strategies
New results on collisions scenarios and human factors leading to collisions between motorcycles and other vehicles is important to the design of CITS and onboard safety systems.	• General public • Researchers • Vehicle, CITS manufacturers • Policy makers	• Generate awareness • Inform • Educate • Impart knowledge	• Peer reviewed articles, conferences • Webinars • Plain language summaries • Short explanatory video(s)
By understanding typical risky scenarios and the factors that make traffic crashes more or less likely, riders and drivers can make better choices to reduce those risks.	• Educators • Driving/riding instructors • New riders & drivers • Parents & driving coaches • Clubs & advocacy groups • Associations & charities	• Generate awareness • Inform • Educate • Impart skills, tools • Promote behaviour change	• Infographics • Infomations, animations • Interactive learning modules
Driver failures account for the majority of crashes between motorcycles and cars in urban areas. Removing distractions and being particularly aware when entering intersections could prevent a motorcyclist from dying today.	• Driving instructors • Educators • Drivers	• Generate awareness • Inform • Educate • Promote behaviour change	• Infographics • Infomations, animations • Interactive learning modules
New results on collisions scenarios and human factors leading to collisions between motorcycles and other vehicles reveals similar results to previous knowledge spanning decades. Capacity building to improve mobilization and implementation of crash research knowledge to improve impact of research is indicated.	• Researchers • Vehicle, CITS manufacturers • Policy makers • …	• Generate awareness • Inform • Educate • Impart skills, tools • Promote behaviour change • Promote policy change	• Infographics • Infomations, animations • Interactive learning modules • Peer reviewed articles, conferences • Webinars • Plain language summaries • Short videos

5 Current context for motorcycle safety efforts

> *"Today, the Safe System approach is at the centre stage of road-safety policy making at the global, regional and national levels."* [25 p. 14]

Table 3 provides a summary of the key road safety issues, initiatives and paradigms that make up the current context and philosophy about road safety. This may be leveraged to create linkages and access tools, initiatives or partnerships for new opportunities in reducing road danger for motorcyclists.

Table 3 Key areas for knowledge synthesis and contextualization of project results.

Directives & current paradigms	Key takeaways, messages	References
UN Sustainable Development Goals & the 2030 Agenda	Goal 3 Good Health and Well-being Goal 5 Gender Equality Goal 10 Reduce Inequalities Goal 11 Sustainable Cities and Communities Goal 13 Climate Action Goal 16 Peace, Justice and Strong Institution	United Nations. (2015) Transforming our world: the 2030 Agenda for Sustainable Development [26]
Vision zero	"Vision Zero is an ethical stance stating that it is not acceptable for human mistakes to have fatal consequences. It can be viewed as a paradigm shift, where the ultimate responsibility for road safety is shifted from the individual road-user to those who design the transport system, for example, road management bodies, vehicle manufacturers, legislators, commercial transport operators, the police authority and others. The responsibility of the road-user is to comply with laws and regulations. Traditional road safety management has put a lot of effort into accident prevention, and most accidents are caused by road-users. The aim of such strategies is therefore to try to create the perfect human who always does the right thing in all situations. If an accident happens, the blame can almost always be put on a road-user. Vision Zero challenges this approach. Instead, it is assumed that there are no perfect humans. It is human to make a mistake, but mistakes should not cost a person's life or health. Instead, much effort is being put into designing the transport system so that accidents will not lead to serious consequences. The focus is on the roads, the vehicles and the stakeholders who use the road transport system, rather than on the behaviour of the individual road-user."	Road Safety Sweden (origin of Vision Zero) [27]
Safe Systems Approach	Four guiding principles of a Safe System: 1. People make mistakes that can lead to crashes. The transport system needs to accommodate human error and unpredictability. 2. The human body has a known, limited physical ability to tolerate crash forces before harm occurs. The impact forces resulting from a collision must therefore be limited to prevent fatal or serious injury. 3. Individuals have a responsibility to act with care and within traffic laws. A shared responsibility exists with those who design, build, manage and use roads and vehicles to prevent crashes resulting in serious injury or death and to provide effective post-crash care. 4. All parts of the system must be strengthened in combination to multiply their effects, and to ensure that road users are still protected if one part of the system fails.	ITF (2016) Zero Road Deaths and Serious Injuries: Leading a Paradigm Shift to a Safe System [28] p. 26
Saving lives beyond 2020: The next steps	Target of 50% reduction in road deaths and serious injuries by 2030. Nine recommendations: 1. Sustainable practices and reporting 2. Procurement 3. Modal shift 4. Child and youth health 5. Infrastructure 6. Safe vehicles across the globe 7. Zero speeding	3rd Global Ministerial Conference on Road Safety, Stockholm 2020 [29]

Directives & current paradigms	Key takeaways, messages	References
	8. 30 km/h 9. Technology	
History of traffic crashes	Deliberate acts by the automobile industry to shift focus from dangers of cars to blaming victims and focus on individual human error as the cause of accidents has led to divisive classifications of road user groups, unrealistic emphasis on punishment and trying to create perfect humans. Systematic co-opting of public space away from pedestrians to privilege ease of car movement. Movements to deconstruct this discourse identify and remediate institutional structures and social and processes that perpetuate it (see Singer, 2022).	Norton, 2008 [30] Singer, 2022 [31]
Language matters	'Accident' is no longer acceptable for talking about and reporting road crashes in journalism and research publications. Historical invention and use of terms to stigmatize and blame victims. Grammatical and word choices assign blame, affect perceived blame and preferred solutions. Best practice guidelines.	Davis, 2001 [32] Norton, 2008 [30] Singer, 2022 [31] Goddard, 2019 [33] Ralph, 2019 [34] Parachute, 2022 [1] Laker [35] Norte [36]

6 Outcomes and discussion

WP 6 was assigned to complement SAFE-UP's holistic approach to future traffic safety through the development of new training and awareness raising schemes on new risks associated with disruptions from future CAV traffic contexts and promote understanding of new safety technology. A special emphasis was given to unprotected (vulnerable) road user safety in urban traffic conflicts with passenger cars.

KT addresses the knowledge-to-action gap using practices and processes for translating research-results into user-centred relevant messages that are understandable, actionable, timely and accessible. By facilitating uptake and implementation of results it reduces research waste and enhances dissemination and uptake of new knowledge and interventions, to inform changes in policy, practice and behaviour. Uptake of innovation has been recognized as a social process. Not surprisingly, KT attributes success to addressing and developing social processes to better mobilize results research for public benefit.

Historical discourse & current paradigms on road safety

"Jay-walking causes most street accidents. 94 per cent. could be avoided.
WATCH YOUR STEP! There are much better ways of getting killed or maimed than by jay-walking across the busy streets. You may be the next victim."

– "Safety message" published in Vancouver newspaper ca. 1920-1930 [37]

"Road users should not have to operate in [or adapt to, be blamed for] a system full of flawed designs that increase the probability of error."

– A manual for practitioners and decision makers
on implementing safe system infrastructure! PIARC, 2009 [38].

Safety network partners from pedestrian and cyclist advocacy groups repeatedly referred to the historical victim-blaming of VRUs by the automobile industry and disenfranchisement of people from public roads to enable motor travel [30]. Hagenzieker et al. (2014) [39] have characterized 5 different historical periods of road safety research, motivated by different paradigms (Table 4). I have added a row of possible messages on motorcycle safety aligned to each paradigm. The analysis by Hagenzieker et al. nicely illustrates the evolution in critical thinking and values progressing from a view of traffic crashes as 'accidents' – bad luck, to inventing scapegoats – 'nut behind the wheel', 'jay-walker', accident-prone' – in order to justify victim-blaming to refocus blame away from car danger, to multifactorial analyses of crash causation and technical remedies. The current paradigm of the safe-systems approach accepts that humans make mistakes and prioritizes system analysis to identify dangerous conditions which either promote human error or produce serious and fatal consequences. In her book, *There Are No Accidents*, Jessie Singer explains the 'layering of systemic inevitabilities' that end in human error with tragic consequences" [31]. Indeed, "the Safe System approach opposes the often-repeated but simplistic claim that driver error is the cause of 90% of road fatalities. At best, driver error is the last failure in a causal chain of events leading to a crash (WHO, 2021: 9)" [25]. Singer further analyzes the socio-economic factors that account for disproportionate levels of risk based on race, economic status, and power differentials, as well as the psycho-sociological tendencies that create incongruities between actual and perceived risk and perpetuate victim-blaming to divert attention from the true sources of danger [31].

As the original authors of Vision Zero, Road Safety Sweden states: "Vision Zero is an ethical stance stating that it is not acceptable for human mistakes to have fatal consequences. It can be viewed as a paradigm shift, where the ultimate responsibility for road safety is shifted from the individual road-user to those who design the transport system, for example, road management bodies, vehicle manufacturers, legislators, commercial transport operators, the police authority and others. The responsibility of the road-user is to comply with laws and regulations." [27] This is the expression of *shared responsibility*.

Table 4 Time periods and their characteristic road safety paradigms, interpreted for motorcycle safety.

	1900-1920	1920-1950	1950-1970	1960-1985	1985/1990-now
Paradigm	Chance phenomenon, bad luck	Road devils, accident prone drivers	Road user, vehicle, road	Multi-causal approach	Result of integral road system
Research focus	What	Who	How: Cause	How: Which causes, technical improvements	Multi-dimensional, economic analysis
Interventions	On an ad hoc basis	Educate, punish	Engineering, education, enforcement.	Technical solutions for vehicle & road	Adapt road system to road user
Possible Message Main	If you ride a motorcycle, sooner or later you will go down. Ride at your own peril.	Reckless riders bring misfortune onto themselves! Follow the rules, pay attention, don't speed … *or else!*	Understand the common hazards to motorcycling to reduce your risk (e.g. vehicle maintenance, road surface hazards, common mistakes made by riders and drivers).	Results on the most common crashes should inform design of safety systems to compensate for rider and driver failings (e.g. ABS, CITS). Riders should purchase bikes with current safety technology and practice using it.	Results on common crash scenarios and human causal factors should inform further systems analysis to identify interacting danger conditions and to guide multi-faceted interventions that address the six pillars of safe systems.

Adapted from Hagenzieker, et al. (2014) [39]

Six pillars of the safe system approach
Source: ITF, Jun 2022

1. Road-safety management
2. Safe roads
3. Safe vehicles
4. Safe speeds
5. Safe road-user behaviour
6. Post-crash care

Thus the tendency to prioritize the individual road-user – driver and and URU alike – as being the 'main causer' and whose behaviour and weaknesses are the 'obvious' targets for interventions such as education and punishment is not only outdated and unethical, but impractical and logically flawed. Instead, the transport system should be examined to understand why the same kinds of crashes keep recurring. From such analyses can come (re)designs to eliminate the factors that promote human error, and interventions to mitigate the consequences when errors *do* happen.

Learning 1: Our choice (implicit or explicit) of road safety paradigms can have serious safety and ethical implications for the research outcomes: "Overstating the role of road-user error may result in a reduced focus on effective countermeasures that address systemic failures in this causal chain" [25, pp. 12-13]."

Road user education is important but should be considered in the context of the *Six pillars of the safe system approach* [25]. With its ranking as fifth for potential impact on road safety educational strategies should be designed with explicit linkages to the other pillars and the entities responsible for them.

Language – supporting the change in discourse

> *"The British Medical Journal banned use of the term 'accident' because it conveys an undue sense of faultlessness and inevitability."* [32]

> "Accident (*avoid in reference to motor vehicles; prefer* collision *or* crash)"
> – Canadian Press Caps and Spelling, 2021 [cited in 1]

Research shows that how journalists report road traffic crashes influences ascribing of blame by readers. This strongly illustrates that grammar can shift the focus of responsibility and perceptions of who is at fault in a car-to-VRU crash [33, 34]. This can focus intervention efforts on the wrong place. Increasingly press agencies are updating their style guides to eliminate the use of the word 'accident' from reports of road crashes. Various organizations have developed guidelines to assist in writing about traffic collisions to avoid unfounded bias in ascribing blame. Figure 3 and Figure 4 are two examples. Note that motorcyclists are missing from these examples.

The community advocacy group for Traverse City (Michigan), Norte, states on their website: "Too often, we use language that categorizes people based on their mobility choice; our fellow citizens become pedestrians, cyclists, and motorists" [36]. Perhaps it's time we took a similar approach in motorcyclist advocacy. Safety Network Partners representing motorcyclists' interests as well as speakers in online events (see Table 3) expressed frustration that PTW riders are often marginalized, overlooked, underrepresented or unprioritized in road safety discussions, or worse, targeted as an unacceptable danger that should be removed from traffic. On the other side, pedestrian and cyclist groups find much common ground and mutual support, but see motorcycles as being closer to cars, so not as relevant to their agendas.

Learning 2: Our conceptualization of road danger/safety is influenced by historical bias, which can be perpetuated by the language used to communicate about road crashes. It is likely that allocation of research funding and determination of research hypotheses are further biased by these structures, negatively impacting production and implementation of motorcycle safety research.

An interesting thought experiment could be to examine how the way we use language to frame main messages from research results might influence how we think about goals and target knowledge users, as presented in Table 4. Understanding and applying current guidelines for reporting on crashes between car drivers and URUs is important to ensure research questions and results interpretations remain aligned with current paradigms. As well, it can have an impact on researchers' credibility in the eyes of URU groups.

Learning 3: As researchers we have ethical and scientific responsibilities to beware of historical social biases being unconsciously inserted into the research process, beginning with the framing of objectives by funders, to formulation of research problems to interpretation and reporting of results. Partnering with groups literate in current accepted discourse on users and their needs will help to avoid negative old habits. We should be particularly aware of language, assumptions and social structures (these are interactive) that unequally attribute blame and danger or limit equitable access to mobility options and safety technology based on demographic differences such as race, gender, age, IT-literacy, socio-economic status, culture, physical and mental capabilities. These priorities are in line with the WHO SDGs.

Who is responsible for achieving safer motorcycling?

Within SAFE-UP, starting from how the original call was written, there has been an ongoing tendency to fixate on the VRUs themselves as target audiences for training and awareness strategies. Yet, working within the safe system paradigm, we must recognize that these are the people least able to influence the systemic dangers. It is imperative not to focus solely on riders (or other VRUs) as the target audiences for safety interventions such as training. We must also look to who has the greatest power to implement research results for a positive impact on safety. Looking at the six pillars of the safe system approach, it may be more impactful to direct efforts towards educating instead those responsible for road management, road design, vehicle manufacturing, policy making and legislation. Barriers to removing and mitigating road danger must also be addressed, such as inequitable funding that provides greater safety for some road use modes (and directly those who use them more) over others. Singer's book [22] can used as a manual for deconstructing the historic discourse (victim-blaming, 'accidents') and systemic institutional barriers (e.g. corporate profit) that may be diverting focus from effective countermeasures and thus maintaining unacceptable danger conditions for certain road users.

Learning 4: Deconstruction of victim-blaming discourse changes the significance of human error and redistributes the shares of responsibility according to who has the real power to remove and mitigate road danger.

Language Matters

STOP		GO
Accidents	→	**Collisions or crashes**
"A car hit a pedestrian."	→	**"A person driving hit someone walking."**
Bikers, Cyclist	→	**People biking**
Pedestrians	→	**People walking**
Drivers	→	**People driving**
Disabled person	→	**A person with a disability**
Transit riders	→	**People using transit**
Transportation Alternatives	→	**Transportation Choices**
"As a cyclist, I..."	→	**"As a [mom, neighbor, teacher, resident] who often bikes, I..."**
"I bike 8th Street and it stresses me out."	→	**"When I drive, bike, or walk 8th Street, I get stressed out."**
Cycle track	→	**Protected bike lane**
Biking advocates, walking advocates	→	**Citizen Advocates or Neighborhood advocates**
R.R.F.B, Pedestrian Hybrid Beacons	→	**Safer ways to cross these stroads!**
Active transportation	→	**Healthy Transportation**

The theme? Let's lose the dehumanizing jargon with its built-in biases and strive for inclusive language. We are all in this together! Getting on a bicycle is simply a means to move, not an identity. Similarly, getting in a car is just an alternative way to get around.

The same streets that are unsafe for us when we use them on foot or on a bike are also the most dangerous and bothersome for us when we use them in a car.

[1] List adapted from a cheat sheet created by *Seattle Neighborhood Greenways'*

Figure 3 Recommended language for talking about road collisions. Source: [36].

Status quo	Better practice	Effect of status quo
Accident: "*Pedestrian killed in accident on Main Street.*"	**Crash**: "*Pedestrian killed in crash on Main Street.*"	Obscures preventable nature of crashes
Non-agentive: "*A pedestrian was hit and killed.*" (no agent)	**Agentive**: "*A pedestrian was hit and killed by a car.*"	Obscures role of a human actor
Focus on pedestrian: "*A pedestrian was hit and killed by a car.*"	**Focus on vehicle**: "*A car hit and killed a pedestrian.*"	Increases blame for the focus of the sentence
Object-based language: "*A car jumped the curb.*"	**Person-based language**: "*A driver drove over the curb.*"	Obscures role of a human actor
Counterfactual statements: "*The pedestrian darted into the street.*"	**Not included**	Increases perceived blame for the victim
Episodic framing: Treats the crash as an isolated incident.	**Thematic framing**: "*This is the tenth fatal collision this year.*"	Prevents readers from connecting the dots between incidents and thus shifts attention to individual-level rather than systematic solutions

Figure 4 Six language choices that affect how people perceive road collisions. From: [21]

Recommendations & paths to explore

Partner with other URU groups to learn from them, identify common needs and combine forces for a stronger voice

Take part in the bigger conversation. The project SAFE-UP considers all VRUs and not just PTW riders. The consideration of potential safety partners was extended to all sectors and aspects of the road safety ecosystem, and organizations representing all VRU modes were engaged. This was advantageous to conceptualizing the problem of motorcycle safety as it prompted learnings about the road safety ecosystem as a whole. This supported system-level thinking and a multiple user POV perspective, providing a more well-rounded view of the road danger problem. Having made this survey, I have come to believe it is important for those of us interested in promoting motorcycle safety and the interests of users, to understand and find linkages with the concerns of groups advocating for other unprotected mobility mode users and their strategies for influencing decision making and policy. Can we combine forces for a stronger voice?

Build capacity for engagement to leverage community and organizational shared interests

Researchers are not traditionally trained in public engagement nor how to access or analyze evidence outside of the peer-reviewed literature. This can lead to in incomplete understanding of the actual work being done towards safety of motorcycling and other mobility modes. Thinking beyond motorcyclists' specific concerns to appreciate road safety issues in general and how they are being tackled could stimulate new thinking about interventions and how to implement them, such as forming intersectoral partnerships and better community engagement. Thinking beyond the motorcycling reality in our own regions to the true diversity of users and their specific concerns may stimulate unexpected safety solutions.

These experiences will likely stimulate new research questions, which, contextualized solidly in the 2030 Agenda, and linked to the SDGs, could increase the profile of motorcycling and correct perceptions about the value of PTWs as mobility options, bringing new funding opportunities. Think beyond leisure & sport riding – make linkages to the hot issues (e.g. highest PTW usage and highest VRU road injuries in underdeveloped countries) to connect with the larger community to identify common goals and needs. As motorcycle researchers if want to have real impact, we must engage with the social processes that enable the uptake of new evidence to generate changes in practice, behaviour and policy. This would also stimulate new, more targeted research questions and support community activism.

Forge stronger links to current paradigms and agendas

Through development of strategies coherent with current paradigms and initiatives and integrated across sectors we may give PTWs a larger spot on the future mobility stage. For example, rider training cannot be considered in isolation, without reference to mobility planning agendas, SDGs, learner-centred research, etc.

Better utilization of research, tools and practices from other disciplines and fields

The intersectoral model from Parachute [see Table 5] integrates many of the themes touched on in this paper, from processes (e.g. Develop a shared language, create a unified vision), to overturning outdated and dangerous paradigms (e.g. end victim blaming and promote accountability). It's comprehensiveness also challenges us to think about how we can leverage contemporary themes and movements to expand our voice and influence while exploring new avenues to address PTW safety (e.g. redefining accessibility, equity in the built environment).

We must broaden our perspectives to include missing expertise and models from outside our knowledge domains. We must build and grow relationships with actors across sectors to strengthen our presence in public policy and planning and the VRU discussions. This requires building our own capacity to perform and disseminate cross-sectoral research.

KT supports a (safe) systems approach to motorcycle safety by providing a framework to guide thinking about intersections with other research domains and sectors. As well it offers processes, tools and resources for those new to the profession, as well as a community of practice eager to support capacity building and to share knowledge and experience to ensure research results make their way into the hands of those who can use them.

Table 5 An intersectoral approach to urban road safety 2022 [21]
Strategic areas of focus and recommendations

Collaborate and communicate
➢ Establish universal standards for safe roads ➢ Promote local and national buy-in ➢ Develop a shared language ➢ Create a unified vision
Change the culture of road use
➢ Change behaviour through evidence-based interventions such as: • Lower speeds • Safer cars [vehicles] • Multi-modal transport • Perceptions of safety ➢ Shift the culture around road safety by: • Ending victim blaming and promoting accountability • Sharing success stories • Eliminating preventable deaths • Rethink who uses roads
Transform data practices
➢ Share data between sectors ➢ Collect more detailed data ➢ Use appropriate measures of impact ➢ Prioritize equity
Champion equity and accessibility
➢ Redefine accessibility ➢ Design roads for everyone ➢ Equity in the built environment ➢ Make the healthy choice the easy choice ➢ Remove bureaucratic barriers to change
Engage communities in co-creation
➢ Prioritize co-creation over consultation ➢ Emphasize safety ➢ Enable meaningful and ongoing community engagement

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Aspects of Accident Avoidance for overtaking motorcycles in maneuvers with left turning cars

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Problem definition
The overtaking of slow vehicles is particularly dangerous for motorcyclists. Cars turning left suddenly sheer out over the center line and it leads to collisions with the overtaking motorcycles. Car drivers often declaring no guilty, because they could not see the motorcycle at short notice or has been too fast. These situations are analyzed in a special survey for finding countermeasures in avoidance of such accidents, which are very often connected with severe injuries.

Examination approach
In the study accidents with overtaking motorcyclists (n=169), sampled in GIDAS (German in Depth-Accident Study) at the Medical University Hannover and VUFO Dresden in total n = 54 accidents of the corresponding accident types were reconstructed in detail and the driving movements of the vehicles were analyzed in the distance- time-relation behavior. Possibilities of avoidance were determined per individual case and suggestions on avoidance strategies were developed and proposed.

Method
For the study accidents with overtaking motorcycles could be selected as accident types 202 and 721 of the official accident type catalogue (n = 54) and technical accident parameters were recorded from the complete collection of all motorcycle accidents with injuries to persons. The accident reconstruction already made in the elevations by means of PC crash could be used for the determination of driving and collision speed of the cycle as well as the car, based on true to scaled drawings of accident traces and vehicle and person final positions of motorcycles and cars. With this the study was able to carry out distance-time-relation-analysis and a simulation of the driving movements for the two collision partners until the collision and combine this with an avoidance analysis.

Results
Accident situations of overtaking motorcycles and left-turning cars are dangerous for cycle-drivers and leads often to severe injuries (12.7% MAIS 3,+) compared to the whole group of motorcyclists (9.0% MAIS 3,+). The body regions thorax (11.8%) and legs (6.9%) are heavily particularly seriously injured (AIS3+).
While 30% of the speeds of motorcycles were at reaction above 70 km/h, 30% of the collision speeds still over 55 km/h, i.e. a speed reduction of the overtaking motorcycles until collision was not really given. The speed limit on road was exceeded in 1/3 of the cases.
The intention for left-turn of the car was carried out by the car-drivers in one third of the cases after the decision of the motorcyclists for the overtaking.
Up to 1,8 Seconds are gone after driving of cars over the center line until the collision. A reaction of motorcyclists therefore are mostly not effective for avoidance. The result of the study is, that 20% of motorcyclists could avoid the collision in reaction to the car movement across the center line of the road, while 58% of the car drivers could avoid the accident in cancellation of the left-turn movement and 98 % could avoid the accident by double-check of the side mirror-rear-view.

Consequences

Accidents of motorcycles at the overtaking and collision with left turning cars can be avoided

1. Motorcycles have the possibility when recognizing the danger of a car suddenly turning left by going over the center line of the road of braking hardly (potential nearly 20%)

2. Double reflection during the turn-left-movement should be prescribed in the STVO.

3. Car drivers turning left should carry out a so-called “double reflection” by looking much more often in the left side mirror even if this at present is not stipulated legally to be able to break off the left-turning movement already if necessary. There would be a potential of 58% for it.

4. Left-turns can be checked intelligently also with the help of assistance systems in cars as well in motorcycles.

Aspekte der Vermeidbarkeit von Unfällen mit überholenden Motorrädern und linksabbiegenden PKW

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Problemstellung
Das Überholen von langsam fahrenden Fahrzeugen ist besonders für Motorradfahrer gefährlich, wenn PKW plötzlich zum Linksabbiegern ausscheren. Häufig erklären die PKW-Fahrer, den überholenden Kradfahrer nicht gesehen zu haben, oder er sei zu schnell gewesen.

Untersuchungsansatz
In einer Studie von Unfällen mit überholenden Motorradfahrern, die aus dem Forschungsverbund GIDAS (German-In-Depth-Accident-Study) der Med. Hochschule Hannover und der TU-Dresden ausgewählt wurden[1], konnten n= 54 Unfälle der entsprechenden Unfalltypen detailliert rekonstruiert und die Fahrbewegungen der miteinander kollidierten Fahrzeuge im Weg-Zeit-Verhalten analysiert und Vermeidbarkeitsanalyse erstellt werden.

Methode
Unfälle mit überholenden Motorrädern (n= 169) wurden aus dem Gesamtkollektiv aller Motorradunfälle mit Personenschaden durch Selektion der Unfalltypen 202 und 721 gesichtet (n= 54) und technische Unfallparameter als Datensatz aufbereitet. Mittels PC crash[2] wurde auf Basis einer maßstabsgetreuen Skizze der Unfallspuren und Fahrzeug- und Personenendlagen die Fahr- und Kollisionsgeschwindigkeiten von Krad und PKW ermittelt und eine Simulation der Fahrbewegungen bis zur Kollision mit einer Vermeidbarkeitsanalyse für beide Kollisionspartner durchgeführt.

Ergebnisse
Unfallsituationen mit überholenden Motorrädern und linksabbiegender PKW sind im Unfallgeschehen von Motorrädern durchaus häufig und auch mit relativ hohen Verletzungsschweren verbunden (12,7 % MAIS 3+, verglichen mit dem Gesamtkollektiv aller Motorradverletzten 9,0 % MAIS 3+). Besonders schwer verletzt (AIS3+) sind die Körperregionen Thorax (11,8 %) und Beine (6,9%).
Während 30 % der Fahrgeschwindigkeiten von Motorrädern bei Reaktion über 70 km/h lagen, waren 30 % der Kollisionsgeschwindigkeiten noch über 55 km/h zu verzeichnen, d.h. eine Geschwindigkeitsreduktion der überholenden Kräder war kaum gegeben. In 1/3 der Fälle wurde die zulässige Höchstgeschwindigkeit überschritten. In einem Drittel der Fälle erfolgte der Abbiegeentschluss des PKW vor dem Entschluss des Motorradfahrers zum Ausscheren/Überholen.
Bei den PKW vergingen in 80 % der Fälle lediglich bis zu 1,8 Sek von Überfahren der Mittellinie bis zur Kollision, die eine Wahrnehmung des Abbiegevorganges für den Motorradfahrer hätte erkennbar werden lassen. Damit war eine zeitgerechte Reaktion für die Kradfahrer häufig nicht gegeben.
Motorradfahrer waren bei eingeleiteten Überholvorgängen lediglich in 20 % der Fälle in der Lage den Unfall bei Reaktion im Moment des Überfahrens der Mittellinie des abbiegenden PKW und unter Einhaltung der eigenen zulässigen Geschwindigkeit zu vermeiden. PKW-Fahrer waren dagegen in 58 % in der Lage durch Abbrechen des Abbiegevorganges den Unfall noch zu vermeiden. Allerdings zeigte sich für PKW-Fahrer bei doppelter Rückschau im Seitenspiegel bis zu dem Moment des Überfahrens der Mittellinie, dass 98 % die Kollision noch hätten vermeiden können.

Konsequenzen
Unfälle von Motorrädern beim Überholen und Kollision mit links abbiegenden PKW lassen sich vermeiden.

1.) Motorräder haben die Möglichkeit (Potential 20% der Fälle) bei Erkennen der Gefahr eines plötzlich links abbiegenden PKW durch Überfahren der Mittellinie den Überholvorgang noch abzubrechen.
2.) Motorradfahrer sollten sensibilisiert werden, lange Schlangen von PKW nicht in Bereichen von Einfahrten/Kreuzungen zu überholen.
3.) Linksabbiegende PKW-Fahrer sollten eine doppelte Rückschau im linken Seitenspiegel vornehmen, Potential 58%.
4.) Abbiegevorgänge können unter Zuhilfenahme von Assistenzsystemen im PKW und Motorrad intelligent kontrolliert werden.

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[1] Dank gilt der Bundesanstalt für Straßenwesen und der VUFO TU-Dresden für die Nutzung von GIDAS Daten, die Auswertung erfolgte im Rahmen einer Studienarbeit an der HTW-Berlin in Zusammenarbeit mit BIOMED-TEC

[2] Kollisionsanalyse Programm PC crash version 13.1 Stefan Daten Graz

Improvement of the frontal thorax airbag test procedure for assessing the protection of motorcyclists in a more realistic impact scenario

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Wei Wie, Catherine Masson and Thierry Serre (University of Gustave Eiffel)

Powered Two-Wheelers (PTWs) riders are one of the most vulnerable road users because of their limited structural protection. This vulnerability is translated in a 20 times higher risk of dead for motorcyclists than for car occupants. Among the all body regions injured during an accident, the thorax is reported, besides the head, as the most severely injured region and therefore potential fatal injuries. As a passive safety solution, inflatable devices have been proposed as passive safety solution to provide injury mitigation and protect the PTW users' thorax. Most of the currently available airbag devices in the market are certified by the European Standard EN 1621-4 for motorcyclist' protective clothing against mechanical impacts. However, some doubts have emerged about the suitability of the standard procedure for the evaluation of the protection performance. The low correspondence to a real accident of the impact conditions together with the uncertain origin of the selected thresholds of force transmitted values suggest a low biofidelity of the procedure and motivates the research of more realistic tests methods for the airbag protection evaluation. As part of its activities, the project PIONEERS (Protective Innovations Of New Equipment for Enhanced Rider Safety) addressed this topic in order to develop of more reliable tests procedures based on biomechanical fundamentals. As possible complementary test procedures to the current Standard EN1621-4 or foreseeing the implementation of a new Standard, two preliminary tests methods using the thorax of a Hybrid III Dummy were proposed for the future assessment of frontal airbag protection performance.

Improvement of the frontal thorax airbag test procedure for assessing the protection of motorcyclists in a more realistic impact scenario

1. Introduction

A Powered Two-Wheeler (PTW) user is one of the most vulnerable road user because PTWs provide little structural protection in case of accident. Traffic accidents involving motorcyclists and moped users account for 28% [1] of all world traffic fatalities and the 17% of the traffic deaths in the European Union [2]. Despite other body regions are more frequently injured, the thorax, besides the head, is the most severely body region injured in motorcycle accidents [3]. In the Motorcycle accident In-Depth Study (MAIDS) report published in 2008 [4], the thorax was reported to be the fourth most common region injured but the one with the highest rate of MAIS3+ injuries. According to Serre et al. (2012) [5], more than 50% of the potential fatal injuries (AIS 4+) analysed were located in the thorax. Despite the high probability of fatal consequences due to thorax injuries few progress have been achieved in reducing those injuries. Two types of protector are currently available as passive safety devices for the protection of PTW users' thorax: inflatable and non-inflatable protectors. A non-inflatable protector is usually a pad cushion wore covering the chest area while an inflatable protector will be deployed in case an accident protecting this area. Both kind of protectors try to absorb the impact energy in order to avoid thorax injuries.

Most of the inflatable protector available on the market meet the performance requirements of the European Standard EN 1621-4:2012 [6]. This current standard evaluates the protection of an inflatable device trigged by a mechanical system (basically a cable linked between the rider and the motorcycle) attending to three points: the impact force attenuation, the intervention time and the duration of the inflated status. However, some doubts about the suitability of the standard procedure have emerged due to its low biofidelity, its low correspondence with the reality and the unknown background of the force transmitted thresholds.

The impact attenuation test is conducted by releasing a 5 kg bar impactor to strike the protector, which placed on a metal anvil, for a total of 50 ± 1.5 J kinetic energy impact. The protection performance is determined according to the value of the impact force measured under the anvil (Level 1: overall mean value ≤ 4.5 kN, single strike ≤ 6 kN; Level 2: overall mean value ≤ 2.5 kN, single strike ≤ 3 kN). However, from the biomechanical point of view, it remains uncertain the reasons why the impact energy level of 50 J was chosen because it is an energy level considerably less than a realistic accident impact energy [7]. Moreover, the values of transmitted force might not be considered as the only indicator of the potential protection performance without complementary based measurements [8].

The intervention time is calculated as the sum of the activation and inflation time. However, the activation time mathematical calculation is based on a formula which considers the motorcycle speed and the trigger cable length. Therefore, this formula is only valid for those devices cable-triggered and not for those one electronically deployable based on the sensors integrated on the motorcycle as well as on the protector.

The limitations presented by the current standard for the evaluation of inflatable thorax protection devices motivate the research of new tests procedures. As part of its activities, the PIONEERS project (Protective Innovation Of New Equipment for Enhanced Rider Safety) addresses this topic in order to propose complementary tests methods to the standard procedure which could improve the protection performance of the thorax airbags. As result of its investigations, the PIONEERS project suggested two preliminary test methods.

2. Test method 1

The first test method proposal for the evaluation of the impact performance of thorax airbag follows the classical conception of a free-fall test procedure (also used on the current standard EN1621) in order to fulfill the requirements of a simple, robust and repeatable procedure. However, new impact conditions were determined as well as the design new drop tower was conducted in order to obtain a more realistic and biofidelic test procedure.

2.1 Test impact conditions

The impact conditions defined for the new test procedure were obtained from the analysis of accident date. In contrast to the standard EN1621-4, where there is no clear evidences of the foundations of the test conditions applied, the new test conditions should be as close as possible to those impact conditions occurring during a real accident. According to the conclusions obtained from the accidents analysis conducted during PIONEERS project [9], two main scenarios were identified as representative of numerous thorax impacts in PTWs accidents which could define could define the impact conditions for the test procedure (see Table 1).

	Velocity (m/s)	Geometry	Moving mass (kg)
Test A	3 m/s	Rigid plane	≈ 75 kg (50^{th} percentile male)
Test B	7 m/s	Rigid cylinder with a radius from 5 to 10cm	≈ 75 kg (50^{th} percentile male)

Table 1. Impact conditions for the evaluation of thorax impact protection.

These two impact scenarios could be the basis for the definition of two impact test for the evaluation of airbags protection performance. The Test A (see Table 1) could be considered a low severity test which could assure a minimal protection from devices more comfort oriented. Test B, as a more severe test and representative of a real accident, could be oriented to those products developed to provide more safety.

2.2 Test setup

The evaluation of the protection performance of airbag devices would be conducted in a free-fall tower where a free falling mass (impactor) would impact the inflated protector. However, on this new procedure a rigid anvil would not be used to place the protector. Instead, it would be substitute for a human surrogate which could better characterize the performance of a human body during an impact. Facing the impossibility of developing a specific surrogate, the thorax of a Hybrid III dummy was selected for that purpose. Figure 1 shows a sketch the free-fall tower developed.

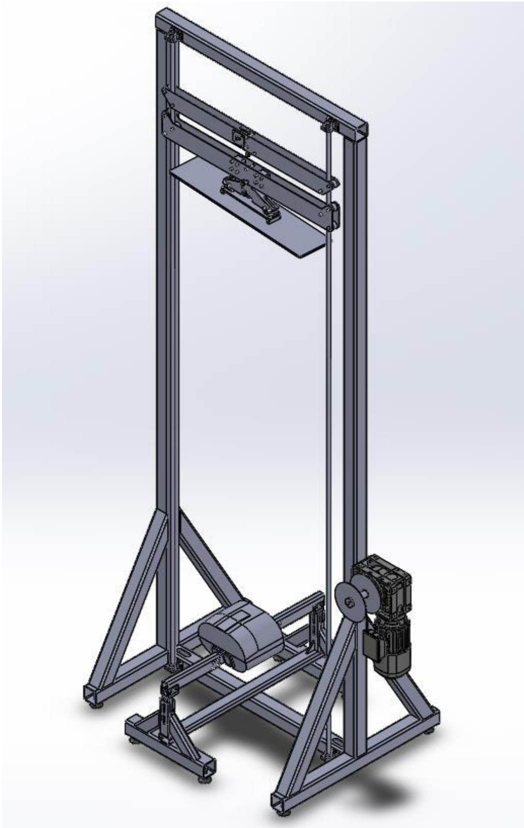

Figure 1. Sketch of the free-fall tower developed for the test procedure [10].

The objective of developing a more realistic test procedure set out the difficulties of the translation of the real accident conditions into a laboratory environment. As it happened on the standard EN1621 test, on the new method a striker would hit the protector (object-to-rider configuration) while in a real accident is the PTW user wearing a protector device who would impact an obstacle (rider-to-object configuration). In this case, an object-to-rider configuration test was preferred because of its more repeatability and technical simplicity. The striker was designed modular. Five kilogram steps could be added to a 10 kg basis impactor in order to variate the impact mass. However, to not assign an unrealistic and arbitrary mass to the impactor, it was necessary to calculate, at least, an approximation of the equivalent effective mass during a rider-to-object configuration impact.

To approximate the equivalent effective mass, the load case situation with Test B on a rider-to-object configuration was simulated in a numerical environment using a FE model of a Hybrid III dummy without airbag protector in order to calculate the thorax deflection (101.8 mm) generated by the impact. At the same time, also a numerical sensitivity analysis was conducted to measure the thorax deflection at the Hybrid III dummy for different impact masses. As result of the comparison of the deflection values obtained from both configurations, it was found that an object mass of 33.75 kg could initially approximate the equivalent effective mass involve during the impact.

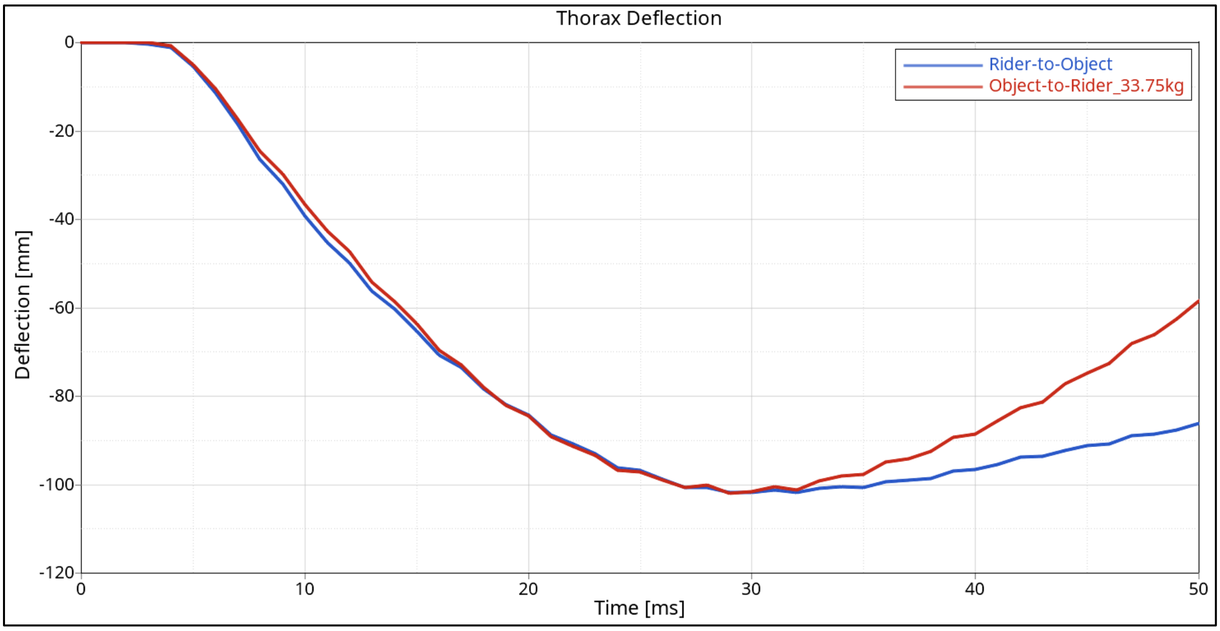

Figure 2. Thorax deflection comparison for the rider-to-object and object-to-rider configuration [11].

2.3 Performance assessment

The use of a human surrogate, in this case the thorax of a Hybrid III dummy, together with the airbag devices would make possible to evaluate the protection performance according to biomechanical parameters and criteria. The thorax of the Hybrid III dummy is equipped with a sensor which enables to measure the thorax deflection and, applying the Compression Criteria [12, 13], would be possible to estimate the severity of possible skeletal injuries as it is shown in Figure 3.

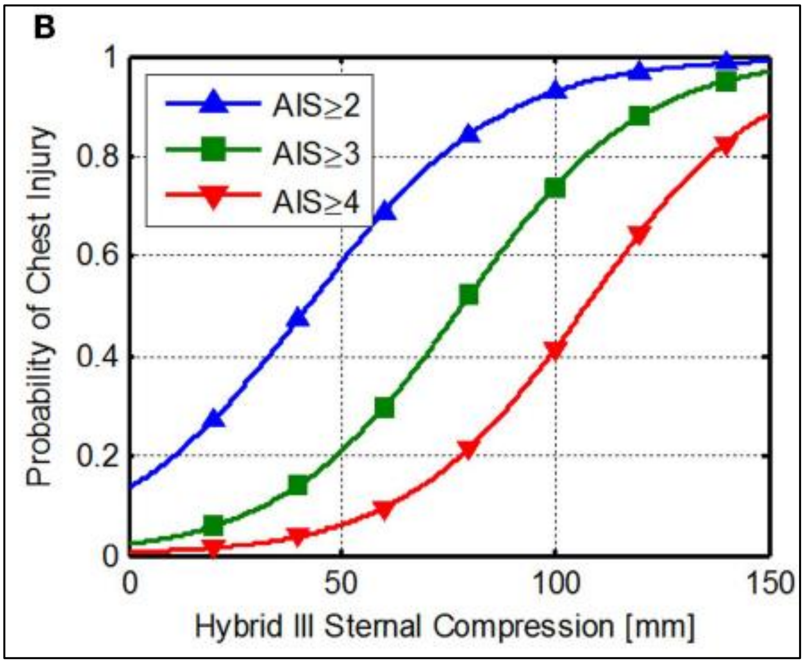

Figure 3. Probability of thorax injury depending of Hybrid III dummy sternal compression [14].

In addition, the measured deflection value could be used to calculate the viscous tolerance applying the Viscous Criteria [15] and after its normalization, it would be possible to estimate the probability of severe soft tissue injuries [16]. See Figure 4.

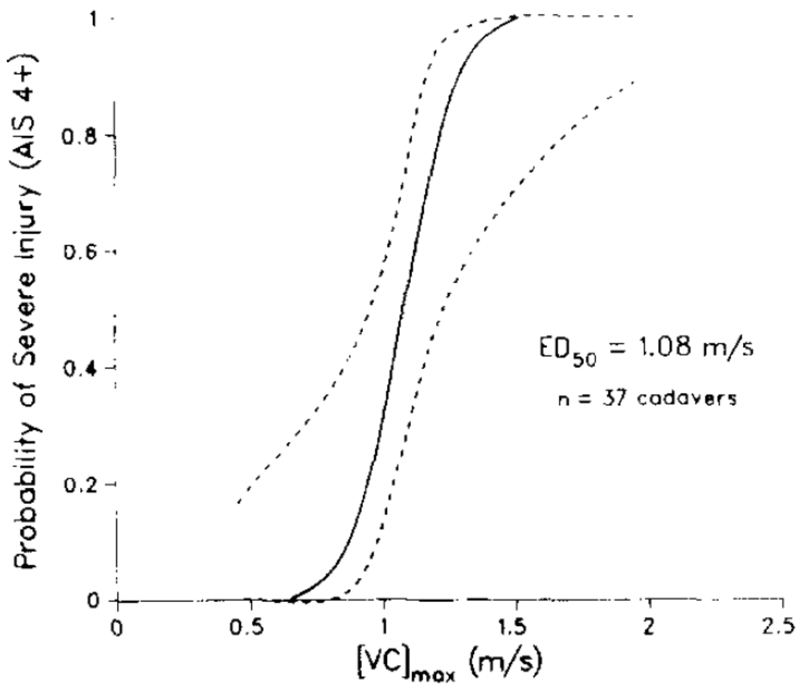

Figure 4. Probability of severe soft tissue injury depending of the viscous tolerance value [15].

The values of deflection and viscous response could be used on this test procedure to assess the protection performance of a protector devices guaranteeing a determined level of protection based on the injury risk derived from those parameters. Additionally, it could be possible to classify the devices' performance in different levels of protection (as the standard EN1621 does) based on biomechanical fundamentals.

3. Test method 2

The second test procedure implemented during PIONEERS was developed to evaluate both calbe-triggering and autonomous-triggering inflatable devices under test conditions close to realistic accident scenarios.

3.1 Test setup

A drop tower was designed with the purpose of evaluating the performance of inflatable protectors for chest protection. The drop tower system was made up of a mobile platform (see Figure 5, which when unhooked, would fall from the height along a vertical trail under gravity. In total, the platform could be lifted along the trail to different height positions up to 4 meters. The drop tower is also equipped with a braking system.

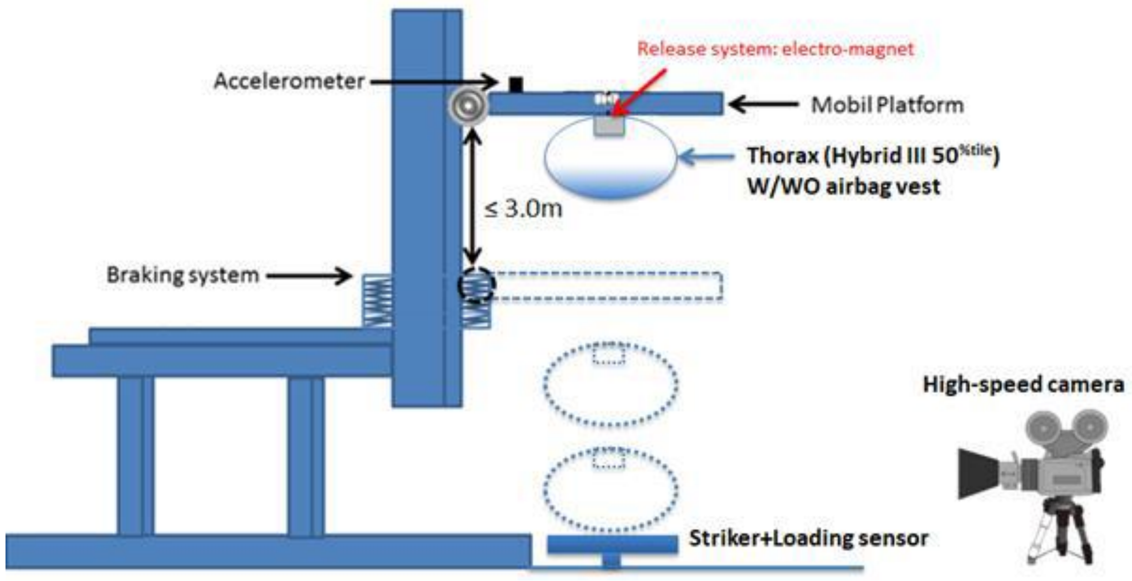

Figure 5. Drop tower system for protection performance evaluation of inflatable protectors [11].

A human thorax surrogate (in this case a Hybrid III male thorax) would be suspended to the mobile platform through a steel cable, a steel bar and an electro-magnet. The frontal thorax would be adjusted so its profile would be oriented horizontally. When unhooked, the platform would drop along the trail. When it reached the height approximately of 1 m, the braking system would start to actuate decelerating the platform. At the moment when the platform reached the height corresponding to the desired impact speed, the electro-magnet would be shut down releasing the surrogate thorax and making it falling freely to hit striker fixed on the floor and equipped with a load cell. The striker used would be a flat steel plate with the size of 21,5cm*27,5cm*1,5cm. The use of a Hybrid III torso (total mass of 19 kg) would make possible to measure the thorax deflection once it hits the striker.

3.2 Inflatable device evaluation

The use of this drop tower would allow to inflate the protector devices during the test by measuring the moment when the airbag is triggered before the impact. An autonomous triggering inflatable system is controlled by the electronics when one of the pre-set conditions arises. However, a cable-triggered system would be mechanically activated. For that purpose, once the inflatable protector is worn by the surrogate and positioned at the platform, a pulley would be fixed on the bottom of the spinal component of the surrogate and the cable of the inflatable device would pass through the pulley to be suspended to the mobile platform (See Figure 6). In this way, the cable would be pulled from a posterior-inferior direction to the thorax triggering the airbag similarly to real accident conditions. The evaluation of the fully inflated state of the airbag would be at this preliminary stage roughly evaluated from with the high-speed video assuming this step would be achieved at the moment which the device shape would not change anymore.

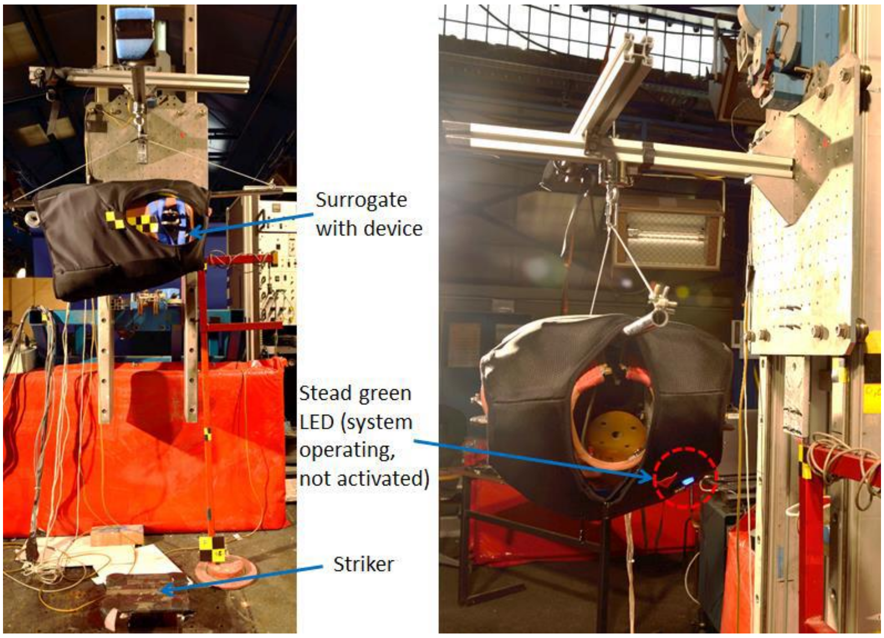

Figure 6. Test setup for electronically-electronically inflatable protector [11].

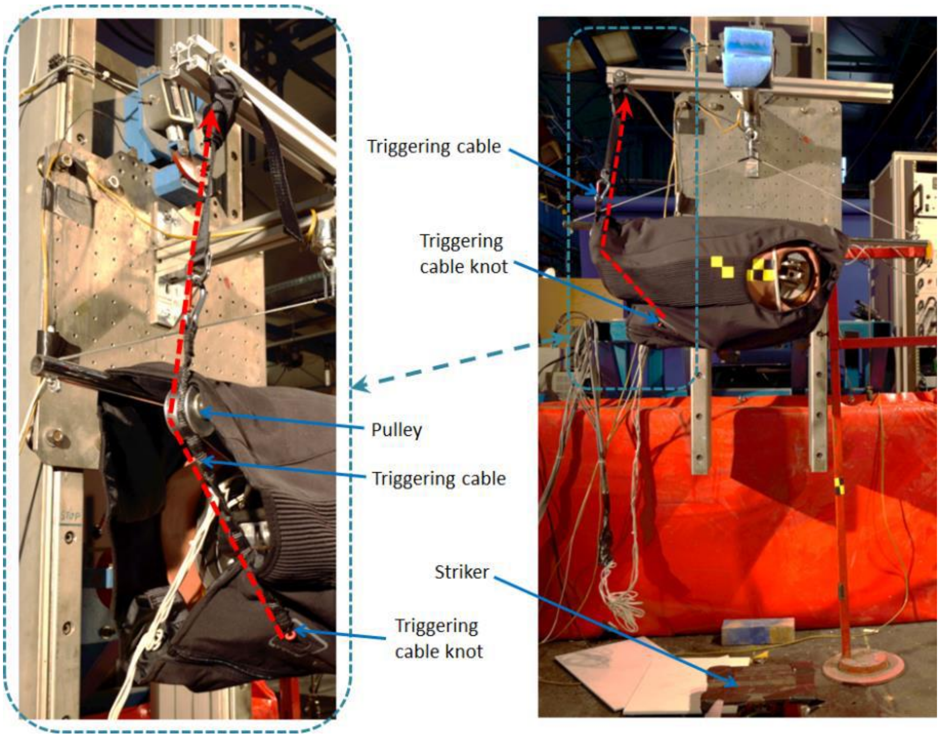

Figure 7. Test setup for cable triggering inflatable protector [11].

4. <u>Summary and conclusion</u>

The emerged doubts about the current standard procedure for the evaluation of the protection performance of inflatable devices together with its limitations have motivated the research of new more realistic and biofidelic test procedures. Within its activities, the project PIONEERS faced this topic proposing two preliminary test procedures.

The first procedure presented consists in a drop tower were a cylinder or a plate would impact the torso of a Hybrid III dummy equipped with the inflatable protector according to the impact conditions found in accident analysis. This procedure would respond to the demand of a simple and repeatable test method making possible the evaluation of the protection performance based on biomechanical parameters through the measurement of the thorax deflection and the application of the Compression and Viscous Criteria. However, this procedure would presents also some limitations. Firstly, the application of the inverse impact configuration with respect to a real accident implies the need of the calculation of the equivalent mass involve in real accidents. In this document an approximation to this value, found during PIONEERS, was exposed but further investigations are needed. Secondly, an impact condition obtained from the accident data could derivate in deflections over 60-65mm which could go beyond the measure limits of the Hybrid III dummy without breaking it. Finally, this procedure could only be conducted with an already inflated protector making no possible to evaluate the trigger and inflation process.

The second procedure proposed a drop tower were a mobile platform attached with the thorax surrogate would impact a fixed striker following. The inflatable protector would be wore flat by the Hybrid III torso and it would be activated during the fall making possible to evaluate not only the impact magnitudes (deflection and thorax, impact force) but also the activation and inflation process of both, cable-triggered and autonomous-triggered airbag. However, this procedure would present also some limitations. Firstly, a rider-to-object configuration should be more realistic according to an accident scenario but also implies a more complex procedure which should be further developed. Secondly, the mass of the Hybrid III torso (19 kg) might not be close to the mass involved during the accident.

Despite the possible limitations, two possible new test procedures were presented as result of PIONEERS investigations. The first one could be a complement to the EN1621 standard in order to improve in a short/midterm the safety and protection performance of frontal thorax airbags. The second one could be the procedure to evaluate inflatable devices in a long term aiming at reproducing closely the impact conditions of a real accident scenario combining the evaluation of the protection performance with the assessment of the inflation phase of the airbag.

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Smart wearable airbags: Benefits for users and remaining challenges after 60 million kilometres and 3000 accidents

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1. Introduction :

Over the last five years, wearable airbag (“wairbag”) protectors have undergone a major technological and usage revolution and are becoming an increasingly popular protection solution for motorcyclists. These safety devices consist of inflatable bags embedded in the garments worn by motorcyclists which are activated in response to an abnormal event, i.e. an accident. The aim is to reduce trauma frequency and severity by inflating the airbag before the impact of the motorcyclist. Therefore, the effectiveness of the device does not only depend on impact attenuation but also on accident detection and inflation in a very short time, key elements to be protective before the first impact.

Epidemiological studies showed the severity of thoracic injuries sustained by motorcyclists and the need of ribcage and internal organs protection [1]. Since wairbags are the only equipment capable of absorbing impacts to the trunk and mitigating these injuries, the promotion of its use and the development of products more adapted to the needs and expectations of users have made it possible to significantly grow the equipped number of motorcyclists. In France, wairbag usage increased from 4% in 2016 to 8% in 2019, but it is still very low compared to helmet (100%), gloves (100%) and jackets (99%) wearing rates [2]. The use of helmets, gloves and jackets is similar in Europe, while the proportion of wairbag users is much lower (0.9%) [3].

The objective of this work is to make a state-of-art of wairbags in terms of product availability, diffusion, difficulties for being equipped with as well as users’ mentality evolution. The approach adopted combines an overall analysis of the wairbag ecosystem with a dedicated survey to obtain feedback from motorcyclists wearing In&motion products.

2. Materials and methods:

2.1 Wairbag ecosystem analysis:

The evolution of wairbag technology has been studied based on a market analysis and the knowledge acquired by In&motion through its strong involvement in the univers of protective equipment. Feedback from partner brands of motorcycle clothing and insurances as well as resellers completed the field information. The equipment of riders in the motorcycle road racing and cross-country world championships has provided data on the use of the product in the most demanding and extreme conditions.

2.2 Feedback from In&motion wairbag users:

In&motion wairbag users (120000 products on the market since 2018) are regularly contacted in order to understand their expectations, their uses and their perception of this technology. In July 2021, part of this population was asked by email to answer an online questionnaire. Data on the characteristics of the users, their riding experience and habits, the wearing of personal protective equipment (PPE) or the wairbag usage were collected.

3. Results:

3.1. Wairbag ecosystem analysis:

3.1.1. History of the wairbag:

The first wairbag for motorcyclist was developed at the end of the 90s and three generations followed one another after its appearance on the market:

1. Mechanical wairbags (1998): The triggering system is physically connected to the motorcycle with a lanyard. The piston that pierces the CO2 gas cartridge to inflate the bag is released when a great enough force is exerted on the cable.
2. Electronic radio wairbags (2012): The sensors allowing the detection of the accident are mounted on the bike. A communication box also installed on the motorcycle communicates by radio link with the wairbag.
3. Electronic autonomous wairbags (2016): All the sensors and electronic components are integrated into the garment worn by the motorcyclist making the wairbag bike-independent. Some of these products can share the recorded riding data and be updated remotely.

The wairbag has experienced a real acceleration over the last 5 years with a strong increase of the economic actors offering this safety equipment (Figure 1a). From 2000 to 2015 the number of manufacturers multiplied by 5, while between 2015 and 2021 the number of brands multiplied by 3.5. In 2022, 50% of companies offered mechanical devices, 30% electronic products and 20% both technologies. Motorcycle is the biggest market with 69% of wairbag brands commercializing these products (Figure 1b) and 1% of new users in France each year from 2019. However, the best seller is the Hovding airbag helmet for cyclists with 425000 units sold since 2013.

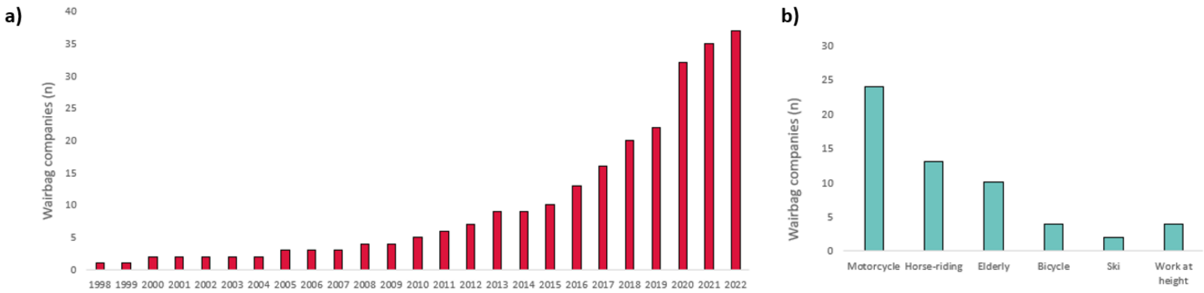

Figure 1. (a) Evolution of the number of companies commercialising wairbags. (b) Usage of the available wairbags in 2021.

3.1.2. The 3 factors explaining the acceleration of wairbag diffusion:

1-Increment and availability of the products

During the last 6 years, the three main manufacturers of electronic wairbags, i.e. In&motion, Dainese and Alpinestars, offer 25 different products which are available in 2000 sales points in Europe (700 in France versus 160 in 2014). Most wairbags are sold in motorcycle clothing and accessory stores, dealers and specialised e-commerce websites.

2-Fall of prices

Figure 2 shows the sale prices evolution of electronic systems for road use. The first products with sensors installed on the motorcycle costing 1300 € were definitively replaced in 2018 by the new generation of autonomous wairbags. Sold from 1200 to 1500 € at launch, their prices have dropped significantly to stabilize around 600-800 €. In&motion purchase and rental options decrease the initial purchase price to 350-400 €. The mechanical devices are sold between 300 and 600 €.

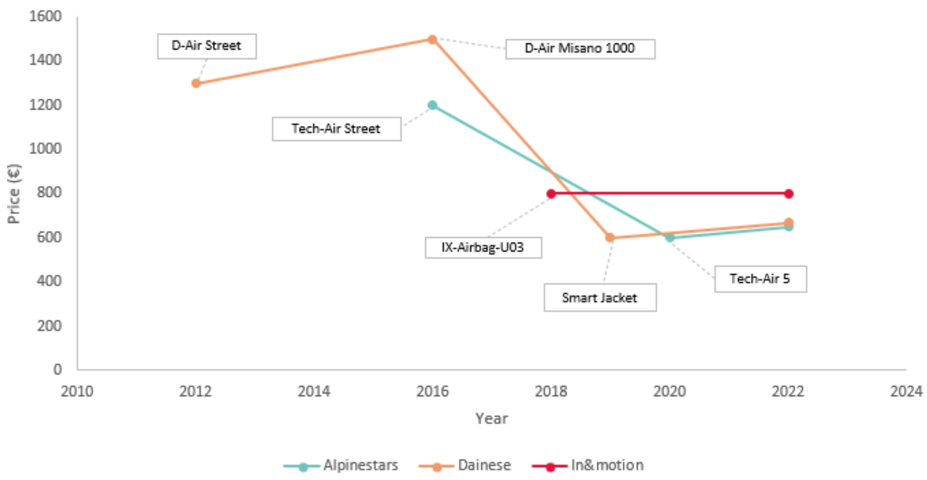

Figure 2. Electronic wairbags price evolution.

3-The involvement of third parties: insurers, governments, federations

At the same time, some stakeholders have promoted the use of motorcycle wairbags. Based on the SRA rating [4], insurers offer purchase aids and formulas to cover the recharge cost or even replace the wairbag after an accident. Today, one in two French motorcyclists can benefit from a wairbag purchase reduction thanks to their insurance company. Governments also helped to the spread of the wairbag with millionaire communication campaigns such as “Plan Airbag” in France (2019 and 2021) or “Ponte Un Airbag” in Spain (2021).

More and more motorcycle championships are recommending or even imposing the use of wairbags. The MotoGP world championship was the first to make the wairbag compulsory in 2018, followed by the Dakar (2021), the JuniorGP (2022) and the IDM (2022). The use of these devices has already paid off with a drop of chest injuries by 50% in the Dakar 2021 compared to the previous edition. In MotoGP, the only compulsory coverage area are the shoulders and wairbags have reduced the number of collarbone fractures. Between 2013 and 2017, collarbone fractures accounted for 24% of the total number of fractures [5], while for the 2020 and 2021 seasons this type of injury decreased to 16% [6,7].

2.2. Feedback from In&motion wairbag users:

The questionnaire was completed by 4653 people, 92.5% were male and 7.5% female. The average age is 46 (similar to that of motorcyclists in France), while 79% of the population is over 35 (Figure 3). The most represented age range for both sexes is 50-64 with 46% of men and 39% of women.

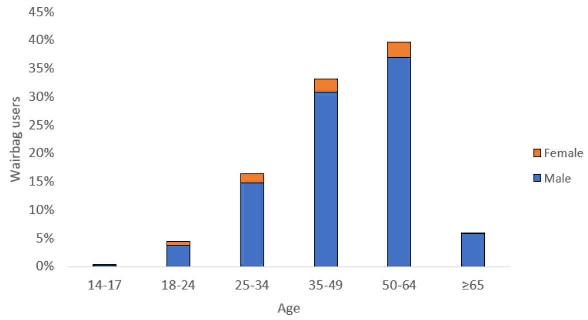

Figure 3. Respondents age distribution.

Regarding riding experience and habits, 74% of respondents have been using a motorcycle for more than 5 years and almost half of the population (48%) is over 15 years of experience. Most bikers (63%) ride during all the year, 23% 8 months/year and 14% only when the weather is nice. Almost 60% of respondents travel more than 5000 km per year (Figure 4).

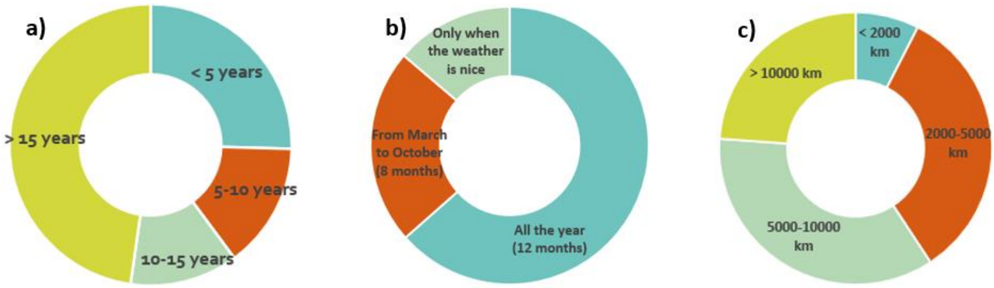

Figure 4. (a) Riding experience. (b) Riding time during the year. (c) Number of kilometres per year.

The protective equipment worn by the participants is listed in Figure 5. In addition to the wairbag and the back protector embedded in, the most used PPEs are the helmet (100%), gloves (93%), jackets (93%) and footwear (90%).

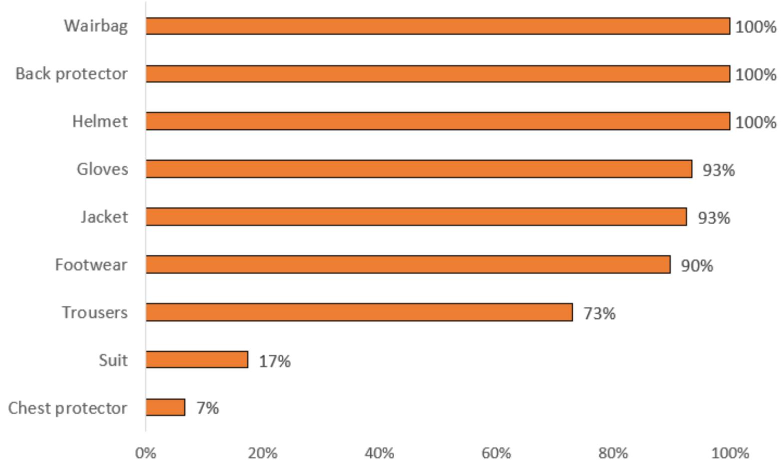

Figure 5. PPE wearing rates.

Only 10% of the sample wore a wairbag before purchasing the In&motion system (75% mechanical and 25% electronic). At the time of purchase of the In&motion device, having an autonomous wairbag was the first buying criterion (55%), followed by wearable under the jacket (13%), the protection zones (7%), the ease of use (5%) and the intervention time (5%).

Among the 4653 respondents, 10% have already had an accident wearing the In&motion wairbag. In 61% of the cases the victim thinks that the inflation of the device has undoubtedly avoided injuries, while 16% of the riders believe that there are still elements to improve even if the device has inflated. The wairbag did not trigger in 23% of the falls, of which 66% were not necessary according to the motorcyclist. Only 8% of the falls were not covered by the wairbag and the victim felt that inflation was necessary. Among the falls where triggering seems necessary (user perception), the system inflated in 91% of the cases (Figure 6a).

Figure 6b shows the opinion of the participants when they are asked about the possibility of riding again without a wairbag. The responses are similar for both samples having had and don't having had an accident with the system. For about 66% of respondents riding without a wairbag is unthinkable and around 30% of people would have moderate discomfort.

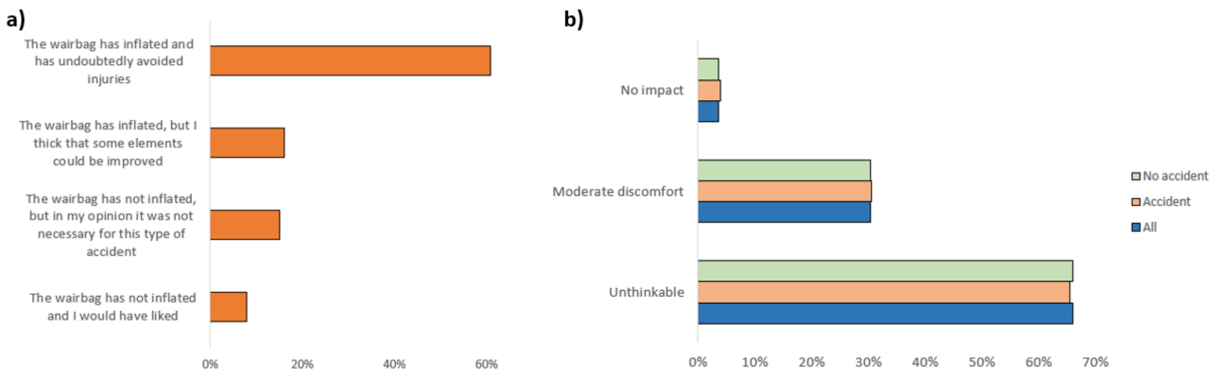

Figure 6. (a) Effectiveness of the wairbag in case of accident. (b) Feeling of riding without wairbag.

In&motion wairbags are connected and their operation requires the creation of an account which allows monitoring the use of the system over time. After more than 3 years and a half, less than 5% of the customers have stopped using the protector with more than a half also stopping the bike. These 2 elements confirm that most of the users don't go back once they decide to wear a wairbag.

Conclusion

Arrived on the French market during the 2000s, the wairbag has evolved from an innovation reserved for the elite to a product available and accessible to most people. It is one of the must-have in accessory stores and its diffusion is following strong growth. Since 2018, the wairbag has experienced a real acceleration: the price of electronic systems reduced by two, massive dissemination in specialized distribution networks, promotional campaigns, obligation in many disciplines and above all, wearing rates constantly growing.

The users of these devices are experienced motorcyclists, most of them between 35 and 65 and well-equipped. They ride during almost all the year and the majority of them travel more than 5000 km per year. Those who have had an accident with the In&motion wairbag highlight the correct functioning of the system and its effectiveness in avoiding injuries. Less than 4% would take the road without being equipped which is confirmed by the very low end-of-use rate (around 2% per year). For any technological innovation, its diffusion to this first group of users called "early adopter" allows its exposure to other groups and thus, when the opinions are positive, the acceleration of its spread among the rest of the users.

Previous studies have estimated the wairbag effectiveness from 1 to 2 levels of AIS reduction for the thorax [8]. In 2022, In&motion has recorded more than 3000 accidents during more than 60 million kilometres travelled. Scientific studies are in progress on this constantly increasing database in order to confirm or refute, via real cases, the levels of injury reduction due to the use of the wairbag.

The wairbag is the biggest safety revolution for motorcyclists since the helmet and its innovation potential is major. Constant improvements of detection algorithms enable to envisage accident coverage rates close to 100% in 2023. The optimization of protective areas and the addition of e-call could further reduce injury severity as well as improve medical intervention in case of accident. In conclusion, the wairbag is positioned as a solution with a unique "ease of diffusion/protection performance" ratio comparable to the helmet 50 years ago.

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Life-saving effects of road markings on bends

Der Beitrag von Bodenmarkierungen in Kurven zur Unfallreduktion

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1 Abstract

In 2017, new road markings were added to eight popular motorbike routes in Austria, predominantly on blind left-hand bends and in the form of bars or ellipses. This measure was successful in encouraging motorcyclists to avoid driving over the road markings. The riders' trajectories significantly changed towards a safer lateral position in the outside part of their lane.

Based on this experience, several bends on typical motorbike routes in Luxembourg were equipped with bar markings, based on a similar concept. Before-and-after-observations showed that road markings vary in effects, e.g., are not as effective on bends with good forward visibility. Besides these effects, this paper and presentation will highlight the opinion-forming process and resistance which had to be overcome as well as the process of design and practical implementation.

Meanwhile, researchers revisited the eight bends (= routes) in Austria. Long-term effects were investigated. It appeared the elliptic markings were even more effective than shortly after implementation. Bar markings improved rider behaviour to an even greater extent and fully caught up with elliptic markings. Moreover, the accident analysis found considerably fewer crashes in the after-period.

During the summer of 2019, 19 bends were equipped with road markings as one of the activities of a motorbike safety program of the Tyrolean regional government with immediate impact as the main goal. On average, there were 13 injuries and 0.6 deaths annually during a seven-year (before) period on these bends. In the 2.5-year after-period, 4 injuries were registered. After accounting for the massive impact of the Covid 19 pandemic on exposure (approx. 10% less commuter traffic, 40% less leisure riding), an 80% decrease in injuries was observed, and there were no more fatalities on the bends with road markings.

2 Kurzfassung

Auf acht beliebten österreichischen Motorradstrecken wurden 2017 in überwiegend unübersichtlichen Linkskurven neuartige Bodenmarkierungen in Form von Ellipsen bzw. Balken entlang der Mittellinie aufgebracht. Diese Bodenmarkierungen stellen eine Hilfe für Motorradfahrer dar, um die Kurve sicher zu durchfahren. Dabei wurde erfolgreich ausgenutzt, dass Motorradfahrer das Überfahren von Bodenmarkierungen meiden. Es wurden kurzfristig signifikante Veränderungen der Fahrlinien von Motorradfahrenden erreicht.

Darauf aufbauend wurden in Luxemburg mehrere typische Motorradstrecken auf Basis eines ähnlichen Konzepts mit Bodenmarkierungen (nur Balkenmarkierung) versehen. Auch hier wurden vor und nach der Aufbringung der Markierungen die Fahrlinien beobachtet. Es zeigte sich, dass die Markierungen nicht in allen Kurven gleich erfolgreich angewendet werden können, beispielsweise sind die Effekte in übersichtlichen Kurven auch vorhanden, jedoch geringer. Neben den Bodenmarkierungen selbst geht dieses Papier auch auf den Meinungsbildungsprozess ein, beleuchtet die Ressentiments, die zu überwinden waren, und stellt die Erfahrungen mit der praktischen Umsetzung und Gestaltung dar.

Währenddessen wurden in Österreich drei Jahre nach der Installation die acht Kurven (= Strecken?) erneut besucht und die längerfristigen Effekte erhoben. Dabei zeigte sich, dass Ellipsenmarkierungen noch besser wirkten als 3 Jahre zu vor; vor allem aber die zunächst weniger wirksamen Balkenmarkierungen in der Wirkung vollends zu den Ellipsen aufschließen konnten. Ferner zeigte eine Unfallanalyse deutlich geringere Unfallzahlen nach der Herstellung der Bodenmarkierungen im Vergleich zum Zeitraum davor.

Im Sommer 2019 wurden in im Zuge eines Motorradsicherheitspakets der Tiroler Landesregierung mit dem eine unmittelbare Reduktion des Unfallgeschehens angepeilt war, 19 Kurven mit Bodenmarkierungen in Ellipsen- oder Balkenform beklebt. In diesen Kurven waren im Beobachtungszeitraum 2012 bis 2018 in Summe durchschnittlich 13 Verletzte und 0,6 getötete Motorradbenutzer pro Jahr registriert worden. Diese Tiroler Motorradsicherheits-Initiative wurde 2022 wiederholt. Dabei wurde festgestellt, dass – auch wenn man den massiven Einfluss der Covid19-Pandemie berücksichtigt (etwa 10% weniger Zweckverkehr, 40 % weniger Freizeitverkehr mit Motorrädern) – die Zahl der verletzten Motorradfahrenden in den betrachteten Kurven um 80% zurückging, getötete gab es in den Kurven mit Bodenmarkierungen gar keine mehr.

3 Introduction

The two most common types of accidents in motorbike accidents are "falling off the vehicle" and "leaving the road to the right in a left-hand bend". It has been shown that cornering is often the starting point for such accidents. In studies (Winkelbauer, Bagar, 2013), 5 out of 6 motorcyclists drove so far to the left that they would have had to correct their trajectory in case of oncoming traffic. In most cases, motorcyclists manage to avoid oncoming traffic, but the second necessary correction of the trajectory fails due to "lean angle anxiety" (see below).

The use of road markings to influence the line choice of motorcyclists in bends was already reported here in 2018 (Winkelbauer, Bagar, Höher, Wollendorfer, 2014). At that time, there were empirical values from initial tests on a combination of bends on the Carinthian side of the South Styrian border road ("Soboth"). There, road markings in a W-shape were stuck on the outside of a guideline in order to visually widen the central separation of opposing traffic. Such markings, according to recognised expert opinion, have less of an effect on motorcyclists through their visual impression, but rather through the very widespread stereotype among motorcyclists that road markings are slippery and that one must keep away from them, especially when driving at an angle. This is also taught in driving schools and cannot be got rid of despite the very sound regulations on the skid resistance of road markings. Currently, the skid resistance of road markings must not differ significantly from the skid resistance of the surrounding road. However, when newer road markings are worn out, much older markings may very well come to the surface that do not comply with these regulations.

The markings along the Soboth proved to be effective. After the application, motorbike accidents were reduced to zero in this area, but when the markings faded after about three years, accidents began to re-occur. Only later were more detailed scientific investigations carried out. The first step was an observation of the trajectories of motorcyclists, which was carried out by the KFV on behalf of the Carinthian provincial government (Winkelbauer, Schneider, Strnad, Braun, Schmied, 2017). The subject of this study was only two bends. The effectiveness of different forms of marking was examined. The reason for this was that the W-shaped markings had occasionally been interpreted by motorists as a no-go area. Although this had not caused any accidents, it was reason enough to look for better solutions. The aforementioned study showed that elliptical markings were the best solution. These are not confused with other markings and have no other legal significance. If they are stuck on at an angle of about 45 degrees to the direction of travel, they give the impression of a "deflector".

Subsequently, several studies were carried out to investigate the effectiveness of road markings in influencing road positioning and the effects on the occurrence of accidents at various locations. The results are presented in this paper.

3.1. Motorbike Accidents

In the last 20 years, one cannot speak of a steady "trend" in accident occurrence involving motorbikes. Due to the Corona pandemic, the years 2020 and 2021 are completely out of line. Motorcyclists were urged not to put themselves in danger unnecessarily and to refrain from unnecessary journeys because hospital capacities were needed for Corona patients. Cycling experienced a boom that was most likely not triggered exclusively by the pandemic. Single-track motor vehicles were also partial substitutes for people who wanted to avoid public transport. These circumstances interfere with an evaluation based on a time-series analysis.

The constant boom (in motorcycle numbers) must be considered in the development of accidents involving motorbikes. Since 2000, the number of motorbikes in Austria has increased by 20,000 to 25,000 units per year; in the two Corona years, new registrations of 40,000 to 50,000 units per year were in the range of the previous years. The fact that this enormous growth of about 5% per year did not lead for quite some time to an equally large increase in the number of accidents was probably mainly due to the generally improving safety levels in Austria and to technical improvements to vehicles. However, 2012 saw a turnaround; both killed and injured motorcyclists have slowly but steadily increased since then, until the pandemic caused the numbers to plummet. This drop is almost certainly due to a decrease in exposure - i.e., mileage. No studies are known on the question of whether this decline is a consequence of the previously mentioned appeals to refrain from non-essential driving or the result of home office and short-time work.

Generally speaking, it can be said that motorbike accidents are the sum of two completely different worlds. Most recently, in 2012 (Winkelbauer & Schwaighofer, 2012) it was found that about three quarters of Austrian motorcyclists are predominantly recreational riders. They go for a ride on their motorbike after work or at the weekend to relax, or they go on holiday by motorbike. About a quarter of motorcyclists are mobility-oriented. They mainly ride in urban environments, take advantage of the free parking for motorised two-wheelers, also hardly have to look for parking space and save time in traffic jams. They often ride scooters, wear little protective clothing and tend to have fewer serious accidents. Intersection accidents and rear-end collisions dominate among these "functional riders". Single-vehicle accidents dominate among recreational riders. Overtaking accidents are particularly severe because they often involve oncoming traffic and overtaking is done at a higher speed than other manoeuvres.

3.2. Cutting curves

The typical recreational rider is looking for winding roads. Often this is also related to scenic beauty, but the experience of riding dynamics, the challenge of a demanding route and the sense of achievement after a successful ride are the dominant motives for such motorcyclists. In this respect, cutting curves seems absurd. People look for curvy routes, often even accept a long journey, and then "bend the curves straight", as it were, by cutting them. No studies could be found on the actual reasons for this behaviour, but it seems reasonable to assume that the triangular relationship between curve radius, speed and lean angle is decisive: higher speed in a curve is made possible by a larger radius (i.e., curve cutting) or greater lean angle. Road safety training also revealed that the same motorcyclists who were first filmed with their heads well beyond the centre line were firmly convinced that they had stayed within their lane. This observation is the reason why video is used in such training courses. And experience shows that the course participants react very surprised when they see from the videos how far over the centre they were.

Motorcyclists often ride in groups. There are several reasons for increased risk in this context: the will to keep up with others in the group can lead to exceeding personal limits (Lang, Kühn, 2020). To compensate, curves are shortened. The fault lies not only with the affected riders themselves, but above all with the rider in front, who overtaxes members of the group. In more than half of the accidents occurring during group rides, members of one's own group are the 3rd party in the accident.

3.3. Lean angle anxiety

Cornering radius, driving speed and lean angle are mathematically related when cornering with single-track vehicles. There are limits to the lean angle, due to the grip of the tyres on the road surface, the ground clearance of the vehicle and the ability of the driver to adopt the lean angle required by the speed and radius.

The term Schräglagenangst (lean angle anxiety) was first recorded in the German-speaking world by the journalist Bernd Spiegel. In his book "Die obere Hälfte des Motorrads" / The upper half of the motorbike (Spiegel, 2015), he wrote about this phenomenon, which had hardly been addressed until then. He argued that motorcyclists who are not specifically trained have a natural lean limit of about 20 degrees, that this can be explained anthropologically and that it also occurs in the same way when running or riding. Meanwhile, it is known that motorcyclists consistently ride at higher lean angles (Winkelbauer, 2018). The German Federal Highway Research Institute has also had the phenomenon studied in detail with regard to the justification of the term "fear" (Scherer et al, 2021). The study showed that motorcyclists have an individual lean angle limit. This is slightly variable, depending on the context and the prevailing conditions. It is not possible to exceed it. To put it simply: If a left turn at the chosen speed is not feasible, or if the planned line of travel is disturbed by oncoming traffic (as a result of a too narrow line of travel), this ends either in an uncontrolled braking manoeuvre and a crash, or in leaving the lane - still sitting on the motorbike.[1] However, the study also found that motorcyclists do not significantly undercut their lean limit. This means that their safety reserves are always low in all bends where the driving speed is selected on the basis of the bend radius and maximum lean angle. In the accident statistics, however, resulting accidents are not only found as "swerving to the right in a left-hand bend" (about 10% of all motorbike accidents), but also as "falling off the vehicle" because jerk-reaction braking leads to an immediate fall (about 12% of motorbike accidents). Only rarely do motorcyclists collide with oncoming traffic in left-hand bends (about 2%). Reaching the lean angle limit is such an intense experience and its effect so extreme that it can be described as a phobia or even "fear", in line with medical phenomena.

4 History and Research

The findings collected in the pilot study were positive enough to subject them to a detailed investigation (i.e., the first evaluation study). Their good results led to great interest in the professional world and to several further applications and investigations, which are presented chronologically below.

4.1. Pilot Study

The markings along the Soboth proved to be effective. After the application, motorbike accidents were reduced to zero in this area, but when the markings faded after about three years, accidents began to re-occur. More detailed scientific investigations were carried out only later. The first step was an observation of the trajecgories of motorcyclists, which the KFV carried out on behalf of the Carinthian provincial government. The subject of this study was only two bends. The effectiveness of different forms of marking was examined. The reason for this was that the W-shaped markings had occasionally been interpreted by motorists as a barrier. Although this had not caused any accidents, it was reason enough to look for better solutions. The aforementioned study showed that elliptical markings were the best solution. These are not to be confused with other markings and have no other legal significance. If they are stuck on at an angle of about 45 degrees to the direction of travel, they give the impression of a "deflector".

[1] For motorcyclists, there are - to put it bluntly - only two types of curves: either the speed determines the lean angle or the lean angle determines the speed. Motorcyclists negotiate narrower bends at a speed that suits their individual lean angle tolerance. For wider bends, the lean angle is determined by the driving speed, which is based on the speed limit or visibility, for example.

4.2. Rakitna, Slovenia

This is a very beautiful, winding excursion route about 30 km south of Ljubljana. On an approximately 10 km long section of road 643, dynamically oriented motorcyclists would measure their driving times and publish them on the Internet, and the number of accidents was correspondingly high. Here, the same W-shaped markings as on the Soboth were placed on numerous bends. According to the responsible official of the Slovenian administration, this led to a massive reduction in the number of accidents. The markings were massively opposed by the motorcyclists' associations, but the initially strong resistance gave way over time. Time trials continued on the route, but it was no longer the motorcyclist who ventured furthest into oncoming traffic who set the best times. The competition was shifted to the rider's own side of the road. This made the illegal races safer and was ultimately appreciated by the motorcyclists. There was no scientific study of the curve lines, the accidents or the opinions of the motorcyclists.

4.3. First evaluation study: rider positioning on nine bends

In order to create a sound data basis for the further application of road markings, nine bends were selected in 2016 for a thorough before-and-after study in cooperation with the provincial administrative authorities of Lower Austria, Burgenland and Carinthia (*Winkelbauer, Schneider, Strnad, Braun, Schmied, 2017*). A video camera was set up at the entrance to the bend, at the apex and at the exit from the bend and left in place for one day. This was usually sufficient to reach the target of 500 observed motorcyclists. After that, ground markings were glued on. As in almost all other applications, the extremely grippy Stamark 380 film from 3M was used for this. The after-observation followed in the same way. The videos were evaluated with the support of automatic image data recognition ("machine vision"). In addition to the elliptical markings already shown, a second design was investigated: as suggested by the Lower Austrian provincial government, bar-shaped markings were designed based on the concept of a "psychological brake”. Here, 50cm wide markings are used on the right and left edges of the lane, leaving a progressively narrower lane as the bend is approached. As with the elliptical markings, the parts along the centre line are sized in order to cover the area of the lane that motorcyclists should not enter and in order to maintain sufficient distance from oncoming traffic. The markings on the outer edge of the bend serve to visually narrow the bend (Figure 1).

Figure 1: bar markings (Arlberg road)

Of the nine bends considered, one was not marked due to a blockage caused by a landslide. One bend at the Loiblpass was not included in the general evaluation due to the special circumstances (e.g., narrow bend radius, missing guiding line). On the remaining bends, there was for the most part a clear improvement in the trajectories of motorcyclists. Figure 2 clearly shows that fewer motorbikes rode in the danger zone with both elliptical and bar markings. This is labelled "inside" in the graph and includes all motorbike rides where the tyres were riding in the left third of their own lane or beyond the centre line. The middle and right thirds of the own lane were defined as the safe zone in this sense.

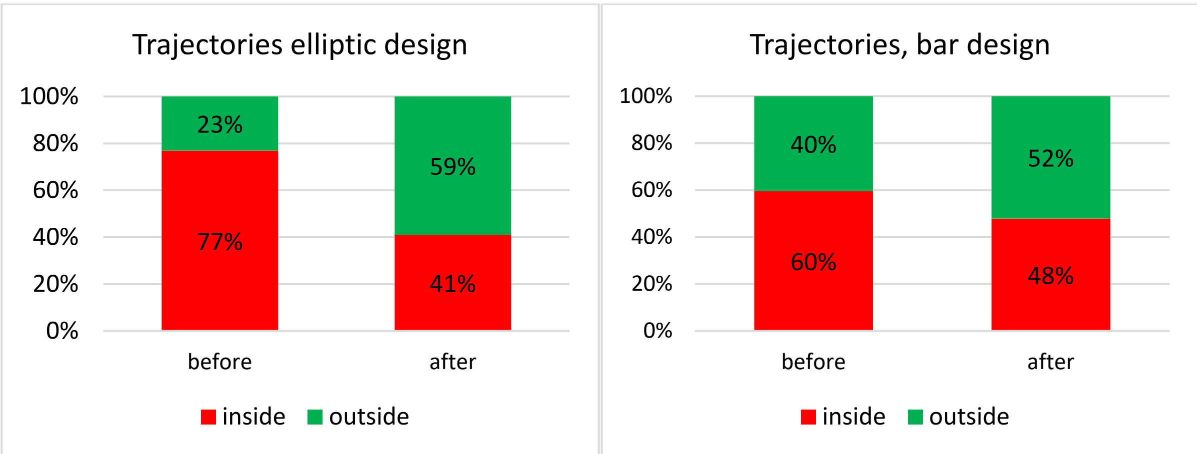

Figure 2: Riders' trajectories at the apex of the bend before and after applying the markings

In this study, the ellipses (see example in Figure 3) had a better effect than the bars. Measurements were also taken at the beginning and end of the bends; these showed desirable changes, although not as clearly.

In addition, surveys were carried out at restaurants frequented by motorcyclists in the vicinity of the marked bends. Understanding of and experience with the markings proved to be positive throughout. The majority of motorcyclists considered the measure sensible and necessary, understood the meaning and also believed that they had behaved correctly. The study created the basis for further applications of the markings.

Figure 3: Ellipse markings in the Namlos Valley

4.4. Großglockner

Due to the initial success of the measure, KFV was invited by Großglockner-Hochalpenstraßen-AG in 2017 to install elliptical road markings on six bends. Special attention was paid at the time to the stricter standard of care in the context of liability to which the Großglockner-Hochalpenstraßen-AG is subject as a toll operator. However, the markings proved to be legally unproblematic: elliptical and bar markings may be affixed as ground markings with a pure traffic guidance function within the meaning of § 55 para 1 StVO (i.e. the Austrian road code). According to § 98 (3) StVO, the road owner may install the markings without an official order because the markings do not express a traffic prohibition or order; however, the authorities may also prescribe their installation or removal.

A follow-up study was only conducted here on a small scale (Winkelbauer, Senitschnig, 2018). The most important finding was that motorcyclists riding on or to the left of the ellipses clearly and significantly more often corrected their line of travel due to oncoming traffic than those riding to the right of the markings. From the perspective of driving dynamics and the presumed causes of accidents, this is a significant and very positive finding.

4.5. Styria

In 2017, the Styrian authority also decided to implement safety measures on bends with above-average motorbike accidents by means of road markings. Fourteen bends were selected. The unusual thing about the Styrian solution was that it was planned on a computer (Figure 4). In contrast to all previous cases, where test rides were always carried out by experienced motorcyclists before the final marking, a fully dimensioned plan was drawn up on the computer based on an orthophoto and theoretical knowledge of correct trajectory selection, which was then implemented by a marking company. Subsequent driving tests showed that this approach also leads to a very satisfactory result. However, this measure was not evaluated.

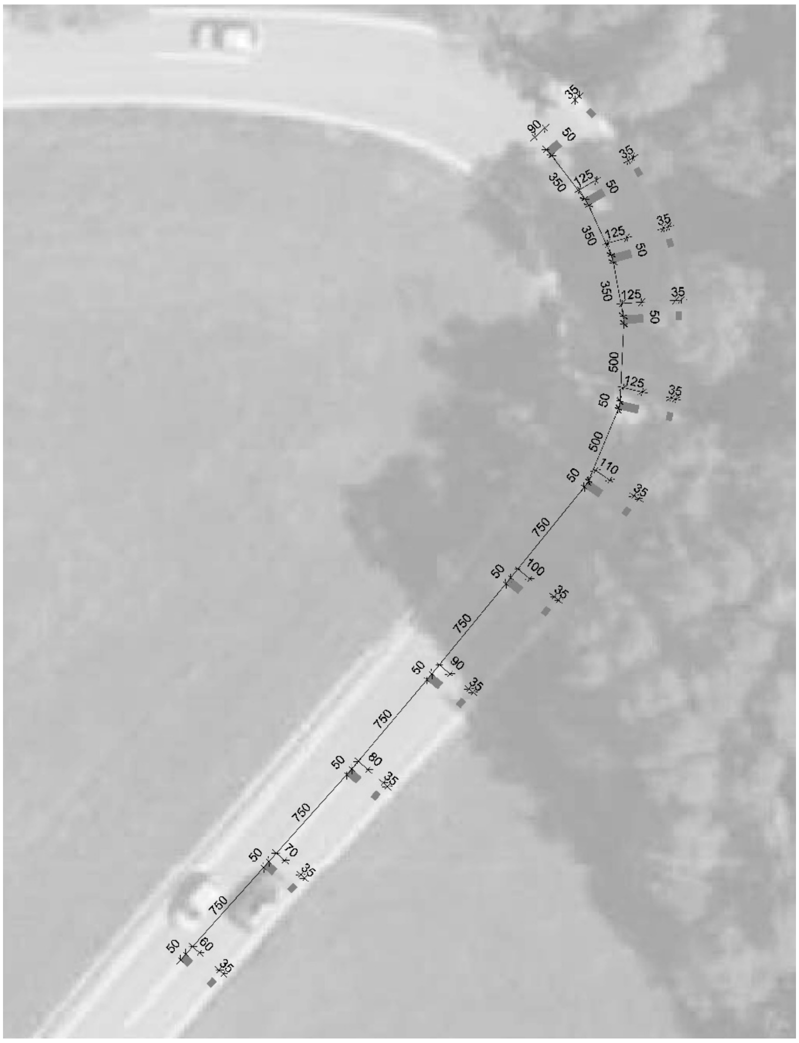

Figure 4: Computer aided design of road markings in bar shape

4.6. Tyrol, 2019

Traffic accidents in Tyrol are characterised by an above-average proportion of motorbike accidents, and these by a high proportion of foreign motorcyclists. The authorities of the province therefore decided to take a new approach. Funded by the Tyrolean Road Safety Fund, a project was launched with the aim of implementing safety measures to take effect in the same year. As a basis, motorbike accidents throughout Tyrol were investigated. Without regard to the usual definitions of accident blackspots, a work programme for about 60 accident-prone bends was determined on the basis of official accident statistics, but also with the help of the experience and expertise of the local road maintenance and police departments. In July and August 2019, the bends were mostly visited together with road maintenance officers and road markings were immediately installed on a total of 19 bends, mostly on typical motorbike routes. In some cases, other measures were carried out immediately or agreed for early completion, for example the installation of additional guide angles or the erection of danger signs. At the end of the year, an informal evaluation of the experience was carried out; the road maintenance managers only gave positive or neutral feedback.

4.7. Tulbingerkogel

The roads around the Tulbingerkogel via the "Dopplerhütte", Königstetten, Katzelsdorf, Passauerhof, Buchenhof and Hainbuch are a typical motorbike route of the Viennese motorbike scene. Motorcyclists do their rounds there, often a dozen a day, partly in one direction and partly in the other, and sometimes they are timing themselves. The residents suffer from the noise, especially at weekends, and the accident figures are correspondingly high. In addition to the bends with above-average accidents, bends with bar markings were also marked here, where the fire brigade or road marshals often retrieve motorbikes from the forest. In order to test a possible influence on noise pollution, bends were also marked that are cut particularly often for the purpose of accelerating on the following straight, and in which a great deal of noise is caused by the acceleration.

Immediately after marking, the effect was noticeable - although not scientifically studied in detail. According to the municipal officials, the motorcyclists came in smaller numbers, did not stay as long, drove more slowly at the crucial points, the complaints from the population were not forthcoming and the fire brigade did not have to pull any more motorbikes out of the forest. No traffic accidents with personal injury were reported after the marking.

The measure cost the municipality of Katzelsdorf about 3,000 euros and, according to their feedback, was "worth every cent". It remains to be seen whether the effect is sustainable. It is difficult to ascertain whether or to what extent this measure leads to a local shift in motorbike journeys.

4.8. Second study: Lasting effects, accident occurrence

One of the crucial questions in road safety measures is almost always whether they have a lasting effect or are merely a flash in the pan. In order to observe changes in accident occurrence, one needs - as macabre as this sounds - enough accidents and thus enough time. As soon as the complete accident data from the three years after the installation of road markings was available as part of the first large study, a further evaluation was therefore carried out. Of the eight bends marked in 2016, Weissenseestraße was closed for renovation in 2020, but the remaining seven bends were visited again, the condition of the markings was checked, video observations were made, and the accident occurrence was analysed.

The surprising result (Figure 5) was that the bar markers had caught up with the ellipses and both interventions can now be considered equally effective. Even more surprising was that the ellipses also increased in effectiveness compared to 2016. Most of the improvements are statistically significant, so the effectiveness can be considered proven. However, there was also a significant deterioration on one bend on the Lorettoer Straße (L213 in Burgenland). It is suspected that the installation of edge lines, which had taken place in the meantime, does not match the trajectory provided by the bars. It is also a fact that the L213, like the Tulbingerkogel, is driven by the same "loop drivers" over and over again. Since the choice of trajectory in 2020 was similar to that before the intervention in 2016, it can be assumed that the drivers who know the area are no longer bothered by the markings.

The observed decrease in the number of accidents was particularly pleasing. In the observed bends, the number of accidents with personal injury decreased from 16 to 7. This change is considerable, but in absolute terms too small to be significant.

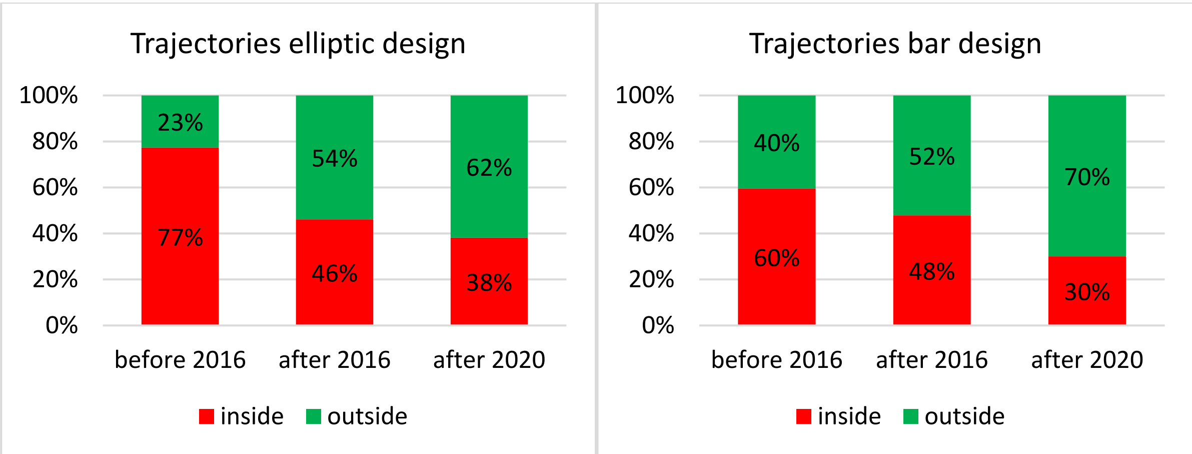

Figure 5: Riders' trajectories at the apex before, after and four years after intervention

4.9. Motorbike accident blackspots: Update Tyrol 2022

In 2021, the Tyrolean provincial government granted funding for a renewed inspection of the roads with regard to accident blackspots. Again, it was planned to immediately install road markings at suitable accident sites. In the course of this process, a follow-up investigation of the accident events of the previous years was also carried out. In the period from 2012 to 2018, an average of 6.3 lightly injured, 6.4 seriously injured and 0.57 fatally injured motorcyclists were registered annually at the 19 bends that were later provided with road markings. In the 2.5 years following the installation of the markings, a total of 2 slightly and 2 seriously injured motorcyclists were recorded. Due to the Covid19 pandemic, the number of riders passing relevant counting points (i.e., those on typical motorbike excursion routes) decreased by about 40%. This means that there was a net 80% reduction in accidents on the bends after the introduction of the road markings. However, due to the extremely small number of accidents after the intervention, it would be premature to speak of a "decrease".

5 Application in Luxembourg

5.1. Initial situation

In 2018, a road safety inspection of the national road N25 between Wiltz and Kautenbach in the north-west of the country revealed an atypical accident cluster based on the 2013-2017 accident data. This did not match the traffic pattern or the accidents on other roads in Luxembourg. Traffic was not distributed over the usual five weekdays and was not lower at weekends, but rather increased at weekends. Most of the recorded accidents happened at the weekend (Figure 6) and this in the best weather and often involving motorcyclists (Figure 7). Luxembourg is a popular destination for motorcyclists and has been struggling for years with a not inconsiderable number of fatal motorbike accidents. It soon became clear that the N25 was such a motorbike route in the north of the country. Besides commuters and local traffic, it attracts many motorbike tourists, especially at weekends and during holidays. The winding back roads in the rural idyll of the Ardennes are the big attraction for motorcycle-loving tourists.

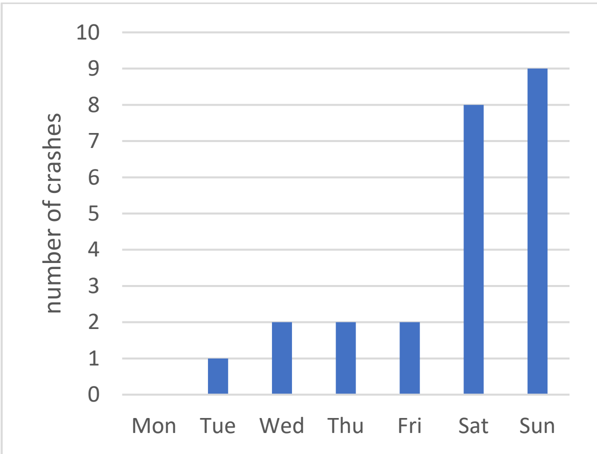

Figure 6: Motorbike Crashes by day of the week, N25 from Wiltz to Kautenbach, Luxembourg

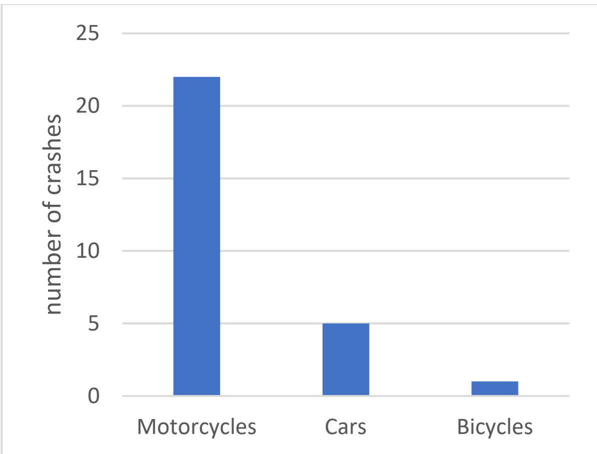

Figure 7: Crashes by mode, N25 from Wiltz to Kautenbach, Luxembourg

The problem to be solved on many of these routes are the ends of bends that cannot be seen, or sequences of bends that cannot be seen. Incorrect entry into the bend requires a correction of the trajectory, i.e., either cutting the curve into oncoming traffic or opening the steering angle and leaving the road at the exit of the bend. However, this ground marking should be understood intuitively and, if possible, have no impact on other road users.

Based on this problem, the Luxembourg National Road Administration looked for solutions abroad and found what they were looking for in Austria. The Austrian Road Safety Board (KFV) had already tested various solutions with road markings (circles, ellipses, ovals, bars, etc.) for safe cornering within the framework of its studies. After an exchange with the KFV, it was decided to launch a pilot project and the question then arose as to how this could be implemented in Luxembourg in the short term and in accordance with Luxembourg law.

Here are a few insights from the discovery phase and then also from the subsequent analysis:

What provisions were there in the road traffic regulations?

Geometric shapes for markings are not specified in the Luxembourg Road Traffic Regulations. However, white lines are described and for transversal bars it is not specified how they are to be arranged (except as a stop line). Nevertheless, within the framework of the *Permission de voirie* i.e., "road construction permit", there are lateral bars within the framework of town entrances. These are familiar to Luxembourgish motorists. Although round shapes have achieved the best results in Austria, they are not provided for by law and it was not possible to obtain any in the short time available (March to June 2018).

How can these lateral bars be applied?

In Austria, geometric plans were made of how the markings should be applied. We also followed this approach. However, it turned out to be more effective to select the bends in advance on the site plans and to indicate the crossbars provisionally on site with adhesive strips and to have them driven on by experienced motorcyclists, in our case by instructors from the Luxembourg police motorcycle squad (Figure 8).

Figure 8: Test ride by a police rider

How should the quality of the bar marking be?

The quality (skid resistance) of the marking must in any case be better (higher) than that of the road surface. This was and still is the case and is checked annually. Our advantage was that we could rely on our own marking team, which then quite quickly got the hang of it and could proceed identically on the further routes. A 2-component cold plastic coating was used.

What should the bend characteristics be like?

The markings work best on bends where the end or the further course of the road is not visible at the beginning. This means that it is not obvious to the driver beyond the apex what the further course of the road is. If this is not the case, the curve is cut more often because there is a visible trajectory. Then there must also be a dashed centre line, with a spacing of 3 / 3 / 3 [m] and, of course, there should be guidelines at the edges of the carriageway to define the carriageway neatly.

What did the before and after analyses show?

On several stretches it was also possible to carry out before-and-after analyses by video recording at selected bends in order to check the driving behaviour of both motorcyclists and other road users. Therefore, the road was divided into 3 different zones (Figure 9) and different time periods were checked at the weekends.

Figure 9: Areas for assessing the trajectory

5.2. Results

Before situation

The analysis of the data obtained in the first step regarding driving behaviour yielded the following results:

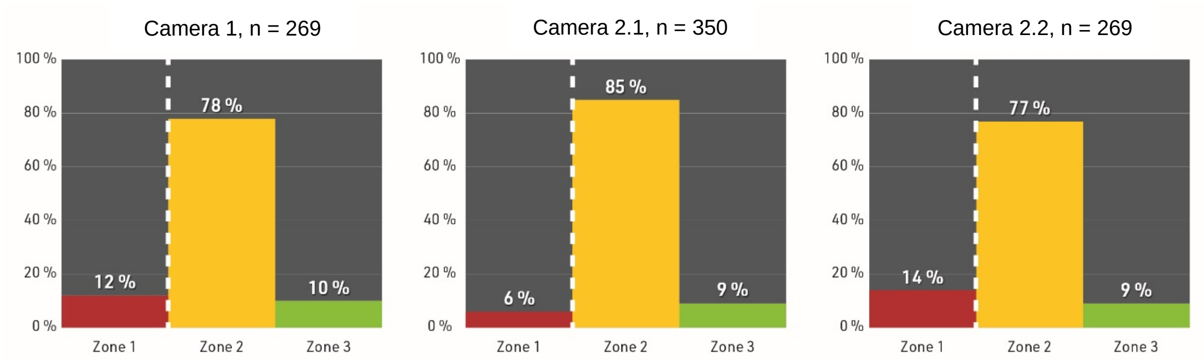

Figure 10 Trajectories of riders before the intervention

From the diagrams of the first weekend without safety markings, it emerged (Figure 10) that between 9% and 10% of the motorcyclists choose a safe curve line on the respective bends and drive through the bend "in the green zone", so to speak. In contrast, 77% to 85% of the motorcyclists drive in the orange zone and between 6% and 14% in the red zone and even to the point where their behaviour constitutes a high accident risk.

After situation

After the application of the lane markings, the driving behaviour was again analysed by video recordings on the same three bends. The analysis was carried out on three different weekends - the following weekend, two weeks later (Figure 11, Figure 12), two months later, and always on weekends during the peak motorbike season - in order to draw conclusions about a possible long-term effect. Between 120 and 350 motorcyclists were recorded on each weekend. The evaluation of the data obtained showed that driving behaviour had improved for the better (Figure 13).

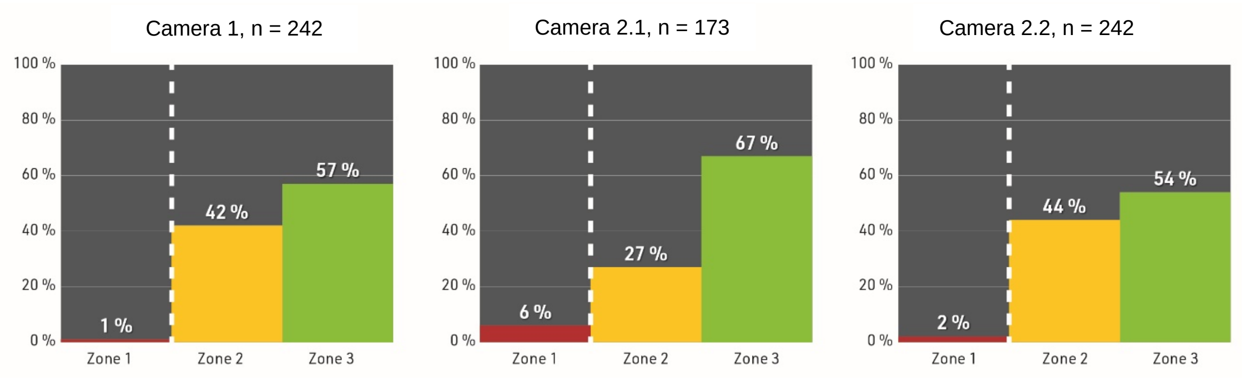

Figure 11: Trajectories of riders a week after the intervention

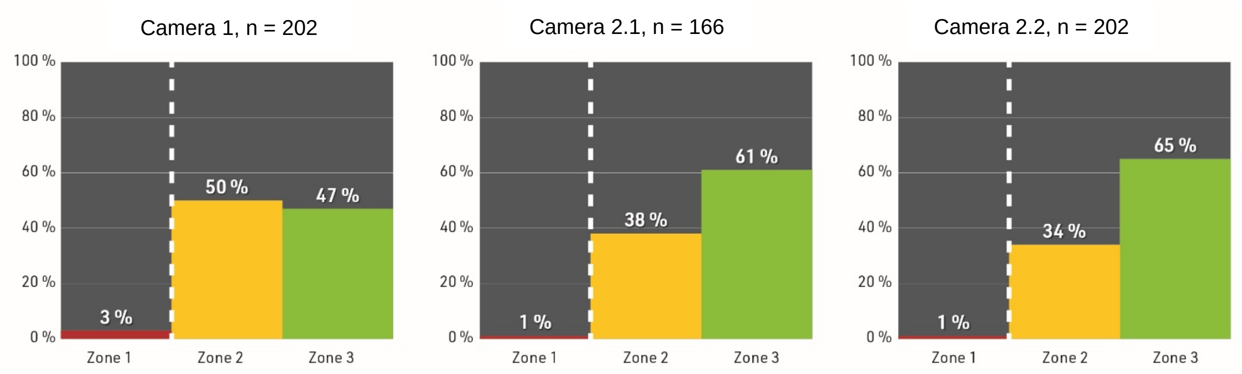

Figure 12: Trajectories of riders two weeks after the intervention

Figure 13 illustrates the development over a period of months taking the three combined bends into account and gives a very clear picture of the fact that the motorcyclists intuitively understand the new safety markings. A negative impact on other road users could not be detected.

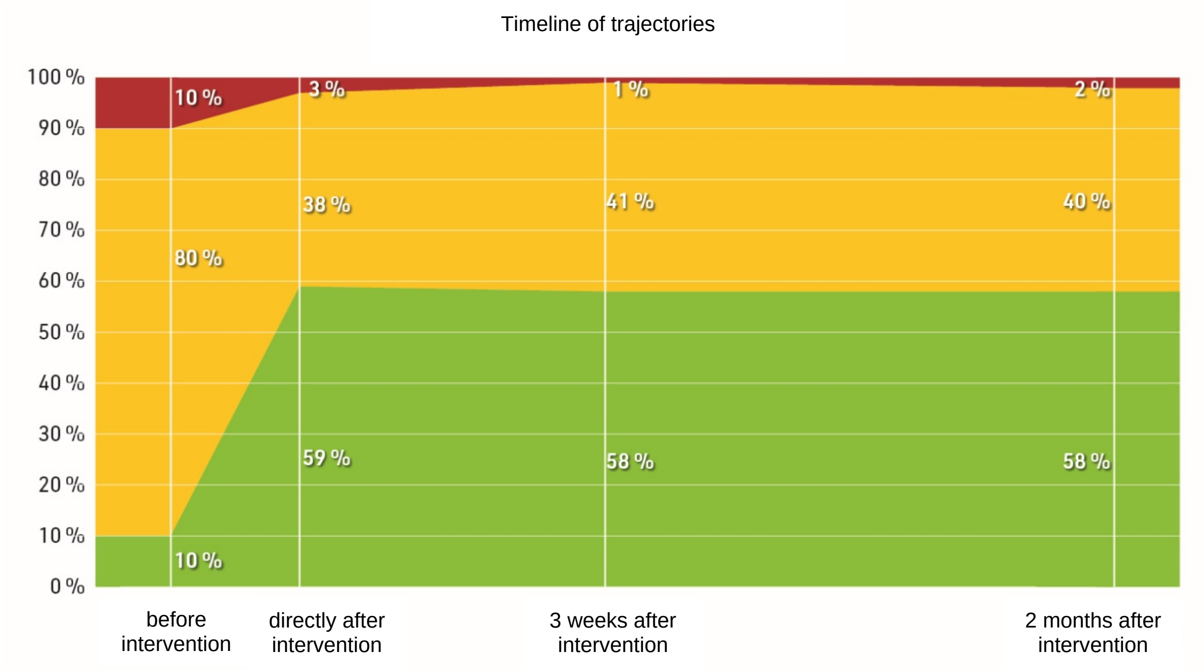

Figure 13: Timeline of rider trajectories

Effects on the occurrence of accidents.

Since the application of the markings, 2 motorbike accidents have occurred on the N25, once outside the marked bends under the influence of alcohol and one in a right-hand bend. There have been no known motorbike accidents on the other routes since then.

Other measures

To increase awareness of the road marking measure, additional information signs (Figure 14) were erected and repeated on the marked routes. Additional signage on the routes at the main border crossings and then in 2019 the dynamic warning signs on the motorway were also used. Additional checks by the Luxembourg police during the summer months were carried out and the mobile radar units were set up on the main motorcycle routes in the north of the country.

Figure 14: Warning sign "Marquage de sécurité" (Safety warning)

5.3. Criticism and complaints

There has been criticism, especially before the measure was introduced. There are no known complaints after the markings were applied. More communication and media presence might have helped, but fear of the unknown can only be changed through self-experience. The Luxembourg drivers knew the routes and the most affected foreign drivers who only come to Luxembourg for a short holiday were and are difficult to reach. After on-site inspection and driving the routes, no one complained or complained that they had slipped/skidded on them.

One feedback from a president of a motorbike club should be mentioned: He rode the route with his daughter and her friend, both beginners, without prior explanation or discussion. Both understood the "message" after 2 bends. As of today, about 50 bends in the north of Luxembourg are equipped with the markings. 1 motorbike track could not be equipped. In the meantime, the road markings have been applied to the two routes of the rider training centres and are part of the training of all novice motorcyclists in Luxembourg. During the 2022 Tour de France, similar markings could also be seen on the Swiss stage.

6 Digression: curve cutting on right-hand bends

If one interprets "corner cutting" in the sense of an incorrect trajectory in connection with inappropriate driving speed and lean angle anxiety, then one can also speak of "corner cutting" on right-hand bends.

Specific areas that can lead to accidents even without oncoming traffic are so-called "dog bends". These are bends that become tighter as they progress; they are usually dangerous as right-hand bends where, on entry into the bend, one cannot see the entire curve. The motorcyclist chooses the driving speed on the basis of what he can see on the approach and what his personal lean angle tolerance allows. If the curve then becomes tighter, the speed is too high, and the lean angle cannot be increased. This phenomenon is so mentally intense that motorcyclists end up on the left side of the road without regard for any oncoming traffic or crash after "emergency braking". In such cases, ABS only helps if it can cope with the given lean angle.[2] In the accident statistics, these accidents can be seen as a coming off the road to the left on a right-hand bend, as a "fall from the vehicle" and, of course, as collisions with oncoming traffic.

[2] A fully cornering-capable anti-lock braking system was first available from Bosch in December 2013, installed on the KTM 1190. This "MSC" (motorbike stability control) works at all lean angles. Conventional ABS can usually cope with lean angles up to about 20 degrees. Without ABS, uncontrolled braking almost always leads to a crash.

It would seem obvious that a danger sign "Dangerous right turn" should solve the problem. In fact, however, experience has shown that the danger sign alone usually does not change anything in terms of accidents involving motorcyclists. There are no known scientific studies on the exact cause of this. However, the explanation seems likely to be that a dangerous bend is precisely what the rider is looking for - dangerous, yes, perhaps, but only really for other road users, not me. There is no patent solution for this dangerous situation. In Lower Austria, a danger sign was used on a trial basis that is not standardised in the Austrian Road Code (Figure 15). A second example of such a bend can be found in East Tyrol just before the top of the Stallersattel pass. There, even a very conspicuous warning had no significant effect (Figure 16). In some places, notices on an additional sign such as "narrowing" or "getting narrower" are used. Using ground markings, on the other hand, is difficult. In such bends, it would be necessary to reduce the approach speed of motorcyclists, and as the tests on left-hand bends showed, the ground markings discussed here had no significant speed-reduction effect. Trying to compensate for a narrowing curve at the beginning of the bend with the use of road markings would be associated with "pushing" the motorcyclists to the inner edge of the bend. This has a negative effect on visibility, and the space available is naturally also limited. If road markings are installed in such bends, then this can only have the general aim of increasing the attention of motorcyclists. One makes use, as it were, of the fact that the ellipse from the left-hand bends is known as an indicator of motorcycle-specific danger. It can also be assumed that the unusual markings - even if the motorcyclists are not familiar with them - trigger scepticism and motivate them to slow down. Observations suggest that this is the case, but there is as yet no solid scientific evidence (Figure 17).

Figure 15: Traffic signs in the Höllental

Figure 16: Stallersattel, very conspicuous marking

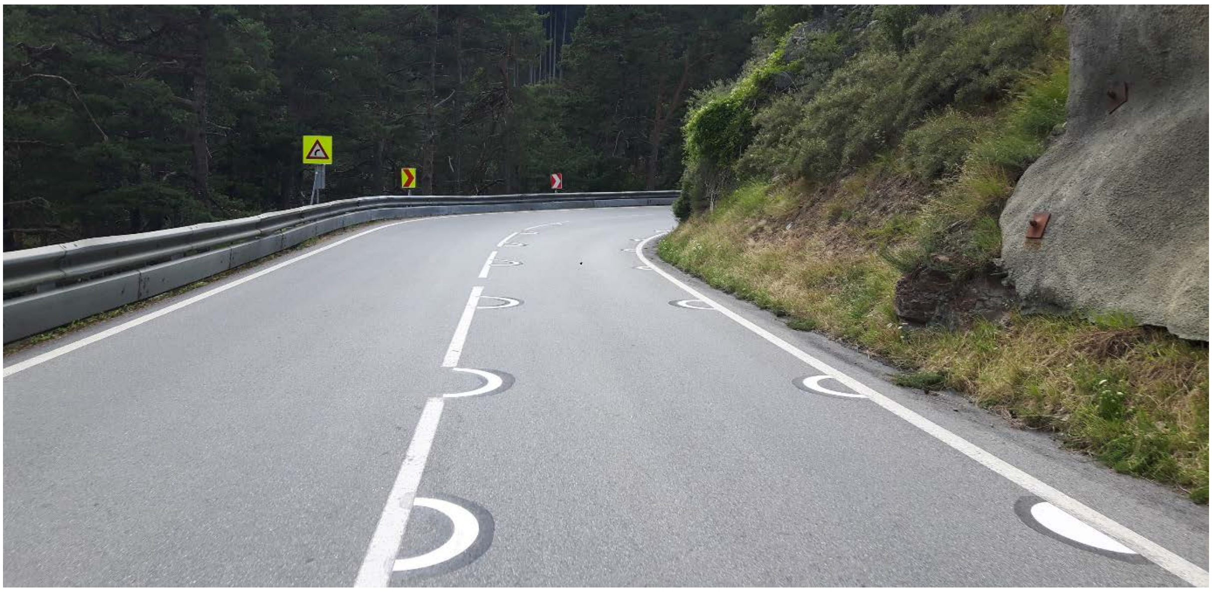

Figure 17: Road markings on a right-hand bend

7 Discussion

The use of road markings to influence the trajectories of motorcyclists has proven successful in all its applications. In some cases, the effects have been formally investigated scientifically, in others only informal feedback is available. Negative feedback or even accidents caused or facilitated by the markings have not been reported. The target group also has a positive attitude towards the measure. On the one hand, this has been shown by surveys of motorcyclists after riding on routes with road markings. On the other hand, the initially vehement rejection of road markings on the part of individual organisations of motorcyclists has now largely fallen silent.

7.1. Transfer of measure to regular operations

The transfer of this hitherto experimental measure to regular operations thus appears to make sense. Even if, as mentioned above, it is not required in Austria, it would make sense, due to the positive scientific assessment, to integrate the markings presented here in the Road Markings Ordinance and in the relevant technical guidelines. Currently, RVS 2.2.42 "Recommendations for improving safety for motorbike traffic" is being revised. This is a technical standard of a recommendatory nature, which is being prepared and published by the Road-Rail-Traffic Research Association (FSV). The standard is expected to contain a general description and some application examples. Publication is planned for 2023. As a technical standard, this first official documentation facilitates application. At the same time, work is also being done on comparable technical standards in other countries.

7.2. Preferred shape of the markings

The W-shaped markings (Figure 18) proved to be very effective against accidents but have the disadvantage that they resemble barrier (no-go) surfaces and can thus be misinterpreted. Ellipses proved to be a better option than bar markings in the first evaluation, but the second investigation showed that the effect on trajectory is very similar. Bar markings have the advantage that they are known from prior use e.g., in front of zebra crossings - as is the desired behaviour. Ellipses seem to increase attention to a higher degree. It can be concluded that they are more suitable for applications where other measures (e.g., speed limit, no overtaking, danger signs, guide angles) have already been used to no avail.

7.3. Need for prior information

The question of whether it is necessary to announce the use of the markings via traffic signs was also discussed. When the W-shaped markings were used in Slovenia, the correct behaviour was shown on a large-format board. (Figure 18). At the Großglockner, a similar approach was taken; for the applications in Lower Austria, the danger sign "andere Gefahren" (other dangers) was used with an additional sign "Sondermarkierung" (special marking). In Luxembourg, an announcement was made at the state border. In all other applications, specific announcements were dispensed with. In the initial stages, an announcement was a precautionary safety measure. In the meantime, however, it can be assumed that the significance of the markings is generally known among motorcyclists. The self-explanatory nature and the positive effect as well as the absence of any negative experiences also make an announcement no longer seem necessary from a legal point of view - as the duty of care of the road maintenance authority.

Figure 18: Announcement/explanation in Slovenia

7.4. Film vs. paint

The studies showed that the use of film material has some advantages. You can apply the film on without gluing them, check the visual impression, test drive it and then make corrections to the position. The application is very easy and can be done by one person. The markings can be driven on immediately after installation. The processing of a bend can normally be completed within half an hour. The durability of markings made of film material is normally at least three years. Film is unsuitable for heavy traffic, which massively reduces its durability. Heavy winter service (e.g., snowploughs with snow chains) also reduces the durability. On the other hand, markings made with conventional paint have not caused problems in any application so far.

7.5. Cost-benefit calculation

The application of road markings is extremely cost-effective, especially compared to the cost of accidents: to tape a bend with film, one usually gets by with material worth less than 1,000 euros, and the use of paint material is even cheaper. Even if one rounds up generously after distributing these costs over a three-year lifespan, one would only have to prevent one lightly injured person every 80 years or one seriously injured person every 1000 years and would still have a positive cost-benefit ratio (for macroeconomic crash costs see Sedlacek, Steinacher, Mayer & Aschenbrenner, 2017).

7.6. Further need for research

Further studies on the effectiveness itself are needed. Unfortunately, the great success of the measure also means that the low accident figures after the intervention make statistical proof of effectiveness impossible. One can include further bends in the evaluation or extend the observation period to broaden the calculation basis.

The same applies to noise abatement. Here, local successes have been achieved, at least in the short term. Whether the improvements for the residents are sustainable should be scientifically investigated.

There is currently too little evidence regarding the use of the material. Neither for film nor for bends processed with paint has there been any negative feedback so far.

As mentioned, the markings should not be used too extensively. However, it seems appealing to educate motorcyclists to select a safe trajectory by marking several bends on a kind of "teaching route". There is a risk, however, that this concept will not work and that instead a habituation process will occur that will reduce the effect of the markings on the particularly dangerous bends. However, such a concept could be tested under appropriate scientific supervision.

Occasionally, right-hand bends have also been provided with markings in previous studies and their effect investigated. It goes without saying that the effect on right-hand bends must be different because it is not possible to influence the trajectory to the same extent as on left-hand bends. There are clear indications that there is another mechanism of action, which consists in the fact that the elliptical markings known from left-hand bends are perceived as a symbol of danger on right-hand bends. This would be a promising hypothesis for further research.

As an additional finding, the presumption that motorcyclists do not take general danger signs seriously was confirmed - to a large extent in the preparatory work for the studies. Ordinary danger signs and regulations often had no effect. In contrast, the road markings studied clearly communicate that their message is aimed at motorcyclists, and this may even be the hidden reason for their effectiveness. In this respect, it is in any case obvious that a motorcyclist-specific message should be conveyed, as in Figure 15. By adding a pictogram of a motorbike to other traffic signs, this aim could also be achieved using other signs. This hypothesis should be investigated further too.

Finally, despite the great progress made by the work commissioned by the German Federal Highway Research Institute (bast), it has not yet been proven that "lean angle anxiety" is actually an anxiety in the pathological sense.

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Figures

SAFETY POTENTIAL OF DATA GLASSES FOR MOTORCYCLISTS

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In the automotive domain, head-up displays (HUD) are well established to present information in the driver's natural line of sight. Comparable display concepts for motorcyclists would be promising as obtaining riding relevant information from the dashboard typically requires head down gazes away from the forward road scene. Further, depending on powered two-wheeler (PTW) ergonomics and type of helmet, the dashboard is not even within the peripheral field of view.

As there is typically no windscreen in motorcycles that can appropriately be used as projection surface, an alternative transparent display technology is needed. For this purpose, so-called data glasses can be used. The presented user study compared the issuing of riding relevant information (i.e., turn-by-turn instructions) in data glasses and a typical dashboard. $N = 24$ riders completed a standardized riding task (ISO Lane Change Test) on a dynamic motorcycle riding simulator. In parallel, riders had to react to changing information on the different display concepts. Besides vehicle dynamics data, questionnaire data was gathered and rider workload was measured with the Detection Response Task (DRT). It was observed that information displayed in the data glasses while riding was detected faster and more reliably. The primary riding task performance showed no difference between the two display concepts. Same holds true for the DRT measures, while the subjectively perceived workload was reduced when wearing the data glasses.

Consequently, the study was able to show a benefit of data glasses when it comes to the perception and recognition of time-critical information, such as warnings. Obviously, before providing a potential safety benefit to a broad range of riders, some other questions need to be addressed (e.g., fitting under full face helmet, interface to motorcycle). Yet, this study on innovative display concepts for motorcyclists shows promising results regarding PTW safety of the future.

Sicherheitspotential von Datenbrillen für Motorradfahrer

Im Pkw-Bereich finden Head-up-Displays (HUD) bereits eine vergleichsweise weite Verbreitung, um den Fahrern Informationen direkt im Sichtfeld darzubieten. Vergleichbare Anzeigekonzepte für Motorradfahrer wären vielversprechend, da für die Betrachtung fahraufgabenrelevanter Informationen typischerweise Blickabwendungen von der Straße weg notwendig werden. Weiterhin ist es häufig aufgrund der Geometrie des jeweiligen Motorrads und dem Tragen eines Helmes nicht möglich, das Kombiinstrument im peripheren Sichtfeld zu erfassen.

Da bei Motorrädern die Windschutzscheibe als geeignete Projektionsfläche typischerweise wegfällt, wird eine alternative Anzeigetechnologie benötigt. Zu diesem Zweck kann eine sogenannte Datenbrillen eingesetzt werden. Die vorgestellte Nutzerstudie vergleicht die Darstellung fahraufgabenrelevanter Informationen (d.h. Turn-by-turn-Navigationsanweisungen) in einer Datenbrille mit einem konventionellen Kombiinstrument. N = 24 Motorradfahrer durchfuhren eine standardisierte Fahraufgabe (ISO Lane Change Test) auf einem dynamischen Motorradfahrsimulator. Gleichzeitig bestand die Aufgabe der Fahrer darin, auf wechselnde Informationen des jeweiligen Display-Konzepts zu reagieren. Neben fahrdynamischen Kenngrößen wurden Fragebogendaten gesammelt. Die Fahrerbeanspruchung wurde mit dem Detection Response Task (DRT) gemessen. Es zeigte sich, dass Informationen, die mittels Datenbrille dargeboten wurden, schneller und verlässlicher erkannt wurden. Die Leistung in der primären Fahraufgabe zeigte keine Unterschiede zwischen den beiden Display-Konzepten, was ebenfalls für die Ergebnisse der DRT-Messung gilt. Hingegen wurde die erlebte Beanspruchung mit der Datenbrille als geringer beurteilt.

Die Studie konnte Vorteile von Datenbrillen bezüglich der Wahrnehmung und Identifikation zeitkritischer Informationen, wie beispielsweise Warnungen, zeigen. Selbstverständlich müssen zur Realisierung des Sicherheitsgewinns für eine große Fahrerpopulation grundlegende Rahmenbedingungen adressiert werden (z.B. Passung der Brille unter Integralhelmen oder die Schnittstelle mit dem Motorrad). Dennoch konnte die Studie das Potential innovativer Displaykonzepte für die zukünftige Motorradsicherheit aufzeigen.

1 BACKGROUND & MOTIVATION

Evaluations of accident data show that distraction from the forward road scene (in the sense of eyes-off-road time) increases the risk of being involved in an accident. For example, approx. 300 out of 777 powered two-wheeler (PTW) accidents on Austrian highways between 2012 and 2019 were primarily caused by distraction (ASFINAG, 2021). The European Motorcycle Accident in Depths Study (MAIDS) identified distraction as self-reported accident contributor in 10.6 % of 921 evaluated crashes (Association of European Motorcycle Manufacturers – ACEM, 2009). The distraction in those cases is not necessarily caused by external sources but can also be a consequence from searching for an information (e.g., current gear or ride mode) in the vehicle's dashboard.

In order to avoid this kind of distraction and to present information in the driver's natural line of sight, head-up displays (HUD) are well established in the automotive domain. Comparable display concepts for motorcycles could likewise be promising in regard of reducing glances away from the forward road scene. Considering the fact that depending on PTW ergonomics and type of helmet, the dashboard is possibly not even within the peripheral field of view, the assumption becomes even more obvious.

As there is typically no windscreen in motorcycles that can appropriately be used as projection surface, an alternative transparent display technology is needed. One possible solution lies in the use of so-called data glasses. The aim of the work described in this paper was to investigate whether and to which extent, data glasses can improve the safety of motorcycling by reducing the necessity of gazes away from the forward road scene (see also Will et al., 2022).

While there are a large number of well-established standards in the passenger car sector for the investigation of assistance systems and display concepts (and their potential disturbance of the driving task), there is a lack of standard investigation procedures for PTWs. For this reason, the development of a PTW specific test method was an essential part of the work described here.

2 DEVELOPMENT OF A METHOD FOR THE INVESTIGATION OF DATA GLASSES FOR MOTORCYCLISTS

In general, studies on the safety potential of assistance systems (not only) for motorcyclists have two major aims: on the one hand, they are supposed to prove the potential safety benefit provided by the intended function, in order to justify its application. In the case of data glasses this could mean improved safety by the reduction of gazes away from the road scene and the potential effects, such as faster information recognition. On the other hand, they shall ensure the safety of the system itself in terms of functional/operational safety (hazards due to malfunctioning behaviour may not cause unreasonable risk, ISO 26262-1, 2016) and controllability (safety in case of a malfunction can be guaranteed), while not causing new risks, such as distracting the rider from their riding task. Besides the ISO 26262 standard, there are further examples known in the area of SOTIF (Safety of the Intended Functionality) from the automotive domain, such as *ISO/PAS 21448: Road vehicles safety and intended functionality* (ISO/PAS, 2019) or *Leitfaden Safety of the Intended Functionality* (Schneider & Hosse, 2019).

Though there are several assessment standards known from the passenger car domain, they cannot be applied to motorcycles without adaptions. The riding task with single-track vehicles contains different components compared to multi-track vehicles. For instance, the stabilization of a PTW is more demanding due to its specific vehicle dynamics. Furthermore, we find different vehicle geometry and ergonomics on a PTW as compared to e.g., a passenger car. The dashboard is usually positioned at a larger downward angle as compared to the line of sight to the forward road scene and therefore requires longer gazes to retrieve displayed information. The described differences result in the necessity to adjust known methods to the specific requirements of the investigation of single-track vehicles. This has already been done for the functional safety standard ISO 26262. Part 12 of this standard represents an adaption for motorcycles (ISO 26262-12, 2016).

Following the theory of resource models (Wickens, 1980, 2008), riders have a limited amount of resources. The combination of the primary riding task and any other activity (secondary task) may not exceed this resource limit to allow the riders to complete their riding task safely (Guth, 2017). Retrieving and processing information from a vehicle's dashboard can be regarded as an example for a secondary task competing for visual resources (Will et al., 2018). Such secondary tasks should be designed to demand minimal workload. Based on this dual-task paradigm the following approach was chosen:

Lane Change Test (LCT)

In the passenger car sector, the task demand due to the interaction with in-vehicle systems with mainly visual tasks is usually evaluated by the standardized dual task method described in the ISO standard 26022, known as ISO Lane Change Test, LCT (ISO, 2010). This test procedure is used to show to what extent a secondary task influences the performance in the primary driving task, i.e., how much of the available resources is shifted from the driving task to the (visual) secondary task. To achieve reliable results on the effect of varying task demands of different display concepts, the primary driving task is designed to be comparable across conditions.

During the LCT, participants travel along a straight three-lane road and have to change lanes according to signs that are placed next to the road. This represents the **primary task**. At a certain point, the lane change sign turns up and confronts the participant with a mainly peripheral visual task (recognizing the sign). This is followed by the actual lane change representing a visual-manual demand (identify and steer to correct lane). After the lane change is completed, there is a section of riding straight until the next sign turns up. This sequence is displayed in Figure 1.

As described before, demand of the riding task on a PTW differs from the driving task in a passenger car. This leads to the necessity to apply some adaptions to the ISO procedure. In order to prevent the participants from experiencing a high amount of additional workload due to the necessity to stabilize the vehicle, the major adaption was an increase of the experiment velocity as set with a speed limiter from 60 km/h (ISO standard) to 80 km/h. Thus, the riders profit from the self-stabilizing effect of the motorcycle and the need to stabilize the vehicle is minimized. To keep the time intervals from the ISO standard (sign turns up at a time-to-arrival of 2.4 s, reaction time of 600 ms after sign pops up, 600 ms interval for actual lane change), the length of the corresponding track intervals has to be increased accordingly, see Figure 1.

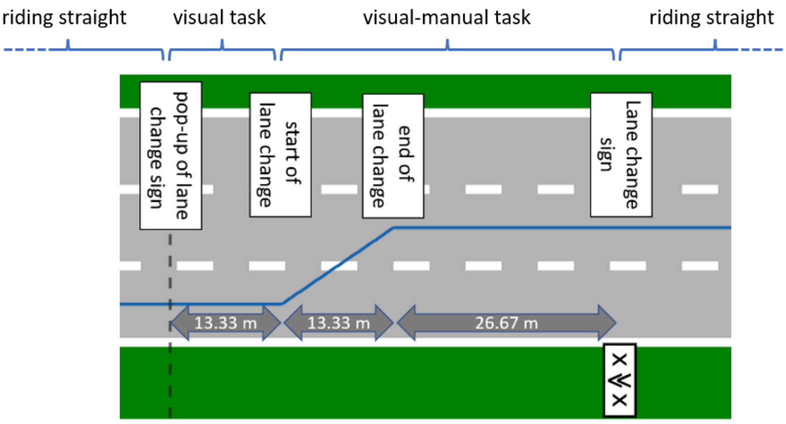


Figure 1: One lane change sequence within the LCT including definitions and adapted lengths of segments.

The ISO LCT consists of 18 lane changes per measurement interval. This number is increased to three blocks of 18 lane changes in the current study. This leads to a total of 54 lane changes per trial (= per condition) and thus allows higher statistical evidence of the results. A complete interval of 3x18 lane changes is conducted for each experimental condition (see next section).

To compare the riders' performance in reacting to a visual stimulus with data glasses, compared to a standard head down display, the secondary task was to react to turn-by-turn indications that were displayed on the respective display technology. The required action was to pull the high beam lever, whenever the displayed indicator changed without reacting to the specific content of the indication. The setup of the secondary task simultaneously defined the four experiment conditions:

- *Baseline:* pure LCT performance without any secondary task and the dashboard displaying no turn-by-turn indicators at all. The riders wore no data glasses.

- *Dashboard:* LCT while completing the secondary task in the dashboard. The riders wore no data glasses.
- *Data glasses:* LCT while completing the secondary task in the data glasses. The riders wore data glasses while the dashboard was covered.
- *Dashboard & data glasses:* LCT while completing the secondary task with the information being displayed synchronously in the dashboard and the data glasses. The riders wore data glasses and the dashboard was visible.

Detection Response Task (DRT)

The continually displayed information either on the dashboard or in the data glasses represents a cause for visual workload. It has to be determined, if this implies the risk of distracting the rider from other relevant events in their surroundings, e.g., in case of the data glasses by covering parts of the scenery while displaying information.

To simulate such risk stimuli in the peripheral field of view, the LCT was combined with the Detection Response Task (DRT) according to ISO 17488 (ISO/TS, 2016). The DRT is based on the so-called Peripheral Detection Task as developed by Harms and Patten (2003). The DRT serves as a proxy measure for riders' visual detection and response ability to relevant on-road events. The visual target detection task was realized by presenting computer- generated elements in the scenery. Red-coloured circles were displayed on five positions along the horizon (0° centre, +/−8.3° and +/−16.7°, see Figure 2). These circles appeared randomly (one at a time) within a time interval of three to five seconds and evenly distributed across the five positions. The riders had to react as fast as possible by pushing the horn button with the left thumb (no horn sound occurred). As soon as the rider reacted to the stimulus, the circle disappeared. This operationalization was chosen as it primarily measures visual load as opposed to cognitive load which is the relevant construct when comparing different visual display technologies. Including different target positions reduces predictability and allows to assess potential differences between the display technologies regarding gaze behaviour respectively attention distribution.

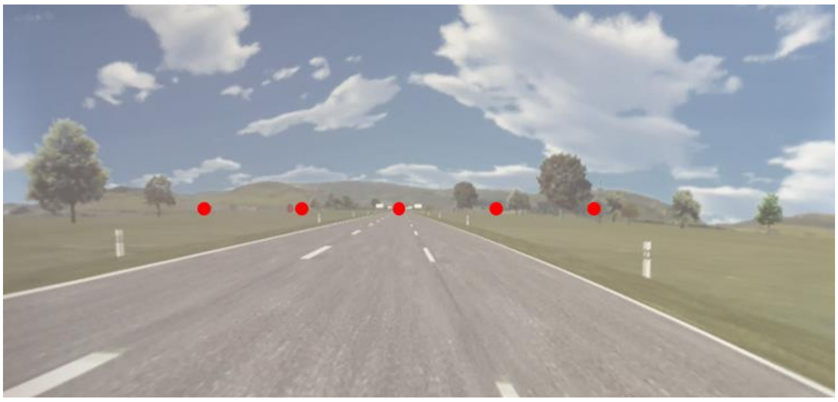


Figure 2: DRT stimuli positions along the horizon in the virtual environment.

Subjective Workload Assessment

Besides the DRT as objective means for workload measurement, the NASA Task Load Index (NASA-TLX: Hart & Staveland, 1988) was used to assess subjectively experienced workload on six different subscales (Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration).

3 Application of the Developed Method

The aim of the conducted study was to investigate the effects of data glasses compared to standard head down displays with regard to the riders' performance in the riding task, information recognition (secondary task) and workload. Based on the approach described before both concepts were compared in a participant study on the dynamic motorcycle riding simulator at WIVW. The experimental setup, as well as the motorcycle simulator and the implemented test course are described in the following sections.

3.1 Motorcycle simulator

The DESMORI dynamic motorcycle riding simulator has been used for the participant study (see Figure 3). It is equipped with a BMW F 800S as mockup, mounted on a six degrees of freedom hydraulic Stewart platform. The mockup enables the rider to interact with fully realistic controls, such as usual handlebar, brake lever / pedal, clutch, gear selector, etc. that he/ she is used to. The manual gear shift uses a sequential six-speed gearbox. An electrical actuator produces a steering torque at the handlebar up to 80 Nm. The rider steers the motorcycle through a combination of steering torque and induced roll torque by shifting his/ her weight. The cylindrical screen with a diameter of 4.5 m and 2.8 m of height enables 220° horizontal field of view. The two rear-mirrors are realized by 7-inch TFT-displays while the dashboard is displayed on a 10-inch TFT-touchscreen and an average dashboard downward angle of 33° measured with the riders of this study’s panel. Sound is provided via body shakers, which are attached to the riders’ individual helmets. Moreover, a shaker that is installed below the seat delivers vibrations from the engine and high frequent road roughness. A rope-towing mechanism simulates longitudinal forces such as wind drag to the rider torso.

Figure 3: DESMORI dynamic motorcycle riding simulator at WIVW.

3.2 Display Technologies

The data glasses to be investigated were the commercially available product Everysight Raptor®. This model uses a projection technology to display monochromatic green information to the riders’ right eye. Information can be displayed on a field of view of approx. 20° in horizontal and 10° in vertical direction.

The data glasses were compared to a state-of-the-art 6.5-inch coloured TFT dashboard. The dashboard layout was based on the graphics of a current BMW Motorrad series model.

The connection between data glasses and dashboard was realized by Bluetooth using an Android-based smartphone application. The content available on both display solutions was the current velocity and gear as well as turn-by-turn indications. The turn-by-turn indications were the basis for the secondary task and had no significance for the riding trajectory.

3.3 Design of the Test course

A test course for one condition contained three blocks with 18 lane changes each (54 lane changes per condition). The 18 lane changes were distributed over a straight road with 4,000 m length. To keep the approx. 180 s duration per block and approx. 9 s between the signs that indicate a lane change, as it is stated in the ISO 26022, the track length had to be adapted to the new test velocity (from 3000 m at 60 km/h in the ISO standard). The test velocity of 80 km/h is supposed to be kept constant during the block by means of an implemented speed limiter. The three blocks of straight three-lane roads were separated by single 90° curves. Each lane had a width of 3.85 m. The number of single and double lane changes was balanced as well as the amount of lane changes from left to right / right to left and the amount of lane changes per section. Additionally, the order of lane changes was permuted between the conditions as defined in the ISO standard. The signs were always visible, yet, the lane indications only became visible 2.4 s prior to passing the sign.

The display of the DRT targets was realized as it is explained in section 2, along the horizon at 0° (centre), +/−8.3° and +/−16.7° of the horizontal field of view in random order. An example is shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**. The DRT was only included in the last of the three blocks for each condition.

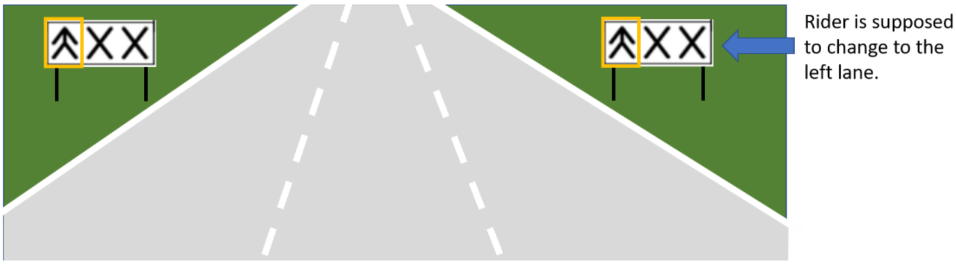


Figure 4: Schematic representation of the LCT and the signs indicating the next lane change (in this case to the left lane).

3.4 Study Procedure

After being welcomed at WIVW, the participants filled out the informed consent with all relevant information on the study as well as the data privacy statement. The riding part of the study began with a test ride to re-familiarize with the simulator handling. The familiarization ride took approx. 5 minutes until the participants started to feel safe and was completed without the data glasses.

In a next step, the riders practiced the different tasks separately (approx. 10 minutes in total):

- *First block:* Focus on the primary riding task (18 lane changes)
- *Second block:* Reaction time task (dealing with turn-by-turn indicators without lane changes)
- *Third block:* Practice detection response task (DRT)

In a third preparatory ride, the participants practiced the dual-task setting (lane changes while reacting to turn-by-turn indicators). This was conducted without (first block) and with the DRT. The third and final part of the preparation rides took approx. 6 minutes.

After that standardized training, all participants completed the four measurement rides (approx. 10 minutes each) in a permuted order. The riders were instructed to always prioritize the primary riding task (LCT) over the secondary task and the latter over the DRT. Between all conditions, the riders had a break and filled in a questionnaire dealing with the experienced workload (NASA-TLX), distraction and perceived usefulness of the given condition's display technology. The study closed with a final inquiry.

The total duration of the study was 2.5 to 3 hours per participant. Figure 5 illustrates the simulator riding part of the study procedure.

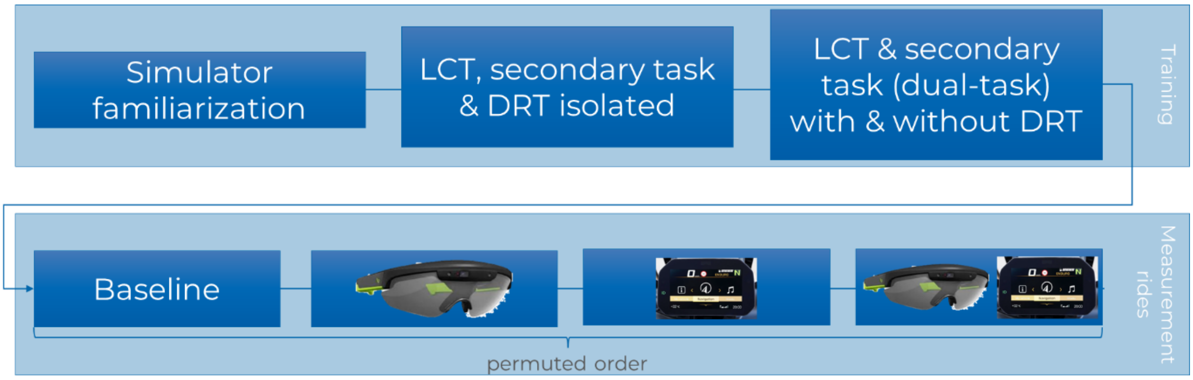


Figure 5: Schematic study procedure: upper row containing preparatory rides, lower row containing actual test rides.

3.5 Participants Panel

A total of N = 24 riders participated in the study, of which n = 4 were female. The riders were recruited from the WIVW participant panel, covering a wide range of different ages and levels of riding experience. The panel consists of non-professional riders who have previously been trained to ride the simulator safely. A summarized description of the panel can be found in Table 1. The study has been approved by WIVW's group in charge for ethical assessment. The strict ethical guideline as defined in the standard operating procedures based on the Guidelines for Safeguarding Good Research Practice of the German Research Foundation (DFG) as well as the Code of Professional Ethics of the German Association of Psychologists (bdp) and the German Psychological Society (DGPs) have been followed.

Table 1: Panel description (N = 24 with n = 4 female riders).

	Mean	***Standard deviation***	***Minimum***	***Maximum***
Age in years	35	10	19	59
Motorcycle mileage covered during the last 12 months in km	4,604	3,261	900	12,000
Motorcycle lifetime mileage in km	68,174	63,562	6,000	300,000

3.6 Data Analysis

As described in the ISO 26022, the effect of the secondary task on LCT performance was characterized by a path deviation measure. The overall deviation was determined by calculating the average deviation from a reference trajectory over the length of the test track (represented by the blue area in Figure 6 divided by the track length). The reference trajectory was calculated according to the 'basis model' described in the ISO standard, that assumes that the rider reacts to the pop-up of the sign after 600 ms (13.33 m at 80 km/h) and needs another 600 ms (13.33 m at 80 km/h) for the actual lane change, at it is shown in Figure 1 (section 2).

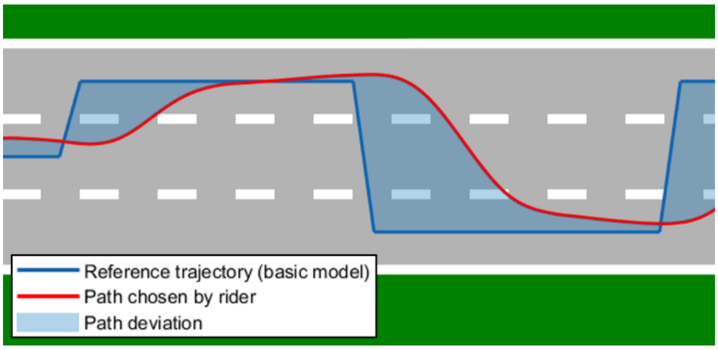


Figure 6: Evaluation of the path deviation.

The reaction to the lane change sign was determined as a failure, if the rider did not succeed to reach the indicated lane before the next sign popped up (start of the next lane change manoeuvre). An example of a failed lane change is shown in Figure 7.

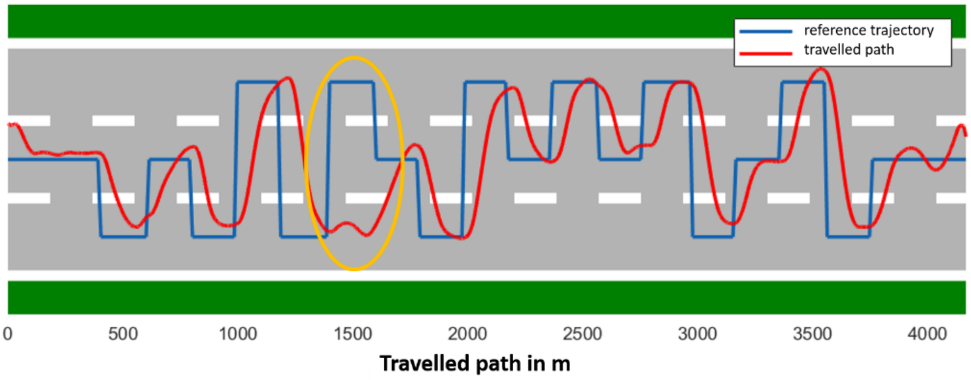


Figure 7: Identification of choosing the wrong lane.

The performance in the secondary task was evaluated in the form of reaction time to the changing turn-by-turn indications and the number of missed indications. The reaction time was determined from the change of the turn-by-turn indication until the rider reacted by pulling the high beam lever. The reaction was counted as a missing, if the rider did not respond within five seconds (in this case it was excluded from the mean reaction time calculation).

For the last block of each condition, the workload was determined according to ISO 17488 (DRT). As for the secondary task performance, reaction times and missed targets were evaluated. Again, the reaction time calculation started with the appearance of the target and ended as soon as the rider responded by pushing the horn button. Target appearances with no reaction within 2.5 s were counted as missings.

Statistics regarding the NASA-TLX on condition level were calculated based on every participant's subscale values.

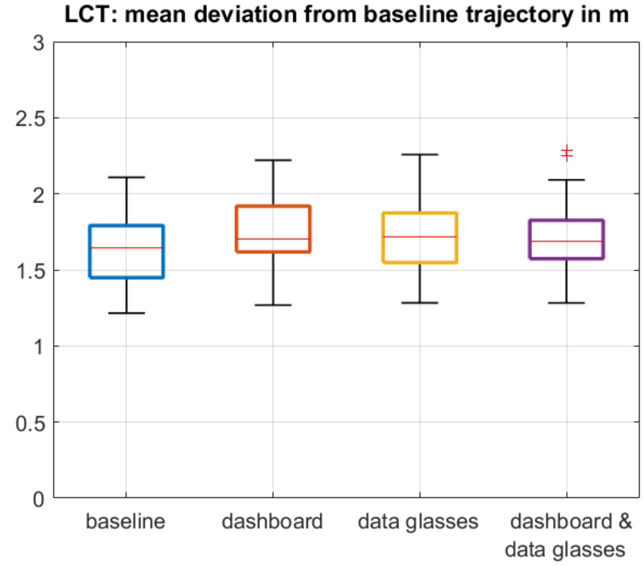
4 Results

With 24 participants who experienced 3 blocks of 18 lane changes per condition, a total of 1296 lane change manoeuvres were performed for each case (*'baseline'*, *'dashboard'*, *'data glasses'* and *'dashboard & data glasses'*). The data was evaluated according to the methods described in section 3.6 and provided the following results:

4.1 PRIMARY RIDING TASK: LANGE CHANGE TEST

In the rides with secondary task, there are higher deviations from the reference trajectory than in the baseline condition. The display of information on the dashboard or via the data glasses influences the riding performance in a comparable dimension. The selection of an incorrect lane (failure) occurs very seldomly for all conditions.

The riding performance data is summarized in Figure 8.



display technology		wrong lane proportion
	baseline	4/1296
	dashboard	8/1296
	data glasses	6/1296
	dashboard & data glasses	7/1296

Figure 8: Mean deviation from the basic model trajectory per condition (left). Number of wrong lane changes per condition (right; 1296 = 24 riders x 54 lane changes).

4.2 SECONDARY TASK: REACTION TO TURN-BY-TURN INDICATIONS

A comparison of the display technologies shows that a change of the turn-by-turn indicator is recognized and confirmed significantly faster in the data glasses than on the dashboard. As Figure 9 shows, especially very high reaction times (more than 2.5 seconds) are reduced. When dashboard and data glasses are both available, the advantages of the data glasses seem to dominate.

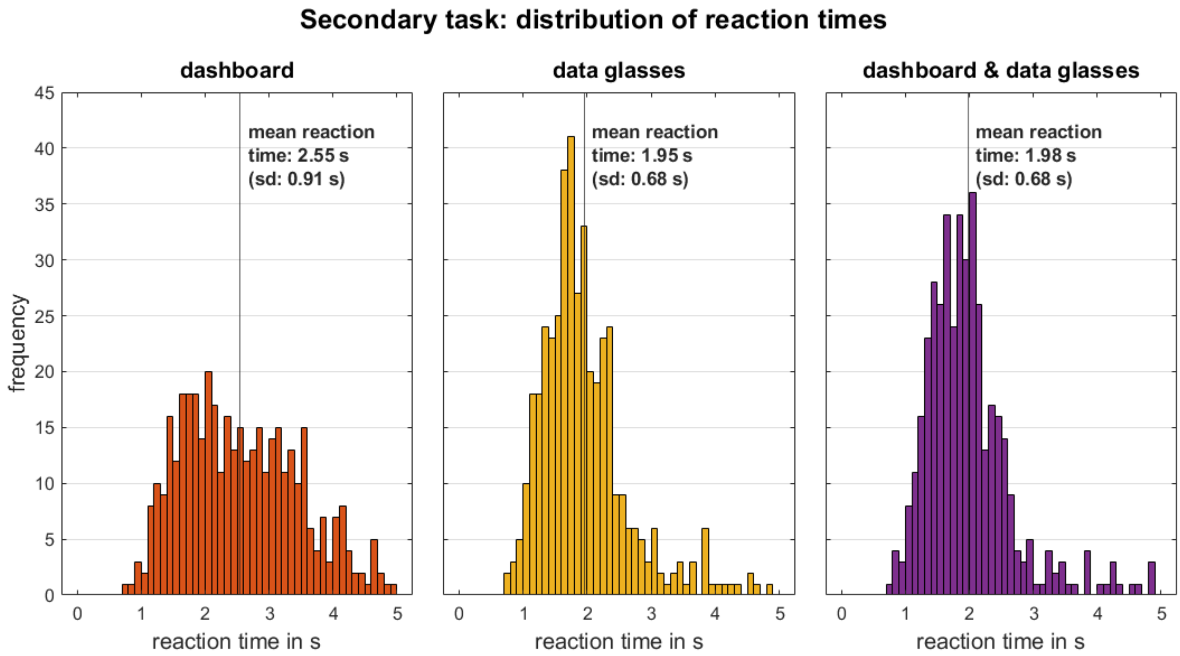


Figure 9: Distribution of reaction times per display technology, including descriptive statistics regarding secondary task performance (mean and standard deviation).

Altogether, the 24 participants experienced 432 turn-by-turn indicators per condition (18 per participant per condition). Table 2 shows the numbers of missed indicators. In the *data glasses* condition, only 1.8 % of the indicators were missed, whereas 6.5 % and 4.4 % were missed during the *dashboard* and *dashboard & data glasses* conditions.

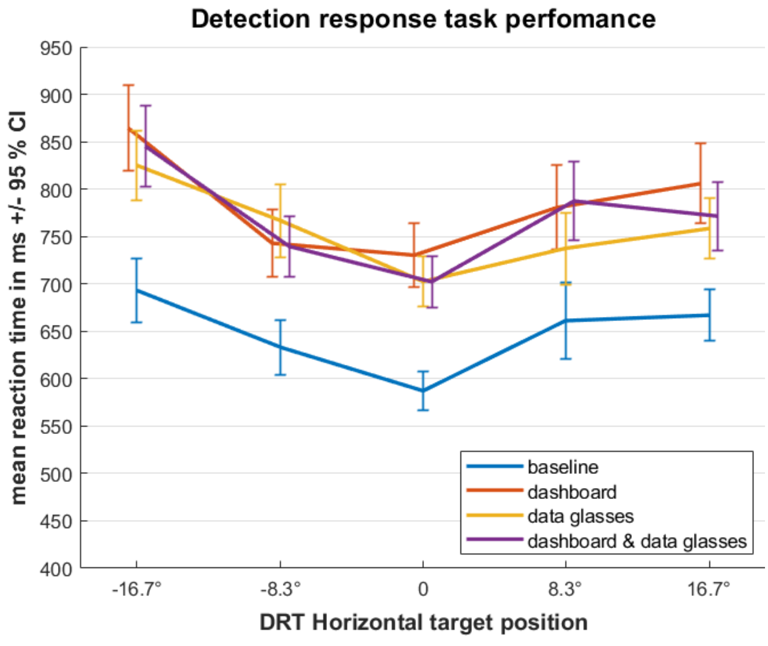
Table 2: Success in recognizing the changing turn-by-turn indicators.

		turn-by-turn indicators	
		missed	***recognized***
display technology	dashboard	28	404
	data glasses	8	424
	dashboard & data glasses	19	413

4.3 Workload Assessment

Detection Response Task

The assessment of the DRT shows that as soon as the riders have to perform the secondary task, the workload increases. As Figure 10 (left) shows, reaction times are considerably higher, while participants have to react to information displayed on the dashboard and/or data glasses. This is confirmed by the number of missings. Stimuli are missed about twice as often in the secondary task conditions (Figure 10, right), however there is a slight reduction of missings when using the data glasses.



		missings
		proportion
display technology	baseline	32/1081
	dashboard	69/1085
	data glasses	54/1083
	dashboard & data glasses	69/1084

Figure 10: Mean reaction times in the detection response task as a function of display technology and target position (left). Number of DRT target missings per condition (right).

Furthermore, the DRT reaction times displayed according to the stimulus position (Figure 10) show that stimuli presented in the centre are perceived faster than those in the periphery. Stimuli at the outer positions tend to be perceived slightly more quickly with the AR glasses.

NASA-TLX

The experienced workload assessed with the NASA-TLX showed the strengths of data glasses as opposed to a regular dashboard. Physical demand, overall performance, effort and level of frustration did not differ between the display technologies. Yet, the mental demand as well as the temporal demand decreased significantly as soon as the information was available in the data glasses (Table 3). Generally, the experienced workload increased compared to the baseline as soon as the riders conducted any secondary task.

Table 3: Descriptive statistics regarding the NASA-TLX.

		Mean (standard deviation) on the NASA-TLX sub scales					
		mental	*physical*	*temporal*	*perfor-mance**	*effort*	*frustration*
Condition	baseline	6,13 (3,76)	4,75 (3,11)	4,62 (3,08)	3,67 (2,22)	8,46 (4,61)	2,96 (2,71)
	dashboard	12,08 (4,46)	7,42 (4,37)	9,67 (4,64)	5,50 (3,16)	12,08 (5,12)	4,00 (2,72)
	data glasses	**8,25 (4,70)**	6,58 (4,24)	**6,63 (3,83)**	4,62 (2,96)	10,46 (5,21)	3,21 (2,55)
	dashboard & data glasses	**10,04 (4,73)**	7,17 (4,92)	**7,21 (4,24)**	4,96 (3,57)	10,13 (5,23)	3,58 (2,78)

**Performance is coded invertedly so that low values indicate perfect performance. Values set in bold indicate statistically significant deviations between conditions containing data glasses and dashboard.*

This is supported by the majority of participants stating that they made use of the information in the data glasses, when both display technologies were available (15/24). Only one rider preferred the information in the dashboard when wearing the data glasses at the same time and the remaining eight participants could not make a deliberate decision.

5 DISCUSSION

The aim of the here described work was to compare two different display concepts 'dashboard' as a state-of-the-art technique and 'data glasses' as a HUD solution for motorcyclists, in order to determine the latter's potential to improve safety during motorcycle riding. A combination of LCT, DRT and NASA-TLX was chosen for the investigations.

Whereas the LCT could show that dealing with the secondary task had an influence on the riders' performance in the riding task in general, no significant difference could be found between the different display technologies. This leads to the conclusion, that retrieving displayed information affects the riding performance in general, while the use of data glasses neither increases nor reduces this effect compared to the standard dashboard.

However, differences between the information recognition can be found. Reactions to information displayed in the data glasses were on average more than 20 % faster than with the standard dashboard setup. This is assumed to be due to the fact that information is displayed closer to the natural line of sight, comparably to HUD-solutions in passenger cars.

The DRT results show that retrieving and processing information from any display generally adds a considerable amount of workload to the actual riding task. Stimuli in the periphery are recognized slightly faster with the data glasses. Again, this might be explained by the necessity of gazes away from the forward road scene when glancing towards the dashboard. This also effects the number of missed stimuli, which is higher for the conditions that include the dashboard.

The tendency of decreased workload with data glasses compared to the dashboard is recognizable in objective as well as in subjective values. Yet, from a statistical evaluation only the mental and temporal demand decreased. Nevertheless, this could be one reason explaining the faster reaction times in the secondary task.

6 Conclusion and Outlook

In the context of the work described in this paper, a method for the comparison of different display technologies for motorcycles has been developed, combining and adapting well-established standards from the passenger car domain. The method was applied to the investigation on the safety potential of data glasses for motorcyclists in form of a participant study on a motorcycle riding simulator.

The ISO Lane Change Test was used as primary riding task (ISO, 2010), while the display technologies were assessed with a reaction time task. Rider workload was measured using the detection response task in pre-defined sections while riding (ISO/TS, 2016).

The method proved to be applicable and provided plausible results, allowing to show differences between the display technologies. While there were no differences concerning the influence on the riding task, information was proceeded faster with the data glasses, shown by a measurable reaction time benefit. The perceived workload was reduced.

Besides the promising results concerning reduced workload and reaction times when displaying relevant information on data glasses instead of showing them on the standard dashboard, the successful implementation of the developed procedure is a very important result of the described work.

Being based on well-established standard methods the developed test procedure could be a basis for future investigations of other new (assistance) systems. Allowing to evaluate motorcycle assistance systems in a safe simulator environment with relatively low effort, as it is already common procedure in the passenger car domain, the method could help to accelerate bringing modern assistance systems into the market.

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MITIGATING MOTORCYCLE ACCIDENTS AT YIELD JUNCTIONS USING COMPUTER VISION AND DEEP LEARNING: A PRELIMINARY STUDY

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ABSTRACT

Accidents involving motorcycles are significantly higher at un-signalised junctions. Recent accident prevention technology for motorcycles is limited to systems designed to scan the environment detecting possible hazards in navigation paths. An accurate prediction of future trajectories could further mitigate the severity of a collision. Therefore, using only monocular video and deep learning methods, we detect, track, and analyse vehicles approaching a junction to predict yield intent before the vehicle enters the motorcycle's navigation path where current rider aids would be triggered. We investigate two methods: real-time predictions based on data passed from deep learning live tracking metrics and perceptron classification prediction from a linear classifier trained on driver behaviour profiles. The results from this prototype based on synthetic data demonstrate that we can advance the collision warning trigger time by adding an intent prediction and measure the effect of this by experimenting with inevitable collision situations.

Index Terms— Motorcycle Junction Accident, Intent Prediction, Computer Vision, Deep Learning, YOLOv5

1. INTRODUCTION

Despite extensive research over the past decade, detecting and classifying objects from a moving platform is still challenging [27] [34] [47] for autonomous vehicles (AV) and advanced driver-assistance systems (ADAS). Significant advances using machine learning have improved the accuracy and performance of collision mitigation systems, in particular when using deep learning techniques such as convolutional neural networks (CNN) [37] and region-based CNN (R-CNN) such as Faster R-CNN [38]. However, the technical challenges increase when using a motorcycle as a moving platform due to the limited capacity to install sensors and associated hardware. Detecting objects from a motorcycle with a compact 2D camera and embedded technology [19] has proved successful and can mitigate the severity of some accidents.

Accidents involving motorcyclists occur at a higher rate at junctions [3], where the majority blame lies with the vehicle's driver entering the main road and colliding with the motorcycle. A study conducted using human drivers and driving simulators [5] has provided the first evidence for an eye movement basis to "look but fail to see" (LBFTS) errors. The study concluded that the LBFTS were authentic perception faults rather than a failure to appraise. In contrast [4], evidence suggests that motorists accept smaller gaps at junctions in front of motorcycles compared to cars. This notable difference suggests that the disparate number of accidents involving motorcycles at junctions may be partly attributed to improper gap selection by drivers. Two thousand five hundred drivers responded to questions about how often they would yield to another driver in 10 hypothetical crossing situations [6] and discovered that over 20% of drivers failed to yield at a given junction.

Predicting another driver's intent is an inherent driver's skill and essential to the act of driving. Autonomous vehicles (AV) are also prone to unintended bias against vulnerable road users (VRU). Research by the Netherlands vehicle authority (RDW) highlighted that vehicles equipped with advanced driving aids needed human intervention to prevent a collision with a vulnerable road user (VRU). RDW warns that systems do not always see and react to small objects like motorcycles [42]. Vehicles controlled by humans, AV, or a mix of both, pose the most significant risk to a motorcyclist at yield junctions.

This paper is preliminary work using simulated environmental conditions from a motorcyclist's perspective and explores how to predict a human driver's intent at an unsignaled junction on UK roads, using deep computer vision (CV) and deep learning (DL). Deceleration profiles studies [50] identify a trend towards higher acceptable deceleration thresholds for intersection approaches and suggest drivers will decelerate progressively towards the junction rather than come to a sudden stop; this investigation builds on this work and will go towards research to shape our baseline for driver intent profiles. Our intent predictions can be amalgamated with appropriate accident mitigation technology to advance the motorcycle-based ADAS's safety windows and, by future experimentation, determine how additional safety margin affects the outcome of previously inevitable collisions.

2. RELATED WORK

2.1. Machine learning

The intent of other road users using ML has been researched extensively and has produced a large body of work. Long short term memory networks (LSTM) [7] can predict a motorists intent up to 150 m before reaching the junction. The results of [7] showed promise for further use of LSTMs, with the mean cross-validated prediction accuracy averaging over 85% for their experiments at a range of junctions, obtaining 83% for the highest throughput intersection. This work showed that supervised classification methods could produce relatively accurate results; however, these methods lack the performance required for fast, accurate object detection, classification, tracking and intent prediction in the real world due to the computational load required. Other methods, combining and mixing different types of neural networks, for example, CNN and LSTM [8] for road lane line detection, car object detection and car trajectory prediction, have shown promising results, reaching an accuracy of 0.91% for line detection and predicting the future trajectory of the car as long as there was no occlusions or noise. Supervised and rule-based methods may have better accuracy rates; however, handcrafted rules usually take significant work to formulate and authenticate and do not have good generalisation abilities. Unfortunately, methods based on learning require large quantities of training data to fulfil a sufficient number of different driving scenarios. Trajectory prediction methods proposed by [9], [10], [11] are good at learning the three-dimensional, shape and geometric features and have a reduced computational load but cannot determine temporal dependencies in sequence data without additional mechanisms. Models with good temporal learning features include [12] [13], showing promise for learning temporal features and dependencies and ensuring temporal coherence. One such system involving a large dataset and a recurrent neural network (RNN) [25] produces excellent results, giving a significant 1.3-s prediction window before any potential collision arises; however, these are generally more challenging to train due to lack of data.

2.2. Intersection accident mitigation.

Motorcycle autonomous emergency braking (MAEB) [14] [15] [17] has been seen as a high priority system for motorcycles, specifically when combined with an anti-lock braking system (ABS) [16]. These studies have shown theoretical reductions of up to 10–14 km/h to motorcycle impact speed, depending on the crash scenario [15]. Collision avoidance technology for motorcycles is limited to systems designed to scan the environment detecting possible hazards in navigation paths. These methods use a range of technologies, including video cameras [18] [19], laser scanners, vehicle to vehicle, or environment to vehicle communication [20] [21]. Studies examining collision warning systems reported high levels of detection accuracy. However, the authors noted limitations with existing technology in terms of real-time implementation [20].

2.3. Fast detection deep learning models

Implicit warning systems can reduce the impact of a collision
between a motorcycle and a car pulling into the rider's path, knowing the intentions of a target vehicle before it pulls into the path of the rider and a collision is imminent could further mitigate the impact or avoid a collision. Driver intent prediction models suitable for the modality of motorcycling will usually be vision-based and use a modified CNN and additional NN frameworks to handle tracking and prediction. Implementing such systems utilising an R-CNN and reinforcement learning using the bounding box area as a metric for determining distance to the vehicle has proved successful [24]. Methods using the YOLO (you only look once) deep learning framework have had success due to the high-performance detection capabilities [22] [23] [29]that exploit the differential pixel area in the ROI to determine the distance of the target vehicle; however, this is detrimental to the overall accuracy of the framework.

3. METHODS

3.1. Behaviour classification based on actual-world data

In order to overcome the lack of labelled datasets of collisions or driver behaviour at UK yield junctions, we had to study driver actions and generate classifications of driver behaviour. We classified four behaviours by gathering empirical evidence of driver behaviour when yielding to vehicles from the right turning left onto a major road. The layout of our study junction is similar to ES3CR in [6]. A summary of observations taken over 3 hours can be seen in Tab.1. One thousand three hundred fifty-six vehicles used the junction to turn left.

The observations were taken between 8 am, and 11 am on a working day; dry and clear weather. Approximately 22% of drivers failed to yield, causing priority traffic to take avoiding action.

Action at junction	Frequenc y
Stop and yield	477
Slow and yield	581
Merge yield	296
No slow, no yield	2

Table 1. Preliminary data shows the proportion of drivers observed at a yield junction entering a major road. These were a car, van and light truck observations.

We established our prediction class baseline, stop and yield, where the driver made a complete stop, merge yield, where the driver pushed into traffic without stopping, slow no stop, where the driver slowed looked and joined the main road, no slow no yield, the driver appeared to enter the main road without slowing or looking. Using pre-study data and related current research into driver behaviour at junctions [49] [4] [20]. We have one method, real-time predictions for calculating real-time velocity and distance gathered from the tracking pipeline. Empirical observations on synthetic data of vehicles approaching a junction create our backbone for the parameters of each class; namely, we apply the behaviour metrics of Velocity and Distance to each class depending on the outcome at the junction and classify them into one of four classes from Tab. 1. The second comparative method, classification prediction, uses a dataset generated by metrics from the real-time method to produce training data for a simple linear predictor.

3.2. YOLO object detection

The DL model YOLO [1] is an established method for object detection. Preceding the introduction of YOLO, the methods for performing object detection using deep learning models included Deformable Parts Models (DPM) and R-CNN [26]. YOLO uses a single NN to detect multiple objects in real-time, focusing on performance rather than accuracy, which is the focus of R-CNN. Performance-based CV tasks favour YOLO as it examines an entire image in one pass. An R-CNN passes an image through numerous small regions in the CNN several times, impacting performance as inference is slow but not detection accuracy. YOLO tackles bottlenecks from a regression point of view using a single network cutting down on inference overheads and demonstrating a high generalisation capacity. Fast R-CNN has a performance of 0.5 frames per second (FPS), YOLO has a performance of 45 FPS. Given the importance of performance in our senario, we use YOLOv5 as a real-time vehicle detection model. Compared to previous versions, YOLOv5 uses anchor boxes, which infers class probabilities, bounding boxes, and objectiveness scores.

Machine learning requires large amounts of data to train for a specific task; however, the lack of UK T-junction datasets requires a different approach from the traditional CNN classification methods. As a starting point, we take advantage of YOLOv5 [28] for detection and classification trained on the coco dataset [48]. We track objects using DeepSORT and build on the methods explored [31]. Although our current study is related to recent evidence [33], it exploits on the high performance of YOLOv5 to offer real-time predictions, which in these earlier studies focus on accuracy. In order to estimate driver intent, the analysis of past and real-time data is required. Velocity and distance data are generated from the video interpretation, and our algorithm analyses real-time data to comparatively predict past data for a linear predictor. We created a dataset using this real-time data and handcrafted features based on the evidence [46], then passed into a linear classifier for an intent classification as a comparison. We have leveraged the frame cascade between CNN and DeepSORT to extract bounding box variables; data capture is instigated by isolating elements of the output array and measuring the relationship with the movement of target vehicles in simulation to create a seamless prediction flow allowing for near real-time performance.

3.3. Tracking objects using the DeepSORT algorithm

DeepSORT is a simple tracking algorithm extending the original sort [30] by using DL. Rather than relying only on movement-based metrics in data association, DeepSORT integrates a deep appearance-based metric derived from a CNN [31]. Solving the correlation between Kalman states [41] and subsequent measurements is achieved using the Hungarian algorithm [32] [39]. Incorporating movement can be accomplished using the squared Mahalanobis distance [40] [41] between predicted Kalman states and subsequent measurements. Kalman filtering produces an approximate location of the object. However, we will have camera motion in our experiments, adding uncertainty to exact object location and producing a Mahalanobis distance metric that will be less accurate through occlusions. [31] integrated a second metric for deep sort to solve this. For each bounding box detection, an appearance descriptor is calculated, and a gallery of the last 100 appearance descriptors are stored for each track allowing for more extended tracking through occlusions and unintended camera motion. Compared with other tracking algorithms, the rationale for using DeepSORT: Tracktor [32] is that an accurate multiple object tracker is not feasible for real-time tracking as the average execution is 3 FPS. TrackR-CNN [33] provides segmentation improving accuracy, however as with Tracktor, not ideal for real-time tracking, having an average execution of 1.6 FPS. DeepSORT can function at 16 FPS on average while maintaining good accuracy and excellent occlusion handling.

3.4. Intent Prediction

Predicting the intent of a vehicle at a junction requires analysis of the 2D input; feature data has to be extracted from each video frame to create optical flow data. We use YOLOv5s for object detection and DeepSORT for tracking in real-time. We use the frame by frame tracking data to generate dataset data and compare the current track to previous track data. Input is in 2D video imagery, which is passed to YOLOv5 for object detection and classification; bounding box reference data predictions are generated and drawn around the object. Bounding box inference data is passed to DeepSORT as a feature vector describing the object contained in the image. The DeepSORT NN analyses the feature vector to estimate a track using an assigned ID. Once an ID is assigned, a tracking vector is created for subsequent frame predictions. Our algorithm takes that vector data and analyses the differential values to predict if the vehicle will yield at the junction. Initial 2D depth estimation used data using handcrafted features from a 2D image [2]; this proved accurate but lethargic. A DNN was developed using a persistent random field for image patches to estimate total image depth [10]. The above methods require precise depth supervision, excluding them from any real-time application.

In the absence of depth image as ground truth, it is possible to estimate the distance of an object in the image [35] [36] [43] [44] from the height of objects. In this manner, the distance can be calculated with the pixel height h and the real-world height h_w and f_y focal length of the object by; $d = h_w f_y / h$ (1).

To estimate the velocity of the target vehicle, we employed some of the methods in [45] in which a minimal and straightforward monocular vision-based approach is proposed. Velocity is calculated using the distance metric described above and the flow of the bounding box transposed during the tracking stage. We define the location where a target vehicle stops at the line demarking the junction exit and calibrate all distance variables from this point. In order to capture driver intent, the analysis of current and past data is required. This data combines bounding box top left-x coordinates and top left-y coordinates a width and a height value a class, id and a confidence score for several past time steps. Data capture is instigated by isolating elements of the array and measuring the relationship with the movement of target vehicles in simulation. It is possible to visually display this data on the live moving target vehicle or produce a real-time trigger for MAEB, see Fig. 2.

4. RESULTS

4.1. Method 1: Real-time predictions

Predictions using real-time data from the tracking cascade were triggered approximately 30m from the junction line-markings and then compared to their later yield behaviour, see Tab.2. and Fig. 1.

Intent prediction												
Predicted	1	1	1	2	2	2	3	3	3	4	4	4
Observed	1	1	3	2	1	1	3	3	4	3	4	4
Precision	1 = 66.7%, 2 = 33.3%, 3 = 66.7%, 4 = 66.7%											

Table 2. Intent predictions from the target vehicle at 30 m compared to observed action at the junction. Key for table 2: stop and yield = 1, merge yield = 2, slow no stop = 3, no slow no yield = 4

Realtime data capture allowed us to make an intent prediction 30 m from the junction and update every 1 s until the stop line. Fig. 1. left image target vehicle predicted to yield, and the right image shows the target predicted no yield.

Fig.1. Visual intent predictions using real-time data.

4.2. Method 2: Linear classifier method

Intent profiles were generated from velocity and distance data captured during real-time intent predictions. We collapsed classes for the linear classification method as there was too much overlap, and we required a binary result of yield or no yield. This data formed a small dataset similar to [46] of intent profiles to train a linear classifier. Test data accuracy was 0.97. Using a confusion matrix as an alternate method for the performance of the whole model, we get an accuracy of 0.89, as seen in Tab. 3.

N=66	Predicted yield	Predicted no yield
Actual yield	37	3
Actual no yield	4	22

Table 3. Confusion matrix for the complete linear classifier

5. DISCUSSION AND FUTURE WORK

As the first step in a larger body of work, we investigated two methods to predict driver intent with the ultimate aim of determining how an additional ADAS safety margin created using CV and DL affects the outcome of previously inevitable motorcycle collisions. Firstly we use an unsupervised real-time method to overcome the lack of labelled data. We observed vehicles approaching a simulated yield junction environment and manually recorded the intent predictions produced by using a minimal and intuitive approach that captures the target vehicle tracking cascade data. This minimises the computational overhead as the distance from the junction line, and the target vehicle's velocity estimations can be generated from concurrent processes. We produced precision metrics from individual classes. Our second method input 66 hypothetical behaviour profiles based on *v* and *d* data in method one into our linear classifier and achieved an accuracy of 0.89. While our second method did not run in real-time, it did prove to be slightly more accurate. We can improve accuracy by incorporating the linear classifier into the tracking cascade in future work while maintaining high performance. Evaluation of the results indicates that although the intent predictions from both methods showed promise on simulated data, it proved the feasibility of the framework rather than evidence of a conclusive study as real-world dynamics increase complexity. MAEB systems are prone to instability [14] [15] [17] if initiated too quickly; having an increased trigger time would not only help to mitigate a collision with a target vehicle but reduce the severity of the automated braking action required. Our contribution emphasises the need for real-time processing and that a minimal approach is required to apply an effective and timely solution to driver intent at junctions. Our subsequent study will focus on determining the effect of an intent prediction on an imminent collision senario on a moving platform from non-yielding vehicles contributing to and developing [7] [24].

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Motorcyclists' Real Use of Vehicle Dynamics

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ABSTRACT

The abnormally high mortality rate of Powered Two-Wheelers (PTW) is probably related to their vulnerability, but also to their behavior and interactions with other road users. There is a need to collect exposure data on PTWs to better understand uses and determinants involved in the mechanisms of accidents since there are almost no naturalistic studies on motorcyclists as on motorists. This paper aims to characterize the actual use dynamic capabilities of PTWs by motorcyclists through objective measures. In 2016-2018, an experiment was carried out to acquire Naturalistic Riding Data from 26 private motorcycles implemented with an Event Data Recorder. For 18 months, in three regions of France, the devices collected aggregated data on each ride thanks to accelerometers and gyrometers, and continuous speeds and trajectories, thanks to GPS. This paper presents the global distributions of accelerations, rotation rates and speed, and the extreme values reached at least once. It also illustrates the variability of behaviors: smooth driving versus sporty driving. 6500 travels were exploited, representing 88000 km. The motorcyclists endure rarely high levels of dynamic demands; especially in acceleration and deceleration, they exceed +-4 m/s² only 0.5% of the time. As far as cornering is concerned, their roll rate exceeds 20°/s only 0.8% and their yaw rate 2.1% of the time. Excluding time spent at standstill or at very low speed (less than 5 km/h), motorcyclists spend 80% of their time below 90 km/h and 3.2% of the time above 130 km/h, with 0.3% of the time above 150 km/h. The behavior varies greatly from one motorcyclist to another, even on the same itineraries. These data characterize the dynamics of motorcycles and discriminate different behaviors of riders.

INTRODUCTION

Accident risk and severity are significantly higher for Powered Two-Wheelers (PTW) riders than for other motorized road users. In 2019, motorcyclists accounted for 18% of road fatalities in Europe [1], although they represent less than 2% of traffic. Several studies on the causes of accidents show that the most common cause is human behavior. For example, Singh [2] reports that in the National Motor Vehicle Accident Causation Survey conducted in the United States between 2005 and 2007, in a sample of 5,470 accidents, the primary reason was attributed to the driver in 94% of cases. Studies of natural driving appear to be essential for a better understanding of accident mechanisms and for improving the safety of road infrastructure ([3], [4], [5]). To date, such studies are rare for motorcyclists.

The aim of this study is to update the data on the use of dynamic capacities of a motorbike thanks to the contribution of new data on exposure during natural driving. The data was acquired using a specific algorithm implemented in road data recorders (EDR) installed in a fleet of private motorcycles. The real-time collection of such data allows to establish the global distribution of speeds, accelerations and rotation rates, which are characteristic of the dynamics of the motorcyclist-motorcycle duo. The dynamic parameters are first analysed in terms of time spent with medium or high loads, in the longitudinal direction (acceleration/braking) and in the lateral direction (cornering). The analysis then focuses on the highest values reached at least once by the riders. The overall dynamic behaviour of the entire fleet is analysed as well as the driving behaviour of individuals is compared (calm/sporty driving). Then, a specific route driven several times by two motorcyclists is presented, where the differences in the dynamic parameters are due to the different longitudinal and lateral behaviours.

MATERIAL AND METHODS

Observational data were collected using on-board recorders on 26 private motorcycles over an 18-month period in three regions of France. This study focused on aggregate data provided for all trips, which crosses accelerometric and gyrometric data as well as speed levels. Approximately 6,500 trips could be analysed, in correspondence with the GPS trajectories, which make it possible to calculate the distances travelled. The overall distance covered during these trips is approximately 88,000 km.

The principle of this synthesis data comes from work on cars based on the concept of the friction circle [6] and presented in detail in [7,8]. The data is not stored as a function of time, but as matrices, aggregating the time spent in a combination of two given loads. For cars the longitudinal and lateral accelerations are considered with intervals of 1 m/s². For PTW, as the lateral acceleration in the motorcycle reference frame is near zero due to the particular dynamics of this vehicle, which leans during cornering, other parameters were used to translate the lateral dynamics, in particular the roll and yaw rates, with intervals of 10°/s. The raw accelerations are acquired at a frequency of 100 Hz and are noisier for a PTW than for a car. Therefore, filtering was applied in real time using a 30-point rolling average.

RESULTS

General data

The general characteristics of the trips are summarized in Table 1. The 26 motorcyclists completed an average of 249 trips. The minimum number of trips is 21 and the maximum 1068. They travelled between 309 and 9063 km, with an average of 3220 km per rider. The average trip distance is 13 km for all 6469 trips. The average trip distance for each rider is 18 km, but this average varies between 4 and 51 km between riders.

	All	Average per motorcyclist	Standard deviation	Minimum	Maximum
Number of trips	6469	249	190	21	1068
Total distance (km)	83714	3220	1841	309	9063
Average distance per trip (km)	13	18	8	4	51

Table 1: Trip and rider statistics

The 6469 trip trajectories considered in this study are shown in Figure 1. The road networks used are varied, with urban, suburban and rural areas.

Figure 1: Trip trajectories with focus on the Normandy-Centre Department, and the cities of Montpellier and Marseille

Speed levels

Overall, the motorcyclists spend 22% of their time at a standstill or at very low speeds. The distribution of speed levels was done by removing the lowest speed level, 0-5 km/h, to better see the distribution at higher speeds (Figure 2). Excluding the time spent below 5 km/h, motorcyclists spend 80% of their time below 90 km/h and 3.2% of the time above 130 km/h, with only 0.3% of the time above 150 km/h.

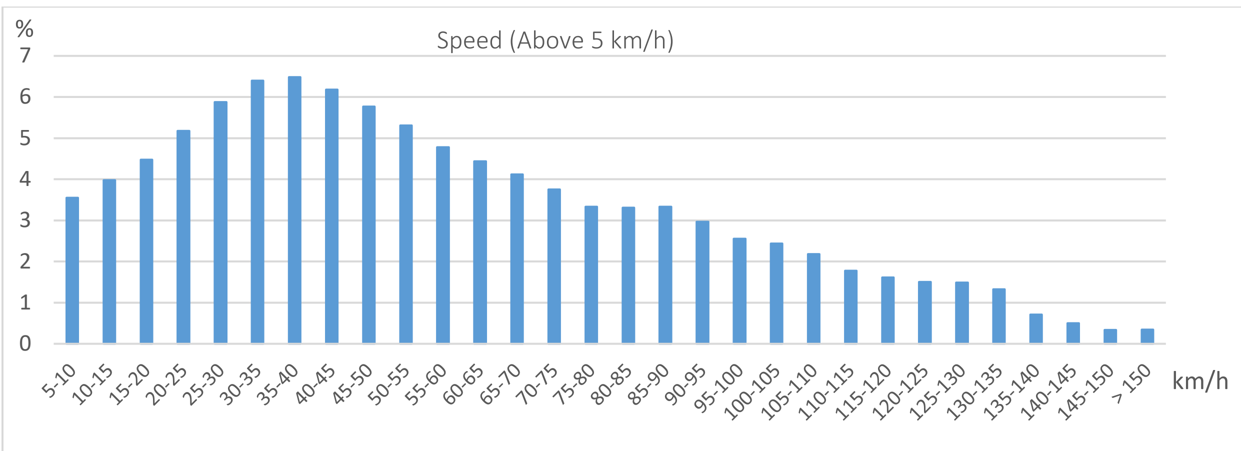

Figure 2: Global distribution of speeds in time spent above 5 km/h

These overall speed distributions must be balanced according to the road environment.

Accelerations and rotation rates

The acceleration distributions are shown in Figure 3 (top) for all trips. When braking, i.e., for negative longitudinal accelerations, motorcyclists are 8.5% of the time between -2 and -1 m/s². Below -2 m/s², the time spent braking is only 2.8% of which only 2.1% between -2 and -3 m/s² and 0.5% between -3 and -4 m/s². The percentage of time spent above -4 m/s² is only 0.2%. Motorcyclists are more often in positive acceleration, between 1 and 2 m/s² (9.2%) and between 2 and 3 m/s² (2.8%), between 3 and 4 m/s² (0.8%) and even beyond 4 m/s² (0.3%).

As expected given the vehicle dynamics specific to a PTW, there is almost never a lateral acceleration higher than 1 m/s². On the other hand, there are negative lateral accelerations between -1 and -4 m/s², 8.5% of the time, which are probably linked to the stopping phases of the PTW leaning on its stand. Specific tests were carried out to verify this hypothesis, which explains the dissymmetry in the distribution of lateral acceleration levels. The high vertical accelerations are partly related to road features (speed bumps, railroad tracks, manholes, etc.) or road defects (potholes, collapsed trenches, etc.), and partly to the transfer of the lateral acceleration to the vertical axis when the motorcyclist turns and the motorcycle leans. They are rare above 2 m/s² (2.1% of the time in total).

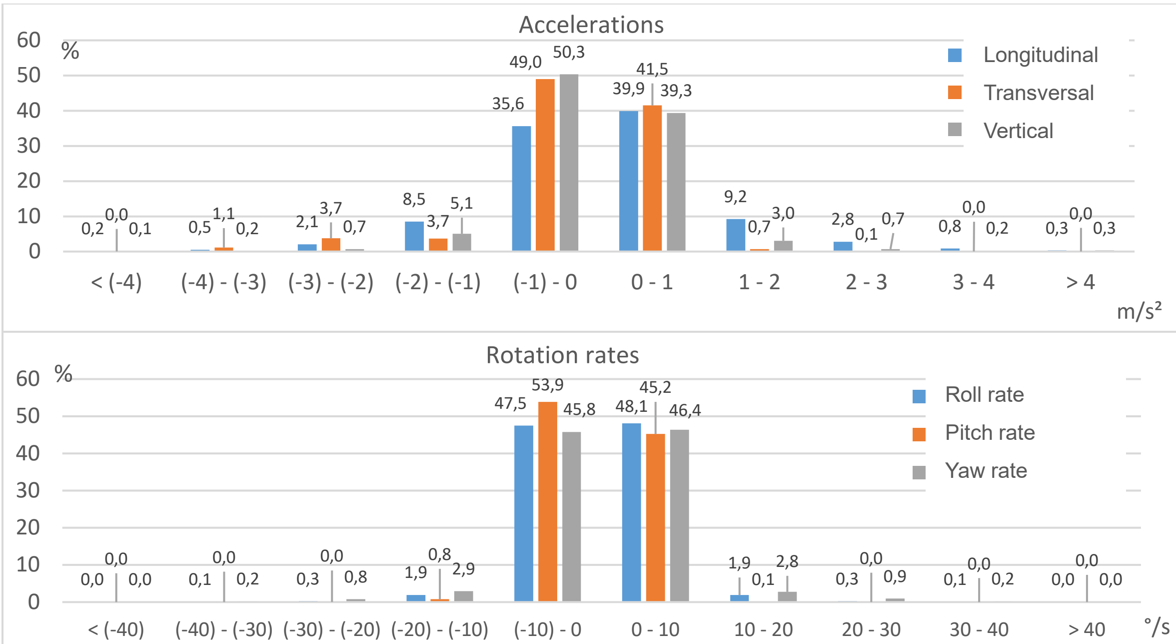

Figure 3: Global distributions of accelerations (top) and rotation rate (bottom)

The rotation rate distributions are shown in Figure 3 (bottom). In pitching, riders are very rarely above 10°/s: 0.1% of the time in positive pitch rate, i.e. braking, and 0.8% of the time in negative pitch rate, i.e. accelerating. The time spent with significant yaw rate and roll rate gives information on the behavior in cornering and changes of direction or shift. Motorcyclists are overall 3.8% of the time in roll rate between (+/-)10 and 20°/s and only 0.8% of the time above +/-20°/s. In terms of yaw rate the times spent are 5.7% between (+/-)10 and 20°/s and 2.1% above 20°/s.

Extreme values

Extreme loads are rare. To observe them, we use the 2D representation, with a [longitudinal acceleration - yaw rate] or [longitudinal acceleration - roll rate] crossover (Figure 4), which shows both braking and acceleration stresses, cornering stresses, and combined stresses, such as braking during cornering.

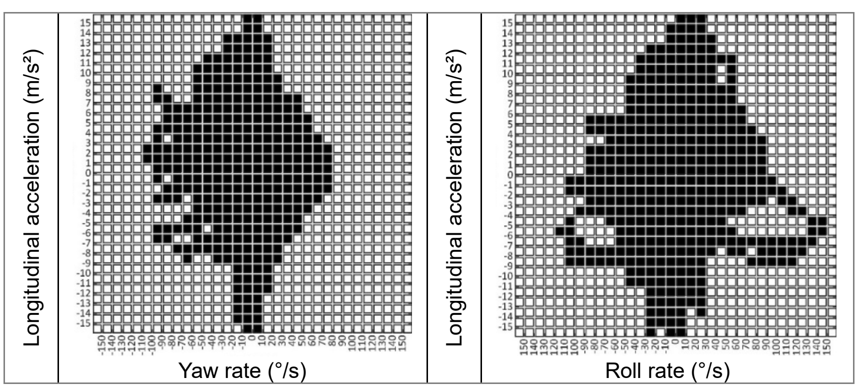

Figure 4: Crossing of loads: Longitudinal acceleration - Yaw rate (left) and Longitudinal acceleration - Roll rate (right)

At the extremes, acceleration and braking can exceed +/-15 m/s². These values are beyond the values encountered in particular in emergency braking tests. It is possible that on some motorcycles the vibration level is still quite high even after filtering, and that such extreme values are sometimes reached. In lateral, the maximum yaw and roll rates are close to +/-90°/s apart from the non-standard combined stresses. These representations will make it possible to differentiate the driving styles of motorcyclists.

Variability of driving profiles

To discriminate the type of driving, indicators of the loads have been calculated. These indices represent the number of black cells in relation to the total number of cells in a crossed representation as in Figure 4. The average and extreme values of these indices are summarized in Table 2. On average, the load indices are 13.5% (with yaw rate) and 14.8% (with roll rate) and vary from the "softest" rider to the "sportiest" rider between (6.1%, 2.2%) and (23.7%, 22.8%).

	Longitudinal acceleration versus Yaw rate	Longitudinal acceleration versus Roll rate
Global fleet (all trips)	31.3%	39.2%
Average per driver	13.5%	14.8%
Motorcyclist with the smoothest riding style	6.1%	2.2%
Motorcyclist with the sportiest riding style	23.7%	22.8%

Table 2: Loads Indicators (Overall Fleet, Smoothest/Sportiest Rider)

To assess differences in practiced speeds, the profiles of the smoothest and sportiest riders were compared with the overall practiced speed profile of the entire fleet (Figure 5).

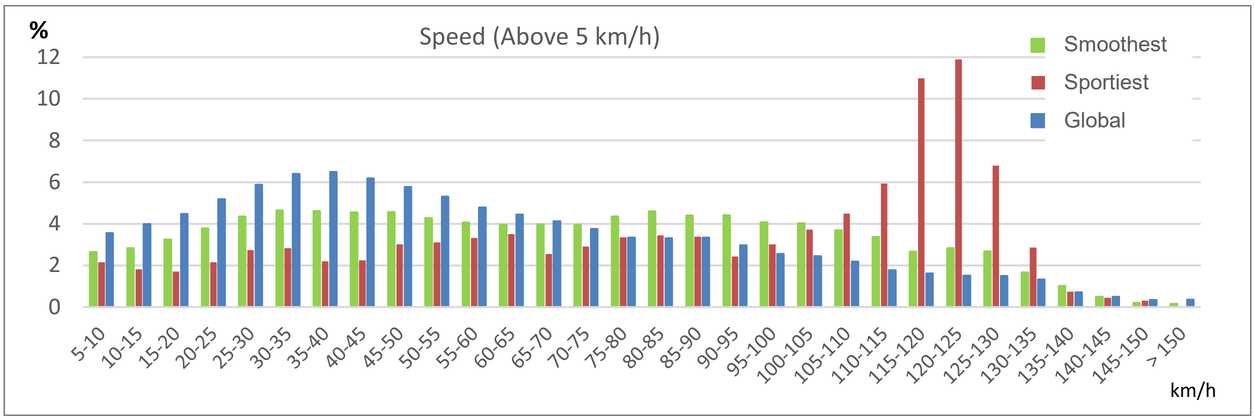

Figure 5: Comparison of the global speed profile, and the smoothest and sportiest driving profiles

The speed profiles are quite varied, with the smoothest motorcyclist riding more often than all riders below 70 km/h, and the sportiest rider riding much more often between 105 and 135 km/h. There was little difference in the amount of time spent above 135 km/h, but it can be seen that the smoothest motorcyclist was most often riding at these higher speeds. The distribution of the indicator [longitudinal acceleration - yaw rate] (Figure 6) shows that the sportiest rider is an extreme case and that the majority of motorcyclists' indicator is between 10 and 18%. There are only two motorcyclists' indicators below 10%.

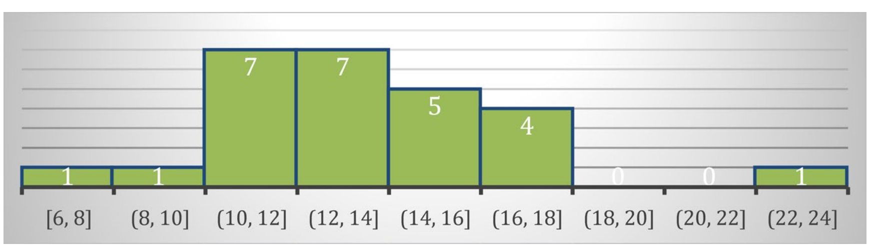

Figure 6: Distribution of load indicators Longitudinal acceleration vs Yaw rate

Figure 7 illustrates the diversity of driving profiles in more detail, with the intersection [longitudinal acceleration - yaw rate] for the 26 motorcyclists. For each rider, the distance travelled and the corresponding stress indicators are given.

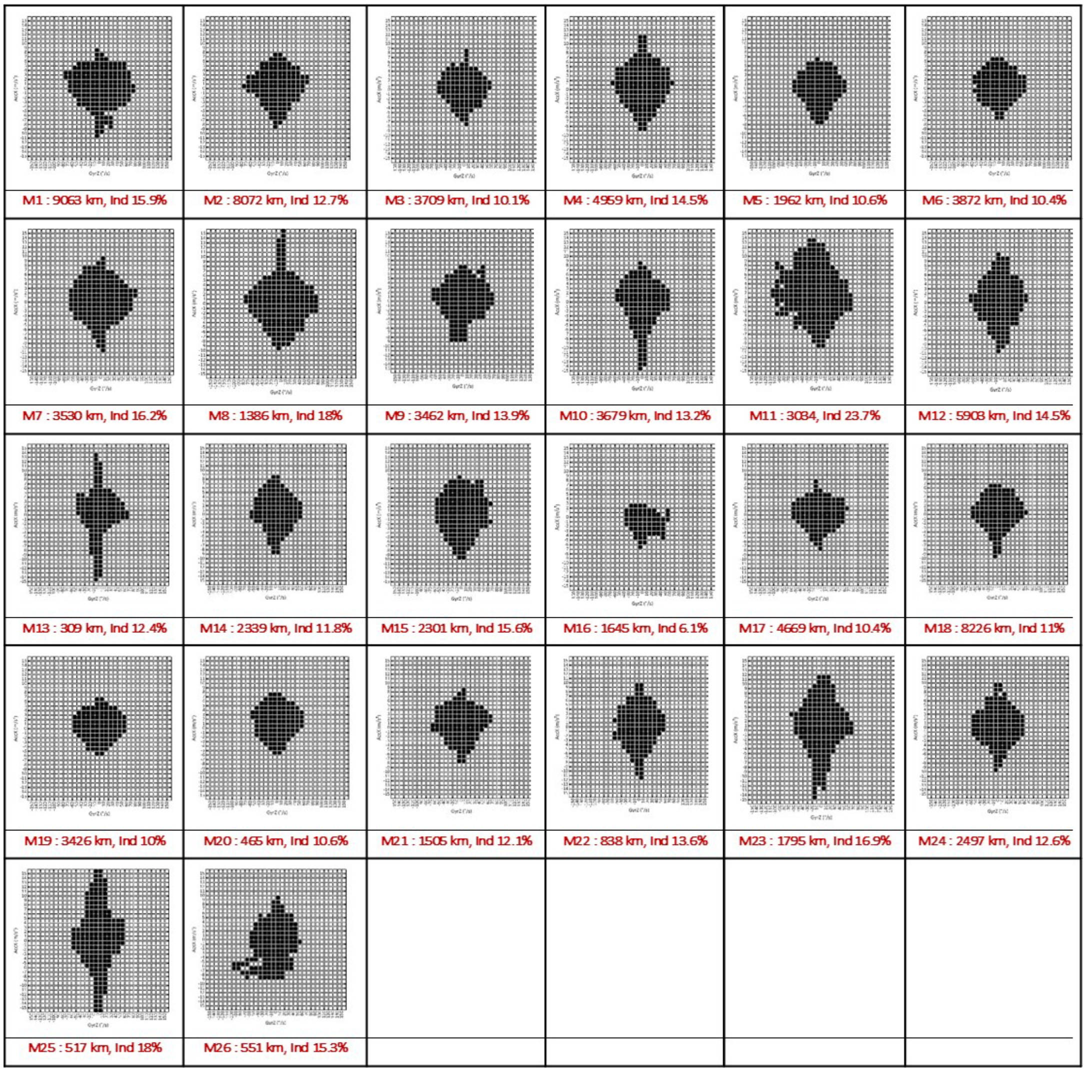

Figure 7: Extreme stress levels of the 26 riders - Longitudinal acceleration vs. Yaw rate

These graphs allow to quickly identify motorcyclists who brake hard, such as M10, M13, those who accelerate hard like M8, and those who brake and accelerate hard like M23 and M25. In lateral direction, the motorcyclists who stress their vehicle the most are M7, M8, and M23, as well as M11 whose graph shows that he or she stresses his vehicle the most in all directions, including in combined stresses. These longitudinal and lateral loads are related to the way the motorcyclist drives, but are also influenced by the type of roads he or she drives on. The vehicle is not stressed in the same way in an urban environment, in the suburbs, on the freeway or on a mountain road. This is why it is important to compare, whenever possible, the riding of several motorcyclists on the same route.

Comparison of riding profiles on a same route

The example shown in Figure 8 corresponds to a route of about 10 km, which was travelled 4 times by rider M7 and 3 times by rider M6. These two motorcyclists have travelled more than 3500 km each and their overall riding profile appears different (Figure 7), with M7 riding more sportily. On this route, the same holds true, with less stress in all directions for M6. In this case the differences in driving profile are confirmed by the study of a common route. The speeds practiced by these two motorcyclists on this route are also quite different, with M7 driving faster overall, which explains why he puts more strain on his vehicle, both longitudinally and transversely.

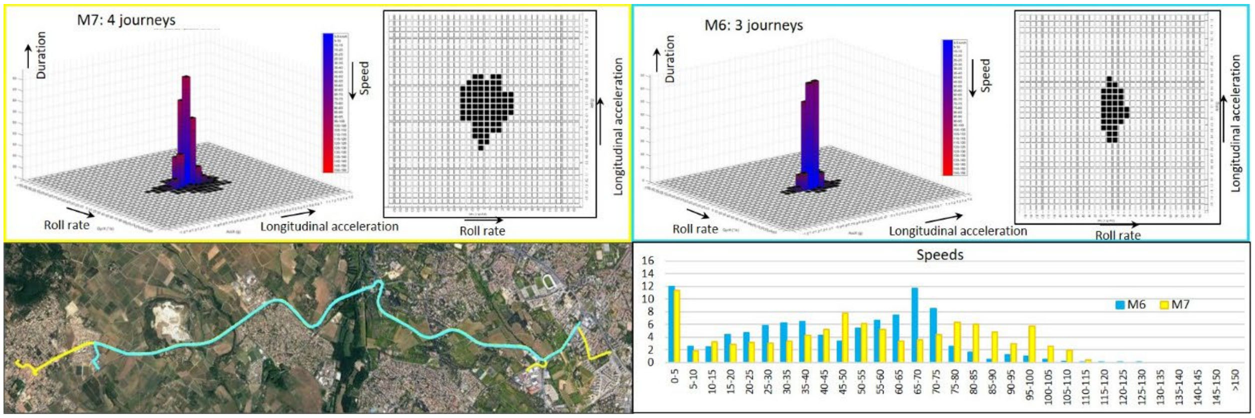

Figure 8: Route taken by two motorcyclists (M7 in yellow, 4 trips, M6 in blue, 3 trips)

CONCLUSION

This naturalistic riding data acquired over a period of 18 months with 26 private motorcycles in three regions of France, have been used to evaluate the actual dynamic loading of PTWs. About 6500 trips could be analysed, for a total distance of 88000 km. The results obtained on the complete set of data concern first the global distributions, in time spent, of the longitudinal, lateral and vertical accelerations, and of the pitch, roll and yaw speeds, then the extreme values reached at least once by the motorcyclists for these same parameters. The variability of behavior is then illustrated, ranging from smooth to sporty riding.

Motorcyclists rarely experience high levels of dynamic demands. In particular, during acceleration and deceleration, they exceed +-4 m/s² only 0.5% of the time. When cornering, their roll speed exceeds 20°/s only 0.8% of the time and their yaw speed only 2.1% of the time. Excluding time spent stopped or at very low speeds (less than 5 km/h), riders spend 80% of their time below 90 km/h and 3.2% of the time above 130 km/h, with only 0.3% of the time above 150 km/h. Behavior varies greatly from rider to rider, even on the same route. This type of natural driving exposure data allows to characterize the vehicle dynamics of motorcycles and to discriminate the different driving profiles of motorcyclists.

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Entwicklung eines Motorradfahrendenmodells zur Trajektorienprädiktion

Development of a motorcyclist model for trajectory prediction

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Zusammenfassung

Die körperlichen und geistigen Fähigkeiten von Motorradfahrenden haben einen großen Einfluss auf ihre eigene Sicherheit. Oft führt die Kombination aus fehlendem Schutzraum und Überschätzung des eigenen Könnens zu schweren Unfällen. Da die Mehrzahl der Motorradfahrenden ihr eigenes Können nur auf öffentlichen Straßen entwickelt, ist es wünschenswert, die Fahrenden durch Assistenzsysteme bestmöglich zu unterstützen. Solche Systeme beruhen auf der Beschreibbarkeit und Interpretierbarkeit fahrendenspezifischer Parameter, die bei ausreichenden Trainingsdaten auch eine Schätzung dieser erlauben.

Es wird ein Modell konzipiert, entwickelt und evaluiert, das zur Vorhersage von Motorradfahrdynamikdaten unter Berücksichtigung des Fahrendeneinflusses eingesetzt werden kann. Dazu wird eine Modellierung durchgeführt, bei der weder fahrenden- noch fahrzeugspezifische Parameter als bekannt vorausgesetzt werden. Es werden parametrisierbare mathematische Funktionen zur Beschreibung des Geschwindigkeits- und Rollwinkelverlaufs entwickelt. Anschließend wird nachgewiesen, dass zwischen einzelnen Fahrenden signifikante Unterschiede hinsichtlich des relativen Streckenfortschritts bestehen. Im Gegensatz zu bisherigen wissenschaftlichen Ansätzen ist es möglich, die dynamischen Daten anhand eindeutiger fahrerspezifischer Parameter zu interpretieren, ihren Verlauf zu approximieren und sie fahrendenübergreifend zu vergleichen. Beispielhafte Parameter sind Korrekturamplituden, Trends und Grenzwerte. Darüber hinaus ermöglichen die Parameter eine zuverlässige Identifikation kritischer Fahrmanöver.

Anschließend wird auf der Basis der beschreibbaren Rollwinkel- und Geschwindigkeitskurven ein Ansatz zur Berechnung der zukünftigen Position entwickelt. Die Grundannahme der stationären Kurvenfahrt wird durch die Entwicklung eines Korrekturfaktors erweitert. Darüber hinaus erlauben die Korrekturfaktoren eine Abschätzung des Fahrstils und bilden zusätzlich auch die Individualität der Fahrenden ab.

Das gewählte Qualitätskriterium für die Bewertung der Gesamtgenauigkeit ist der laterale Versatz zwischen der berechneten und der gemessenen Trajektorie in Abhängigkeit der gefahrenen Strecke. Die Bewertung erfolgt auf Basis von Messdaten mehrerer Kurvendurchfahrten aus einer Probandenstudie auf abgesperrtem Gelände. Für mehr als 85 % der Manöver kann ein Fehler von weniger als 1,5 % festgestellt werden.

Mit dem hier vorgestellten Modell wird in Zukunft eine fahrendenabhängige Vorhersage der zu erwartenden Trajektorien durch einen vorausliegenden Streckenabschnitt unter Berücksichtigung eines Unsicherheitsintervalls möglich sein.

Abstract

The physical and mental abilities of motorcyclists have a great influence on their own safety. Often, the combination of a lack of protective space and overestimation of one's own ability leads to serious accidents. Since the majority of motorcyclists only develop their own skills on public roads, it is desirable to support riders as best as possible through assistance systems. Such systems are based on the describability and interpretability of rider-specific parameters, which, given sufficient training data, also allow these to be estimated.

A model is designed, developed and evaluated, which is used to predict motorcycle driving dynamics data under consideration of the rider's influence. For this purpose, modelling is carried out in which neither rider- nor vehicle-specific parameters are assumed to be known. Parameterisable mathematical functions are developed to describe the speed and roll angle characteristics. Subsequently, it is demonstrated that significant differences exist between individual riders with regard to relative distance progress. In contrast to previous scientific approaches, it is possible to interpret the dynamic data on the basis of unique rider-specific parameters, to approximate their course and to compare them across riders. Exemplary parameters are correction amplitudes, trends and limit values. Furthermore, the parameters enable a reliable identification of critical driving manoeuvres.

Subsequently, an approach for calculating the future position is developed on the basis of the describable roll angle and speed curves. The basic assumption of stationary cornering is extended by the development of a correction factor. In addition, the correction factors allow an estimation of the riding style and thus also map the individuality of the riders.

The chosen quality criterion for the evaluation of the overall accuracy is the lateral offset between the calculated and the measured trajectory as a function of the distance driven. The evaluation is based on measurement data of different curves from a test person study on closed-off terrain. For more than 85 % of the manoeuvres, an offset error of less than 1.5 % can be determined.

With the model presented here, it will be possible in the future to make a rider-dependent prediction of the expected trajectories through a section of road ahead, taking into account an uncertainty interval.

Entwicklung eines Motorradfahrendenmodells zur Trajektorienprädiktion

1 Einleitung

Reduzierter Raum für motorisierte Fahrzeuge in urbanen Gebieten, die Forderung nach umweltfreundlichen Fortbewegungsmitteln kombiniert mit einem gleichzeitig hohen Anspruch an die Individualmobilität und Reichweite ermöglichen dem Motorrad – z.B. in elektrifizierter Form - eine mögliche Zukunft im Verkehrsgeschehen. Ein Defizit des Motorrads gegenüber dem Automobil ist im Bereich der Sicherheit und dem Fahrendenschutz zu verzeichnen. Prinzipbedingt existieren beim Motorrad wenig passive Sicherheitselemente aufgrund des nicht vorhandenen Schutzraums. Im Bereich der Unfallvermeidung durch den Einsatz von Assistenzsystemen existiert weiterhin noch ein ungenutztes Sicherheitspotential (aktive Sicherheit).

Die Unfallstatistik zeigt, dass 33,7 % aller Motorradunfälle im Jahr 2020 als Alleinunfälle einzuordnen sind[1a]. Motorradfahrende im Alter zwischen 15 und 24 Jahren stellen mit über einem Drittel[1b] aller verunglückten Fahrer die stärkste betroffene Altersgruppe dar. Als häufigste Unfallursache von Krafträdern mit amtlichen Kennzeichen wurde in 22,4 % der Fälle eine „nicht angepasste Geschwindigkeit"[1c] festgestellt. Eine Studie des ADAC[2] aus dem Jahr 2015, zuletzt aktualisiert 2019, untersuchte Motorradunfalltypen differenzierter nach Unfallursachen in Kombination mit Fahrmanövern und stellte bei 21 % eine „unangepasste Geschwindigkeit im Kurvenbereich"[3] als Unfallursache fest.

Die Kurvendurchfahrt des Motorrades hängt im Vergleich zum Personenkraftwagen (Pkw) in besonderem Maße von der aufgebauten Schräglage ab. Hierdurch spielt das fahrendenspezifische Können sowohl in physischer als auch in psychischer Hinsicht eine zentrale Rolle. Zur Weiterentwicklung aktiver Sicherheitssysteme wird mit fahrdynamischen Messgrößen und unter Berücksichtigung von Fahrendeneinflüssen eine Zustandsprädiktion des eigenen Fahrzeuges möglich. Auf Basis dieser Vorhersage besteht bspw. die Möglichkeit Motorradfahrenden vor Einfahrt in eine Kurve eine individuelle, optimale Kurvenanfahrt anzuzeigen oder die Fähigkeiten der Fahrenden mit Hilfe einer detaillierten Fahranalyse zu verbessern.

In dieser Veröffentlichung werden zuerst die Grundlagen aus aktuellen Forschungsarbeiten zur Fahrendenindividualität vorgestellt. Hierauf aufbauend wird die Modellentwicklung zur Berücksichtigung fahrendenspezifischer Einflüsse bei wiederholter Durchfahrt einer Kurve vorgestellt. Anschließend wird das entwickelte Modell zur Berechnung einer Kurvenfahrt herangezogen und mit Referenzwerten verglichen.

Das hier entwickelte Modell basiert auf aktuellen Forschungsergebnissen zur Untersuchung der Fahrendenindividualität, die nachfolgend vorgestellt werden.

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[1] Vgl. Destatis: Verkehrsunfälle (2021), a: S. 8; b: S. 7.; c: S.8

[2] Allgemeiner Deutscher Automobil-Club e.V.

[3] Pschenitza, M.: Auswertung von Motorradunfällen: Konstellationen, Besonderheiten, Abhilfemaßnahmen (2019), S. 7.

2 Stand der Wissenschaft

Im Rahmen des Forschungsprojektes „Schräglagenangst" (gefördert durch die BAST[4] im Projekt FE 82.0710/2018) wurde durch FZD[5] die WIVW GmbH[6] und AMFD[7] das Vorhandensein und Ausmaß einer Schräglagenschwelle bei Motorradfahrenden untersucht. Weiterhin wurde die subjektive Einschätzung der Fahrenden hinsichtlich ihrer Fahrweise mit den ermittelten Schräglagen verglichen.

Zur Untersuchung fahrendenspezifischer Rollwinkelgrenzen und der Ermittlung eines *Komfortrollwinkels* wird eine 180 ° Normkurve eingeführt. Diese ist durch einen konstanten Kurvenradius von R=12 m und einer Richtungsänderung von 180 ° definiert. Die Studie vergleicht die erfassten maximalen Rollwinkel bei wiederholter Durchfahrt dieser Normkurve mit denen pseudokritischer Kurvenfahrten. Pseudokritische Manöver zeichnen sich durch als kritisch empfunden, in der Realität ohne Erhöhung der Gefährdung vorliegende[8] Situationen aus. Beispielhaft wurden die Fahrenden in der genannten Studie mit einem verdeckten Hindernis konfrontiert, das erst nach mehrfacher normaler Durchfahrt einer Kurve aufgestellt wurde. Die Untersuchung wurde auf einem abgesperrten Testgelände durchgeführt. Scherer et. al kommen zu dem Ergebnis, dass bei den zehn Probanden während der normalen Kurvendurchfahrt keine kollektive fahrendenübergreifende Schräglagenschwelle feststellbar ist. Vielmehr sind die maximalen erfassten Schräglagen bei normalen Fahrmanövern fahrendenspezifisch und teilweise abhängig von der Kurvenrichtung. Es zeigt sich, dass die Streuung der maximalen Rollwinkel beim mehrmaligen Durchfahren derselben Kurve bei Probanden mit längerer Fahrpraxis weniger stark ausgeprägt ist verglichen mit unerfahrenen Probanden[9]. In Abbildung 1 sind die maximalen Rollwinkel - inklusive Streuung - der pseudokritischen Manöver im Vergleich zu den normalen Manövern in der Normbewertungskurve dargestellt.

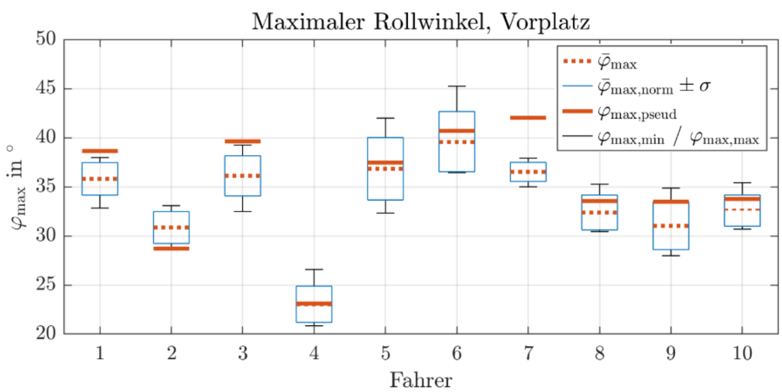

Abbildung 1 Maximale Rollwinkel normaler vs. pseudokritischer Manöver[8b]

Abbildung 1 zeigt die maximal erfassten Rollwinkel der normalen Kurvendurchfahrten ($\varphi_{\max,\mathrm{norm}}$), deren Median ($\bar{\varphi}_{\max}$) und deren 25/75 % Quartil (σ). Der maximale Rollwinkel des pseudokritischen Manövers ($\varphi_{\max,\mathrm{pseud}}$) liegt bei keinem der Probanden unter und nur einmal über dem Vergleichsrollwinkel der normalen Kurvenfahrten[9b]. Wird die Rollrate über dem Rollwinkel aufgetragen ergeben sich charakteristische Merkmale, wie in Abbildung 2 zu sehen.

[4] Bundesanstalt für Straßenwesen
[5] TU Darmstadt Fachgebiet Fahrzeugtechnik.
[6] Würzburger Institut für Verkehrswissenschaften.
[7] Auto Mobil Forschung Dresden GmbH
[8] Scherer, F. et al.: Schräglagenangst (2021), a: S.21, b: S.43
[9] Pless, R. et al.: Untersuchung der Existenz einer Schräglagenschwelle (2020), a: S.13, b:S.14, c: S.21

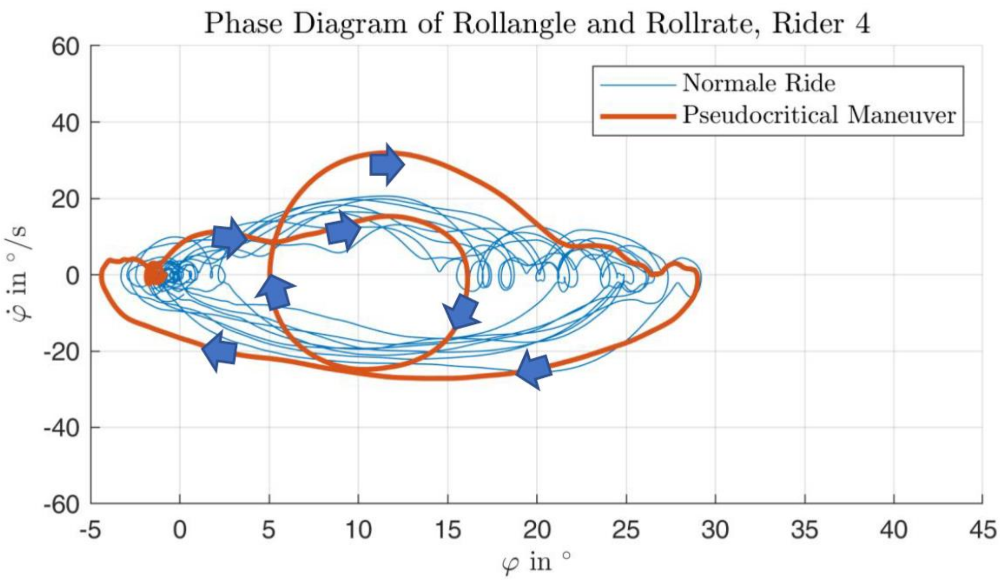

Abbildung 2 Phasendiagramm-Rollraten- /Rollwinkelverlauf[9b]

Die Abbildung zeigt das Phasendiagramm der Rollrate und Rollwinkel für ein Rechtskurve. Die Zunahme des Rollwinkels zum maximalen Komfortrollwinkel erfolgt bei den Standardmanövern allmählich und „mit mehreren kleinen Schritten“ [9b]. Der Verlauf des pseudokritischen Manövers unterscheidet sich stark von den übrigen Durchfahrten[9b]. Während der Kurveneinleitung beim pseudokritischen Manöver wird der Rollwinkelaufbau unterbrochen. Dies zeigt sich in Form einer großen Schleife im Phasendiagramm. Weiterhin wird deutlich, dass der maximale erreichte Rollwinkel des pseudokritischen Manövers nicht deutlich von denen bei normaler Kurvendurchfahrt abweicht. Die Autoren kommen zu dem Schluss, dass eine fahrerindividuelle Schräglagenschwelle existiert, welche jedoch in kritischen Manövern nicht signifikant steigt oder sinkt.

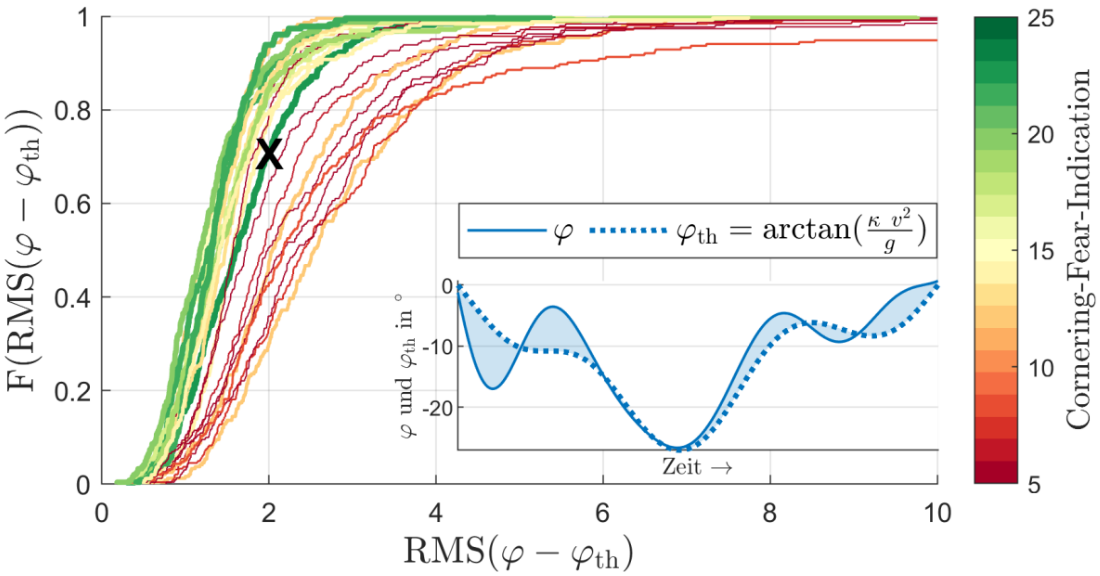

Abbildung 3 CFD Plot der RMS - Abweichungen von der Quasistatischen Beziehung[9c]

Zudem wird durch Pleß et. al. im selben Zusammenhang eine erste Korrelation zwischen der individuellen Angstbewertung der Fahrenden und der Abweichung des realen zum theoretischen Rollwinkel festgestellt. Wie in Abbildung 3 dargestellt fahren Probanden mit einer geringeren eigenen Kurvenangsteinschätzung dieselbe Kurve mit einer anderen – den Fahrstreifen mehr ausnutzenden – Trajektorie und größerem realen Rollwinkel als vergleichbare Probanden mit einer höheren Selbsteinschätzung der Angst vor hohen Schräglagenwerten. Ängstliche Fahrende bevorzugen laut diesem Ergebnis somit eine direktere und kurvenschneidende Linienwahl.

Eine weitere wissenschaftliche Arbeit auf der dieses Paper beruht ist die Dissertationsschrift von Magiera[10], in welcher statistisch die Unterscheidbarkeit verschiedener Fahrfähigkeiten von Motorradfahrenden untersucht wird. Magiera teilt hierbei die Kurvenfahrt in Teilbereiche und entwickelt anschließend eine Bewertung einzelner Fahrmanöver anhand statistischer Kennwerte. Abschließend erfolgt eine Clusterbildung hinsichtlich der Fahrfertigkeitsniveaus der Fahrenden.

Magiera zieht hierfür gesamte Messdatensätze aus dem Straßenverkehr heran und keine repräsentative Kurve[11] wie in diesem Paper. Hierfür wird eine Methode zur Extraktion einzelner relevanter Manöver aus den Gesamtmessdaten entwickelt, konkret die der Kurvenfahrten. Diese Kurvenfahrten werden anschließend weiter unterteilt, in sogenannte „Manöverprimitive“. Abbildung 4 zeigt die definierten Primitive der Kurvenfahrt.

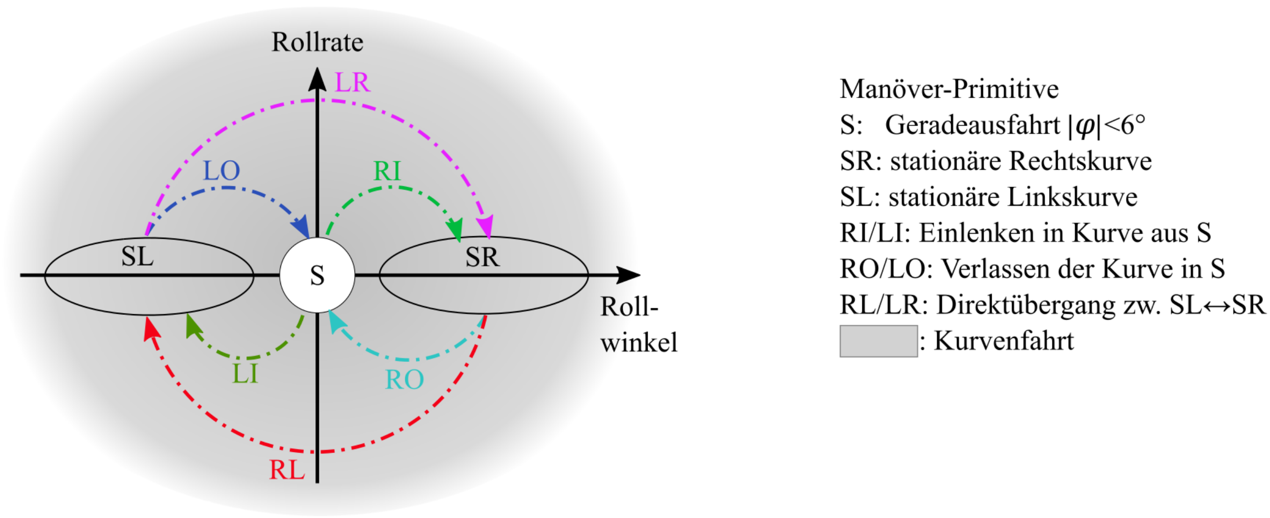

Abbildung 4 Manöverprimitive-Bestandteile der Kurvenfahrt[12]

Die Bezeichnung R oder L ergibt sich aus der Kurvenrichtung (rechts/links) und die Klassifizierung der Ein- bzw. Ausleitung durch die Abkürzung I bzw. O (in/out). Hierbei ist zu beachten, dass sich die in diesem Paper gewählte Nomenklatur von Magiera leicht unterscheidet.

Aus der Definition der Primitive ergeben sich Einschränkungen hinsichtlich deren Abfolge. Hier sei beispielhaft das LI/RI-Primitiv genannt, welches als einziges Primitiv auf die Geradeausfahrt (S) folgen kann. Zur Beurteilung der Fahrfertigkeiten werden die einzelnen Manöverprimitive betrachtet. Untersuchungsgegenstand sind hierbei sowohl die stationäre und instationäre Kurvenfahrt als auch die Linienwahl der Fahrer. Bei Untersuchung der Kurvenfahrten von geübten und ungeübten Fahrern sind Unterschiede im Rollwinkelverlauf und verstärkt in der Rollrate zu erkennen[13a]. Zur Quantifizierung entsprechender Zusammenhänge werden Kennwerte definiert. Anhand dieser erfolgt anschließend eine Betrachtung der unterschiedlichen Fahrendentypen bei stationärer Kurvenfahrt.

Die segmentierten Manöver werden hinsichtlich des Rollwinkels und der Rollrate untersucht. Der frequenzbasierte Kennwert im Zeitbereich des Rollwinkels wird gemäß Formel (1) [13b] definiert.

$$K_{\mathrm{RB,Freq},\varphi} = \sqrt{\int_0^{t_{\mathrm{seq}}} \breve{\varphi}_{\mathrm{BP}}(t)^2 dt} = \frac{1}{T_{\mathrm{Abtast}}} \sqrt{\sum_{i=1}^{N} \breve{\varphi}_{\mathrm{BP},i}{}^2} \qquad (1)$$

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[10] Magiera, N.: Diss., Identifikation Fahrfertigkeitsniveau v. Motorradfahrern.

[11] Hierzu zählt bspw. das mehrfache Durchfahren einer identischen Kurve, häufig auf abgesperrtem Gelände.

[12] Basten, T.: Math Prädiktion, S. 19 nach Magiera, N.: Diss., Identifikation Fahrfertigkeitsniveau, S. 9.

[13] Vgl. Magiera, N.: Diss., Identifikation Fahrfertigkeitsniveau v. Motorradfahrern, a: S. 71.; b: S.76

Hierbei steht $K_{\mathrm{RB,Freq,\varphi}}$ für den Kennwert *(K)* des Rollwinkels, welcher durch die Quadratur der bandpassgefilterten Messwerte[14] ($\breve{\varphi}_{BP}$), die anschließende Integration über die Sequenzdauer t_{seq} und dem Ziehen der Wurzel entsteht. Neben dem frequenzbasierten Kennwert definiert Magiera regressionsbasierte Kennwerte. Diese Kennwerte basieren auf einer Regression der Messdatenverläufe mit kubischen Splines. Formel (2)[15a] veranschaulicht die Definition der regressionsbasierten Kennwerte am Beispiel der Rollrate.

$$K_{\mathrm{RB,Reg,\dot{\varphi}}} = \sqrt{\int_0^{t_{\mathrm{seq}}} \left(\dot{\varphi}(t) - S_{\mathrm{RB,\dot{\varphi}}}(t)\right)^2 dt} \cong \frac{1}{T_{\mathrm{Abtast}}} \sqrt{\sum_{i=1}^{N} \left(\dot{\varphi}_i - S_{\mathrm{RB,\dot{\varphi}},i}\right)^2} \quad (2)$$

Hierbei steht $K_{\mathrm{RB,Reg,\dot{\varphi}}}$ für den regressionsbasierten Kennwert der Rollrate, welcher durch die Quadratur der Residuen zwischen dem Regressionsmodell $S_{\mathrm{RB,\dot{\varphi}}}$ und den Messwerten der Rollrate $\dot{\varphi}_i$ über die Sequenzdauer t_{seq} entsteht.

Für eine Vergleichbarkeit der Kennwerte von unterschiedlichen Fahrenden sind diese von nicht fahrendenspezifischen Einflüssen zu bereinigen. Zu diesen Einflüssen zählen bspw. die Kurvenlängen und Kurvenwinkel des jeweiligen Manövers. Die Bereinigung der Umgebungseinflüsse geschieht in zwei Schritten. Zunächst wird eine Korrektur der Kennwerte gemäß Formel (3)[15b] vorgenommen.

$$\begin{aligned} K_{\mathrm{RB},i,\mathrm{corr}} = {} & K_{\mathrm{RB},i} - c_{\mathrm{RB,corr,1},i} \cdot \varphi_{\max} - c_{\mathrm{RB,corr,2},i} \cdot \bar{\kappa} \ldots \\ & - c_{\mathrm{RB,corr,3},i} \cdot l_{\mathrm{Kurve}} - c_{\mathrm{RB,corr,4},i} \cdot \Delta\psi \end{aligned} \quad (3)$$

Hierbei ist $K_{\mathrm{RB},i,\mathrm{korr}}$ der korrigierte Kennwert und $K_{\mathrm{RB},i}$ der noch nicht von den Umgebungseinflüssen bereinigte Kennwert. Der Parameter $c_{\mathrm{RB,korr,1-4},i}$ stellt die mittels multivarianter Regression bestimmten Zusammenhänge der unkorrigierten Kennwerte mit den Umgebungseinflüssen dar. Die zu bereinigenden Einflüsse sind der maximale Rollwinkel $\varphi_{\max}$, die durchschnittliche Kurvenkrümmung $\bar{\kappa}$, die Kurvenlänge l_{Kurve} und die Gierwinkeldifferenz zwischen Kurveneingang und -ausgang der betrachteten Sequenz. Anschließend erfolgt eine Normierung der korrigierten Kennwerte mittels deren Standardabweichung gemäß Formel (4)[15b].

$$K_{\mathrm{RB},i,\mathrm{norm}} = \frac{K_{\mathrm{RB},i,\mathrm{corr}}}{c_{\mathrm{RB,corr,5},i}} \quad (4)$$

Eine Zuordnung der erkannten Unterschiede zu Clustern zeigt, dass die stationäre Kurvenfahrt in fünf unterschiedliche Fahrfertigkeitsniveaus einteilbar ist[16a]. Abbildung 5 zeigt das 50 % Perzentil der frequenz- und regressionsbasierten Werte über dem Median der Rollwinkelverteilung für die stationäre Kurvenfahrt. Die unterschiedlichen Stufen sind beim frequenzbasierten Kennwert (Abb. links) eindeutig erkennbar und abgrenzbar.

[14] Untere Grenzfrequenz: 0,7Hz; obere Grenzfrequenz: 2,2Hz.

[15] Magiera, N.: Diss., Identifikation Fahrfertigkeitsniveau v. Motorradfahrern, a: S. 80; b: S. 82.

[16] Vgl. Magiera, N.: Diss., Identifikation Fahrfertigkeitsniveau v. Motorradfahrern, a: S. 122; b: S. 137.

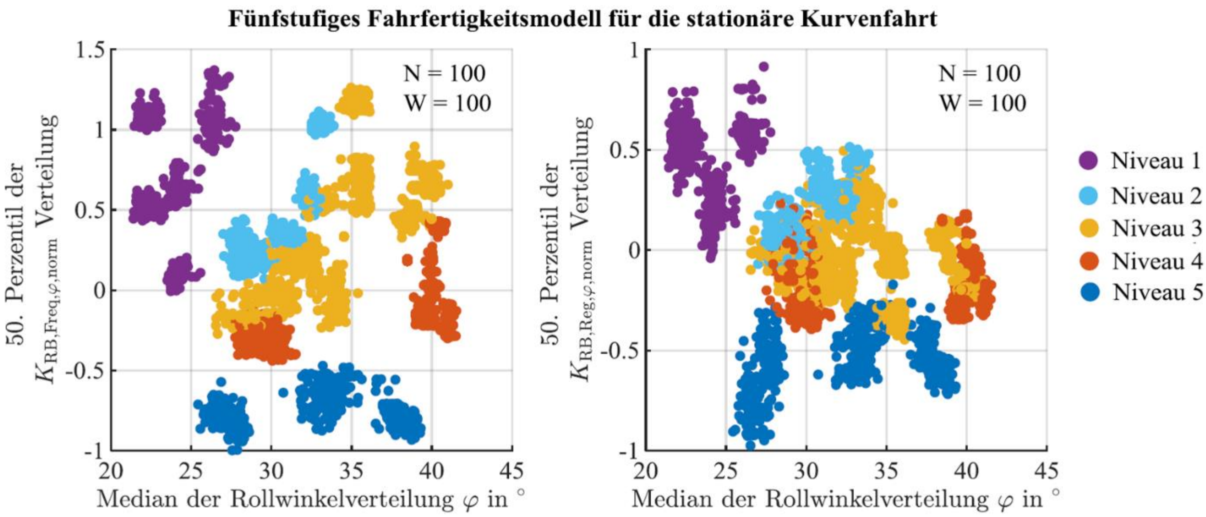

Abbildung 5: Fahrfertigkeitsmodell der stationären Kurvenfahrt[17a]

Auch die dynamische Kurvenfahrt ist hinsichtlich der Fertigkeitsniveaus in drei Stufen unterscheidbar. Bei der Linienwahl hingegen ist kein eindeutiger Trend hinsichtlich gewähltem Linienverlauf und Fertigkeitsniveaus feststellbar.

Magiera stellt fest, dass die Fahrfertigkeiten der Fahrenden am besten durch die stationäre Kurvenfahrt oder beim Einlenken in diese zu beurteilen sind. Bei Berücksichtigung der Kennwertverteilung in Kombination mit dem Rollwinkel sind drei bis fünfstufige Fahrfertigkeitslevel aufzeigbar. Eine Differenzierung ohne Berücksichtigung des Rollwinkels ist nicht möglich[16b]. Diese Erkenntnis deckt sich mit dem Ergebnis von Scherer et al[18]. Hier wird explizit der Rollwinkel als zentrale Untersuchungsgröße betrachtet.

Forschungshypothese

Aus dem Stand der Wissenschaft geht hervor, dass auch ohne eine umfangreiche Kenntnis systemspezifischer Größen eine Unterscheidbarkeit fahrendenspezifischer Einflüsse in Rollwinkel- und Rollratenverläufen möglich ist.

Aktuelle Forschungsergebnisse zeigen zudem, dass der Fahrendeneinfluss eine signifikante Einschränkung der theoretisch möglichen fahrdynamischen Grenzen darstellt. Es besteht die Möglichkeit Fahrende in unterschiedliche Fertigkeitsstufen einzuteilen. Im Einklang hiermit sind fahrendenspezifische Grenzwerte sowohl für den maximal erreichten Rollwinkel als auch für die maximale Rollrate beobachtbar.

Aus den beschriebenen Sachverhalten leitet sich folgende Fragestellung ab:

In wieweit besteht die Möglichkeit, anhand von erfassten fahrdynamischen Größen und unter Beachtung fahrendenspezifischer Einflüsse, den zukünftigen Fahrzeugzustand zu modellieren und prädizieren, ohne eine detaillierte Kenntnis fahrzeugfester Parameter vorauszusetzen?

[17] Magiera, N.: Diss., Identifikation Fahrfertigkeitsniveau v. Motorradfahrern, a: S. 123; b: -; c:127.
[18] Pless, R. et al.: Untersuchung der Existenz einer Schräglagenschwelle (2020).

3 Modellbildung

Die in diesem Paper vorgestellte Modellbildung wird in zwei Bereiche untergliedert. Zu Beginn wird untersucht, in welchen dynamischen Parametern eine Fahrendenspezifität erkennbar ist. Anschließend wird ein Ansatz zur Beschreibung dieser Größen entwickelt. Danach ein Ansatz zur Berechnung der Fahrspur aus den beschriebenen dynamischen Parametern entworfen.

Die Untersuchung und Beschreibung der Fahrendenindividualität wird anhand von Messdaten aus Fahrversuchen vorgenommen, welche im Rahmen der Studie „Schräglagenangst“[19] durchgeführt wurden. Messdaten aus dem Realverkehr werden zur Reduktion von Einflüssen durch nicht eindeutig bekannte Fahrbahnverläufe und Umgebungseinflüsse nicht genutzt. Insgesamt stehen vier Kurvenarten und 424 Kurvendurchfahrten von zehn unterschiedlichen Fahrenden zur Untersuchung zur Verfügung. Die zehn Probanden weisen unterschiedliche Fahrerfahrungen auf. Abbildung 6 zeigt eine Übersicht eines Rundkurses auf dem August Euler Flugplatz in Griesheim – nahe Darmstadt – mit den zur Untersuchung geeigneten Manövern. In diesem Paper wird stellvertretend für alle anderen möglichen Kurven ausschließlich die 180 ° Normbewertungskurve zur Modellbildung vorgestellt (Abbildung 6, oben rechts).

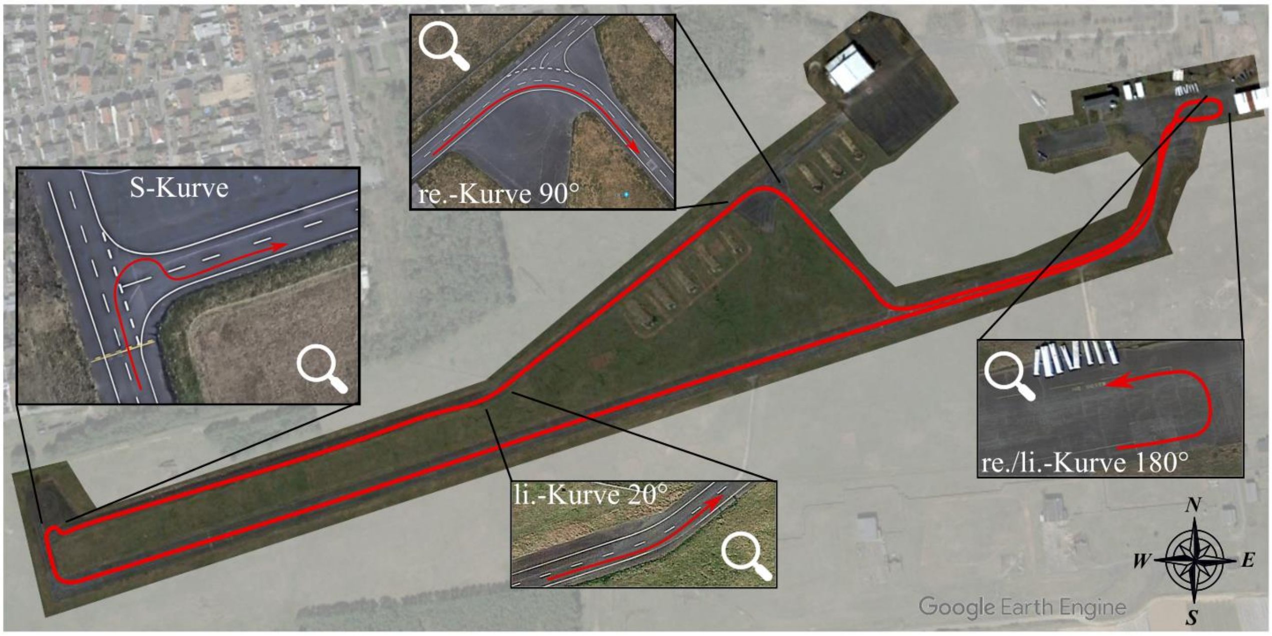

Abbildung 6: Untersuchungskurven Schräglagenangststudie[20a]

Der in diesem Paper vorgestellte Ansatz zur Schätzung fahrendenspezifischer Fahrdynamikdaten basiert auf einem probabilistischen Ansatz. Dies bedeutet, dass alle Fahrenden ein Manöver mehrfach durchfahren, wobei die Art und Weise der Manöverdurchfahrt variiert, jedoch fahrendenspezifische Charakteristika feststellbar sind. Für die Vergleichbarkeit einzelner Kurvendurchfahrten und für weitere statistische Berechnungen ist es hierbei notwendig, dass die Einzelmessschriebe identischer Kurven vergleichbar sind. Der Beginn und das Ende eines Manövers werden mittels Vorbeifahrt an definierten GPS-Punkten ermittelt. Diese liegen vor dem Kurvenbeginn und nach dem Kurvenende. Die Auswahl des Einzelmessschriebes der Gesamtkurve erfolgt somit ortsbasiert. Dieser Ansatz bietet sich für den Versuchsaufbau an, da die gefahrenen Manöver örtlich voneinander abgrenzbar sind und weiterhin eine genaue Kenntnis der Örtlichkeit vorliegt. Abbildung 7 verdeutlicht das Prinzip der Auswahl der Einzelmessschriebe anhand der 180°-Norm-Linkskurven eines beispielhaften Fahrers.

[19] Scherer, F. et al.: Schräglagenangst (2021)

[20] Basten, T.: Prädiktionsmodell (2021), a:S. 38 – Bildquelle: Google; b: S.40, c: S.41

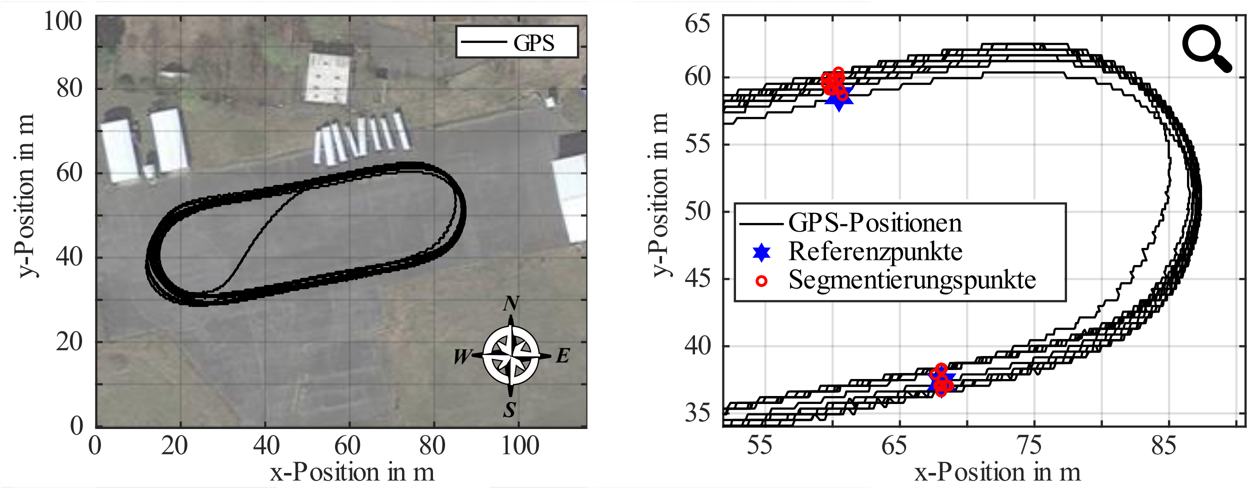

Abbildung 7: Ortsbasierte Extraktion der Manöver aus Gesamtmessschrieb[20b]

Die Positionswerte mehrerer Kurvendurchfahrten eines Fahrers weichen leicht voneinander ab, sodass die einzelnen Segmentierungspunkte keine identische Position besitzen. Weiterhin wird an dem eckigen GPS-Verlauf – hier sind die ungefilterten Rohdaten dargestellt – deutlich, dass die Positionsgenauigkeit sowohl durch die GPS-Genauigkeit als auch durch die Abtastzeit beeinflusst wird.

Messdatentransformation in den Kurvenfortschrittsbereich

Abbildung 8 zeigt fünf Rollwinkel- und Geschwindigkeitsverläufe eines Fahrers für ein identisches Manöver über der Zeit. Bedingt durch die unterschiedlich gefahrenen Geschwindigkeiten variiert die zeitliche Dauer der Kurvendurchfahrten für das identische Manöver. Hierdurch ist keine Vergleichbarkeit eines Manövers für mehrere Kurvendurchfahrten im Zeitbereich gegeben. Zur Herstellung der Vergleichbarkeit, zur Fahrendenbeschreibung und für die zukünftige Schätzung der dynamischen Parameter werden die dynamisch erfassten Daten bezüglich des relativen Streckenfortschrittes betrachtet. Die Betrachtung im Ortsbereich basiert auf der Grundannahme, dass die Gesamtlänge des Manövers annähernd[21] gleich bleibt, unabhängig wie viel Zeit ein Fahrer für das Manöver benötigt.

Die relative örtliche Betrachtung des Kurvenfortschritts erzeugt aus den äquidistanten Zeitschritten des Messschriebes den streckenbezogenen Kurvenfortschritt, dessen diskrete Schritte in der unabhängigen Variablen zunächst keine Äquidistanz mehr aufweisen. Da eine äquidistante Schrittweite der unabhängigen Variablen für die weitere Messdatenverarbeitung von Vorteil ist, erfolgt eine lineare Interpolation, sodass wieder eine Äquidistanz der diskreten Werte der unabhängigen Variable[22] vorliegt. Im Sinne der Handhabbarkeit und einer effizienten Messdatenweiterverarbeitung ist es zielführend, die Schrittweite der Diskretisierung des Kurvenfortschrittes so groß wie möglich und so gering wie nötig zu wählen.

[21] Die zurückgelegte Strecke in einem Manöver kann je Durchfahrt variieren, da die gefahrenen Trajektorien eines identischen Manövers sowohl fahrendenindividuell als auch fahrendenübergeifend variieren.

[22] Unabhängige Variable: relativer Streckenfortschritt.

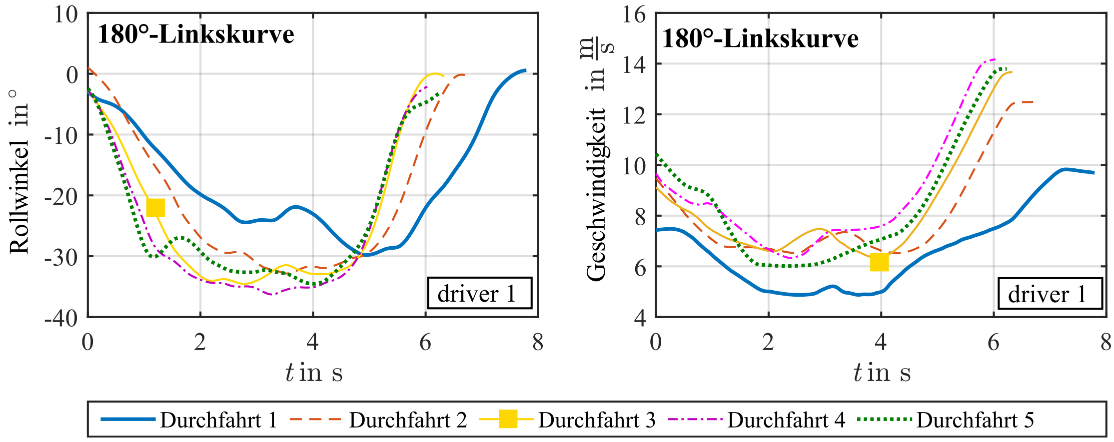

Abbildung 8: Zeitbereich vs. Kurvenfortschrittsbereich[20c]

Da mit der Wandlung aus dem Zeitbereich in den Kurvenfortschrittsbereich eine von der Geschwindigkeitsänderung abhängige Streckung bzw. Stauchung der Signale einhergeht, ist einer möglichen Frequenzerhöhung[23] durch die Transformation Rechnung zu tragen. Dies ist insbesondere bei der Festlegung der minimal notwendigen prozentualen Schrittweite im Kurvenfortschrittsbereich relevant.

Die Streckung bzw. Stauchung führt zu einer Frequenzveränderung des streckenbezogenen Signals gegenüber dem Zeitsignal. Formel (5) beschreibt die Transformation eines periodischen Signals aus dem Zeitbereich in den streckenfortschrittsbezogenen Bereich.

$$y(\check{s}) = e^{i\alpha \int_0^{s_{\text{ges}} \cdot \check{s}} \left(\frac{1}{v}\right) \cdot s_{\text{ges}} \cdot ds} \rightarrow \check{f} = \frac{\alpha}{2\pi} \cdot \int_0^{s_{\text{ges}} \cdot \check{s}} \left(\frac{1}{v}\right) ds \text{ mit } \check{s} = \frac{s}{s_{\text{ges}}} \tag{5}$$

Hierbei steht $\check{s}$ für den prozentualen Streckenfortschritt, α für die Kreisfrequenz des Ursprungssignals im Zeitbereich, v für die aktuelle Geschwindigkeit im Zeitbereich, s_{ges} für die Gesamtlänge des Manövers und $\check{f}$ für die Frequenz des Signals y im Kurvenfortschrittsbereich. Da die Frequenz im Kurvenfortschrittsbereich abhängig von der veränderlichen Geschwindigkeit ist, wird im Sinne einer konservativen Abschätzung der ungünstigste auftretende Fall betrachtet. Dieser Fall liegt bei einer niedrigen Geschwindigkeit v, einer hohen Gesamtmanöverstrecke s_{ges} und einer hohen Frequenz des zu transformierenden Zeitsignals vor. Die notwendige Abtastfrequenz im Kurvenfortschrittsbereich, welche dem Reziprokwert der benötigten diskreten Auflösung des Kurvenfortschrittes entspricht, ergibt sich bei Berücksichtigung des Shannon'schen Theorems vereinfacht nach Formel (6).

$$\check{f}_{\text{abtast}} = \frac{1}{\check{T}_{\text{abtast}}} = 2 \cdot \check{f}_{\max} = 2 \cdot \frac{\alpha}{2\pi} \cdot \frac{s_{\text{ges}}}{v} \tag{6}$$

Unter der Annahme einer maximalen Regelfrequenz bei Fahrendeneingaben von 3 Hz im Zeitbereich, einer Mindestgeschwindigkeit von 4 m/s und einer Manöverlänge von 100 m ergibt sich eine notwendige Auflösung des Kurvenfortschrittssignals von circa 0,7 %. Für die vorliegenden Manöver wird eine Auflösung des kurvenfortschrittsbezogenen Signals von 0,5 % gewählt. Eine Erhöhung der Auflösung ist bei gleichzeitiger Erhöhung des Rechenaufwandes jederzeit möglich.

[23] Eine Verringerung der kleinsten Frequenzen ist hinsichtlich des Shannonschen Theorems unrelevant.

3.1 Fahrendenspezifität

Für eine fahrendenspezifische Beschreibung der Messdatenverläufe wird untersucht, ob eine Unterscheidbarkeit der Messdatenverläufe unterschiedlicher Probanden feststellbar ist. Diese Unterscheidbarkeit stellt die Basis für die weitere Untersuchung und mögliche fahrendenindividuelle Beschreibungen dar. Im Folgenden werden beispielhafte Messdatenverläufe von ausgewählten Fahrenden vorgestellt und diskutiert. Dies dient zur Identifikation erster Zusammenhänge und möglicher Unterscheidungsmerkmale bei der späteren Beschreibung der Fahrendenspezifität.

Abbildung 9 zeigt die gemessenen Rollwinkel-/ Geschwindigkeits- und Gierratenverläufe von drei unterschiedlichen Fahrenden bezogen auf den relativen Streckenfortschritt der 180°-Norm-Rechts-/ Linkskurven.

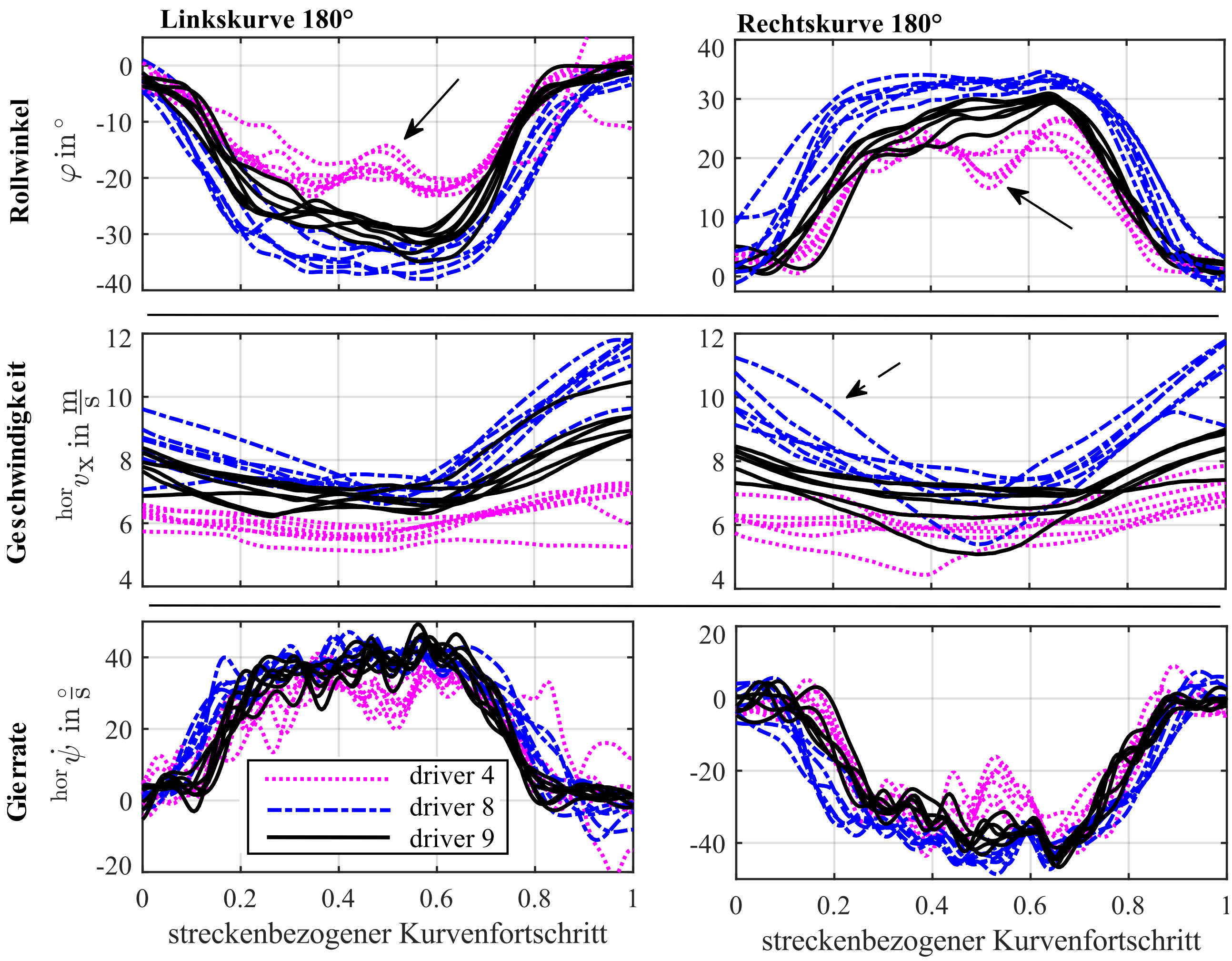

Abbildung 9: Übersicht- Links-/ Rechtskurven 180°[24a]

[24] Basten, T.: Prädiktionsmodell (2021), a:S. 44; b: S.45, c: S.46, d: S.47

Es sind Unterschiede zwischen den einzelnen Signalverläufen festzustellen. Neben den bereits bekannten Unterschieden hinsichtlich der erreichten Maximalwerte sind auch Differenzen in der Art und Ausprägung der Verläufe erkennbar. So zeigt Fahrer 4 im Rollwinkelverlauf während der Phase der stationären Kurvenfahrt bei mehreren Durchläufen ein ausgeprägtes korrigierendes Verhalten (s. Pfeil). Diese Korrektur tritt wiederholt in der Nähe des Kurvenscheitelpunktes auf und ist sowohl bei Links- wie Rechtskurven erkennbar. Die Rollwinkelverläufe von Fahrer 9 zeigen im stationären Kurvenabschnitt für beide Kurvenrichtungen eine betragsmäßig steigende Tendenz mit zunehmendem Kurvenfortschritt. Fahrer 8 hingegen zeigt im Gegensatz zu Fahrer 4 bzw. 9 weder ausgeprägte Rollwinkelkorrekturen noch Rollwinkeltendenzen während der stationären Phase.

Auch die Geschwindigkeitsverläufe der einzelnen Fahrenden unterscheiden sich. Neben den absoluten Geschwindigkeitswerten, welche fahrdynamisch mit der Höhe der erreichten Rollwinkel während der stationären Kurvenfahrt korrelieren, lassen sich insbesondere zu Beginn der Kurve und am Kurvenende Unterschiede zwischen den Fahrern feststellen. Besonders auffällig ist hierbei Fahrer 8, welcher in den Rechtskurven bis zum Kurvenmittelpunkt verzögert (s. gestrichelter Pfeil) und anschließend die Geschwindigkeit wieder erhöht. Dieses „in die Kurve hineinbremsende" -Verhalten ist bei Fahrer 4 nicht feststellbar. Dieser fährt ein nahezu konstantes Geschwindigkeitsprofil über den gesamten Kurvenverlauf.

Die horizontierten Gierratenverläufe der Fahrer weisen ebenfalls Unterschiede auf. Die Gierratenschwingungen treten, verglichen zu den Schwingungen der Rollwinkel- und Geschwindigkeitssignale, höherfrequenter auf. Dies ist auf mehrere Ursachen zurückzuführen. Einerseits spiegeln sich in den Drehraten, aufgrund der systemimmanenten Instabilität des Motorrades, permanente Regel- und Steuereingaben der Fahrenden wider. Andererseits ist zu berücksichtigen, dass ein Motorrad, verglichen mit einem Zweispurfahrzeug, durch den zusätzlichen Freiheitsgrad[25] des Rollwinkels tendenziell eine höhere Volatilität der horizontierten Gierrate aufweist.

Wird neben dem Rollwinkel auch die Rollrate betrachtet, lässt sich aus diesen Größen ein Phasendiagramm aufstellen. Bei Darstellung mehrerer Kurvendurchfahrten eines Fahrers im Phasendiagramm, besteht die Möglichkeit sog. Vertrauensellipsen zu bilden. Diese Ellipsen repräsentieren die Streuung der gegeneinander aufgetragenen Parameter bei Betrachtung mehrerer Kurvendurchfahrten. Abbildung 10 verdeutlicht die einzelnen Bestandteile und die Bedeutung der Ellipsen.

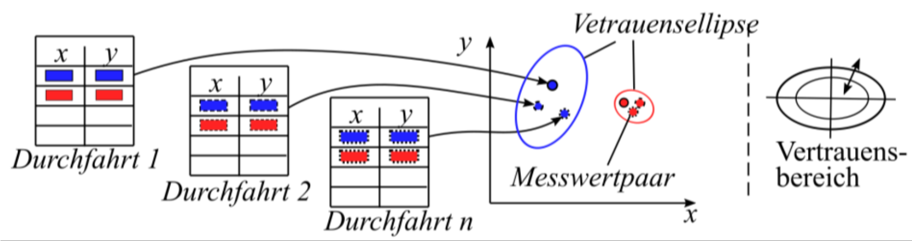

Abbildung 10: Bedeutung der Vertrauensellipsen[24b]

Zunächst werden die Messwertpaare (im Falle des Phasendiagramms Rollrate und Rollwinkel) mehrerer Kurvendurchfahrten bei gleichem relativen Streckenfortschritt im Diagramm dargestellt. Dies ist in Abbildung 10 links zu sehen. Aus der Streuung der Messwertpaare und dem gewählten Vertrauensbereich resultieren die Seitenlängen der Ellipse und somit deren Größe. Die Orientierung der Ellipse ergibt sich aus den Steigungen der Eigenvektoren des größten Eigenwertes der Kovarianzmatrizen der gegeneinander aufgetragenen Variablen. Daher veranschaulicht die

[25] Unter Vernachlässigung der Wankbewegung des Zweispurfahrzeuges.

Orientierung der Ellipse eine Korrelation bzgl. der Streuung der aufgetragenen *x*- und *y*-Wertepaare (s. Abbildung 10 rechts). Dieses Vorgehen wird für jeden diskreten Wert des relativen Streckenfortschrittes wiederholt.

Abbildung 11 zeigt das Phasendiagramm aller 180°- Rechts-/Linkskurven für Fahrer 4 und Fahrer 8 mit den entsprechenden Vertrauensellipsen. Ein Zeitbezug bzw. Kurvenfortschrittsbezug ist aus dem Phasendiagramm nicht mehr direkt ersichtlich.

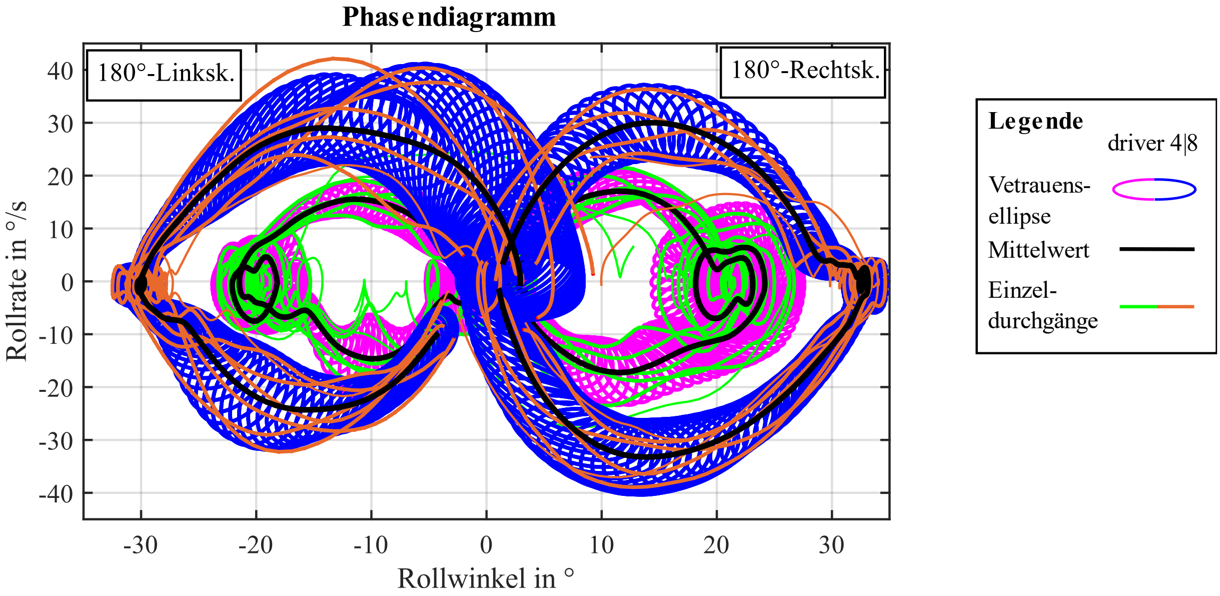

Abbildung 11: Phasendiagramm von Rollwinkel/-rate der 180°-Kurve[24c]

Auf der Abszisse ist der gemessene Rollwinkel und auf der Ordinate die erfasste Rollrate aufgetragen. Die Streuung der Messwerte und die daraus resultierenden Ellipsen ergeben sich bei dieser Betrachtungsweise nicht aus einer Messungenauigkeit, sondern stellen vielmehr die Reproduzierbarkeit dar, mit welcher ein Fahrer in der Lage ist, ein identisches Manöver wiederholt zu fahren. Das gewählte Vertrauensintervall entspricht 63 % (Standardabweichung). Aufgrund der geringen Messgrößenanzahl wird das Vertrauensintervall für die Student-t-Verteilung zugrunde gelegt[26]. Das Phasendiagramm verdeutlicht die bereits in Abbildung 9 dargestellten Unterschiede in den Rollwinkelverläufen zwischen Fahrer 4 und Fahrer 8. Zusätzlich veranschaulicht es die Unterschiede in den erfassten Rollraten.

Es zeigt sich, dass Fahrer 8 bei den Kurvenausleitungen der Linkskurve bzgl. der Rollrate stärker variiert verglichen mit den Kurvenausleitungen der Rechtskurve. Dies äußert sich in den größeren Vertrauensellipsen. Weiterhin ist ersichtlich, dass sich die erreichten maximalen Rollwinkel/ -raten zwischen Fahrer 4 und Fahrer 8 unterscheiden. Außerdem zeigen sich fahrerspezifische Charakteristika in der Art des Verlaufes der Phasendiagramme. Abbildung 12 zeigt eine Vergrößerung der relevanten Bereiche.

Die Korrekturamplituden des Rollwinkelverlaufes von Fahrer 4 äußern sich in Form von Schleifen im Phasendiagramm. Weiterhin zeigt sich, dass die Korrekturamplituden von Fahrer 8 im Vergleich zu Fahrer 4 geringer ausfallen. Außerdem ist zu beobachten, dass sich nicht nur die Fahrer untereinander unterscheiden, sondern auch Unterschiede abhängig von der Kurvenrichtung bei dem gleichen Fahrer vorliegen. So erreicht Fahrer 4 in den Rechtskurven einen betragsmäßig höheren Rollwinkel als in den Linkskurven, allerdings zeigen sich in den Rechtskurven gleichzeitig größere Korrekturamplituden im Rollwinkelverlauf. Bei Fahrer 8 ist keine kurvenrichtungsabhängige Rollwinkelkorrektur feststellbar, allerdings sind die betragsmäßig erreichten Rollwinkel von Fahrer 8 in den Rechtskurven ebenfalls größer als die in den Linkskurven.

[26] Student (1908): The Probable Error of a Mean

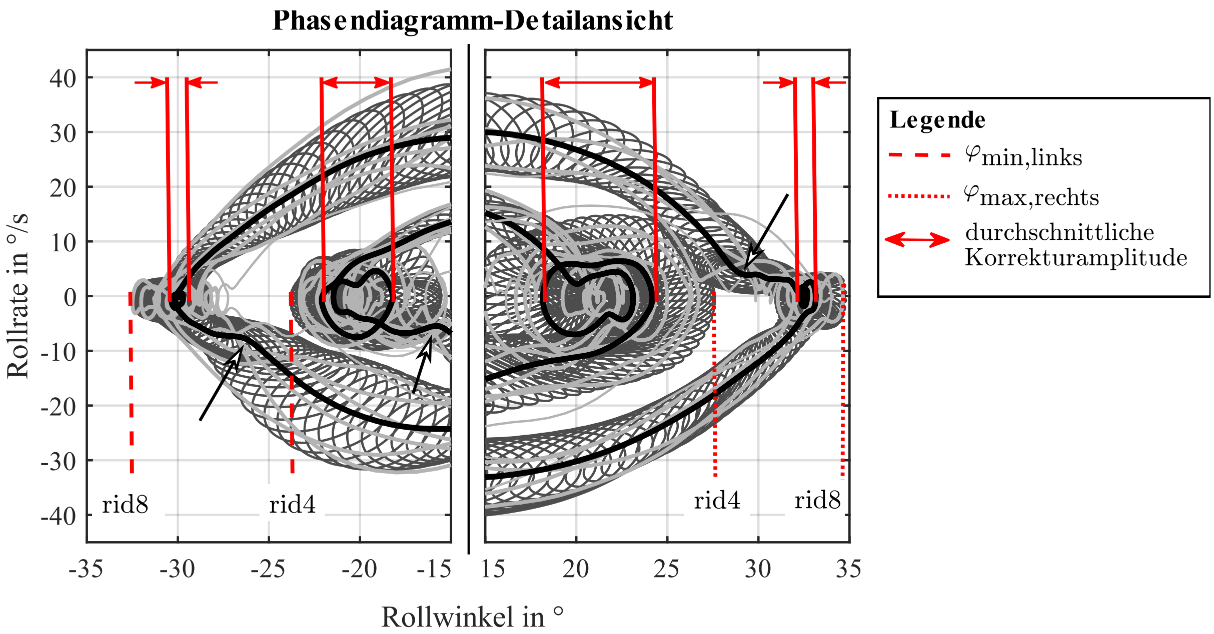

Abbildung 12: Phasendiagramm von Rollwinkel/-rate der 180°-Kurve -Detailansicht[24d]

Dieses Verhalten ist insgesamt bei sechs von zehn Fahrern der Studie beobachtbar. Beim Vergleich von Kurvenein- und Kurvenausleitung fällt auf, dass die Verläufe der Kurvenausleitung von Fahrer 4 und 8 im Phasendiagramm glatter und ellipsenförmiger verlaufen, während die Kurveneinleitung teilweise von Knicken im Phasendiagramm gekennzeichnet ist (s. Pfeil). Dies lässt sich darauf zurückführen, dass die betragsmäßige Rollwinkelverkleinerung am Kurvenausgang hauptsächlich durch eine Erhöhung der Fahrzeuggeschwindigkeit und daraus resultierend eine Zunahme der Fliehkraft erreicht wird. Das Einrollen des Fahrzeuges aus der Geradeausfahrt hingegen ist nicht nur durch die Reduktion der Geschwindigkeit möglich. Somit erfordert das Einrollen des Fahrzeuges umfangreichere Steuereingaben des Fahrers.

3.2 Mathematische Beschreibung der Fahrendenmodellparameter

Zur Modellierung der Fahrendenspezifität werden mathematische Ansatzfunktionen mit interpretierbaren Parametern vorgestellt. Voraussetzung hierfür sind durch eine Transformation in den Kurvenfortschrittsbereich vergleichbar gemachte und segmentierte Datensätze Sowohl die Schwankungsbreite als auch der Wertebereich unterscheiden sich zwischen den Fahrenden. Abbildung 13 stellt die im Folgenden häufig genutzten Bezeichnungen dar.

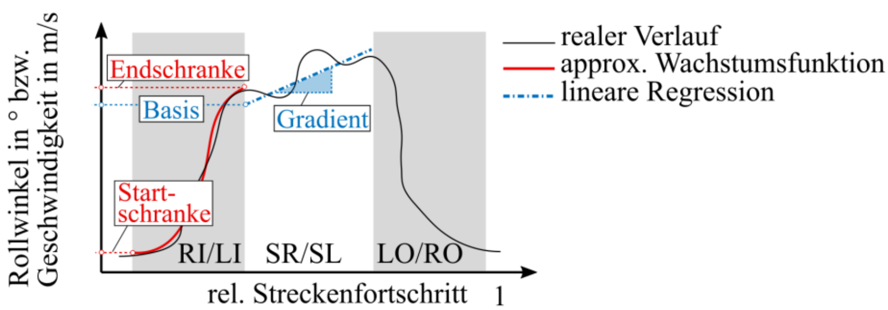

Abbildung 13: Parameterinterpretation[27a]

Zentrale Betrachtungsgrößen sind die Start- und Endschranken der Wachstumsfunktionen, die Basis- und Gradientenwerte der linearen Regression (stationäres Primitiv) und die überlagerten

Schwingungen. Zur besseren Übersichtlichkeit sind die überlagerten Schwingungen und die Approximation der Kurvenausleitung in Abbildung 13 nicht dargestellt.

Zur Unterscheidung der Koeffizienten der nachfolgenden Ansatzfunktionen und zur Verdeutlichung der jeweils betrachteten Größe, wird die Nomenklatur gemäß Formel (7) verwendet.

$$ {}^{i_1}_{i_2}k_{i_3} \tag{7} $$

Hierbei steht *k* für den Koeffizienten der Ansatzfunktion. Der Index i_1 verdeutlicht die approximierte Messgröße (Rollwinkel/ Geschwindigkeit) und der Index i_2 beinhaltet die Information über das betrachtete Primitiv. Sofern mehrere Ausprägungen des Koeffizienten existieren wird dies durch den Index i_3 verdeutlicht. Tabelle 1 gibt einen Überblick über die Bedeutung der Indizes.

Tabelle 1: Nomenklatur/ Indizierung d. Koeffizienten der Ansatzfunktion

Variable			**Bedeutung**
k	Koeffizient der Ansatzfunktion	vz	Richtung der Wachstumsfunktion
		b	Exponentenkoeffizient der Wachstumsfunktion
		$s_s = vz(a+d)$	Startschranke der Wachstumsfunktion
		$s_e = vz(c+d)$	Endschranke der Wachstumsfunktion
		$base$	Basis der linearen Regression
		g	Steigung der linearen Regression
		$\tilde{a}$	Amplitude überlagerte Schwingung
		$\tilde{f}$	Frequenz überlagerte Schwingung
		$\tilde{l}$	Phasenverschiebung überlagerte Schwingung
Index			**Bedeutung**
i_1	Approximiertes Signal	roll	Rollwinkelsignal
		vel	Geschwindigkeitssignal
i_2	Betrachtetes Primitiv	LI/RI	Kurveneinleitung (Links-/Rechtskurve)
		LO/RO	Kurvenausleitung (Links-/Rechtskurve)
		LR/RL	Richtungswechsel S-Kurve
		SL/SR	Stationäre Kurvenfahrt (Links-/ Rechtskurve)
i_3	Ausprägung	1	Erste überlagerte Schwingung
		2	Zweite überlagerte Schwingung
		s	Start(-schranke)
		e	End(-schranke)

Während der Kurveneinleitung wird der Rollwinkel von einem niedrigeren Niveau auf ein höheres Niveau vergrößert. Aufgrund des begrenztes Wachstums mit Erreichen eines Sättigungswertes wird als Ansatz eine logistische Wachstumsfunktion gewählt, die je nach Kurvenrichtung das Vorzeichen wechselt

$$ f(x) = vz \cdot \left(\frac{a \cdot c \cdot e^{b \cdot x}}{c + a \cdot (e^{b \cdot x} - 1)} + d \right) + \tilde{a} \cdot \sin\left(2\pi \cdot \tilde{f} \cdot (x + \tilde{l})\right) \tag{8} $$

Die Konstanten *a*, *b* und *c* definieren die grundformbeeinflussenden Parameter der logistischen Wachstumsfunktion. Da Wachstumsfunktionen keinen Offset in den Lösungsdaten abbilden können, wird zusätzlich das Konstantglied *d* definiert, welches eine vertikale Verschiebung der Funktion bewirkt. Abbildung 14 verdeutlicht den Einfluss der einzelnen Parameter der gewählten Ansatzfunktion.

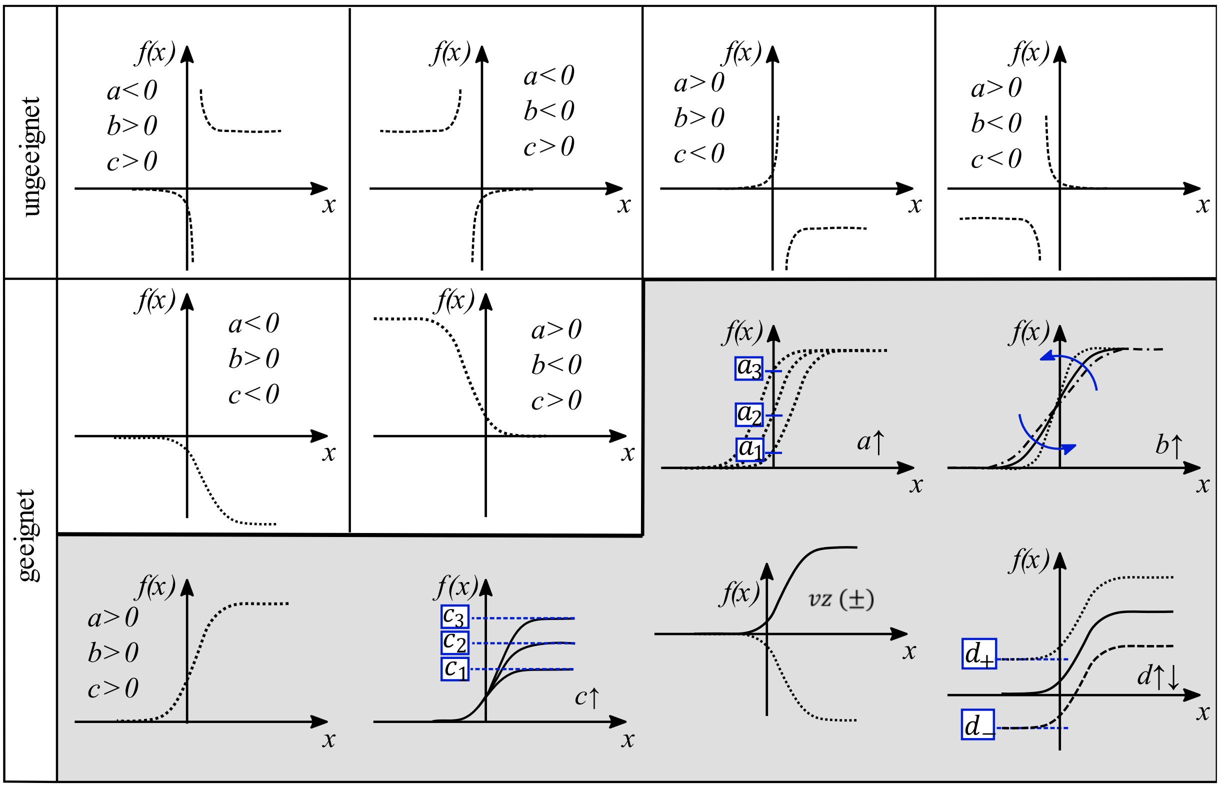

Abbildung 14: Parametervariation der logistischen Wachstumsfunktion[27b]

Es zeigt sich, dass nicht alle Parametervariationen einen Funktionsverlauf hervorrufen, welcher in der Grundform dem Rollwinkelverlauf im LI/RI-Primitiv entspricht. Sowohl zur besseren Interpretierbarkeit als auch zur effizienteren Lösungsfindung wird der Lösungsbereich der Parameter *a, b* und *c* auf positive Werte beschränkt. Zur Abbildung von Linkskurven wird ein zusätzlicher Parameter in Form des Vorzeichens *vz* definiert, welcher eine achsensymmetrische Spiegelung um die Abszisse bewirkt (s. Abbildung 14).

Kurveneinleitung

Da insbesondere bei der Kurveneinleitung teilweise ein Hineintasten in die Kurve in den Messdatenverläufen zu beobachten ist, wird die logistische Wachstumsfunktion durch eine Sinusschwingung überlagert. Je ausgeprägter diese Schwingung auftritt, desto stärker weicht der reale Messdatenverlauf von der symmetrischen Funktion ab. Formel (8) zeigt die gesamte mathematische Beschreibung für das Manöverprimitiv.

Die Parameter $\tilde{a}$, $\tilde{f}$ und $\tilde{l}$ stehen hierbei für die Amplitude, Frequenz und die Phasenverschiebung der logistischen Wachstumsfunktion überlagerten Schwingung.[27]

Abbildung 15 links zeigt die Schranken der logistischen Wachstumsfunktion der Rollwinkelverläufe des LI/RI-Primitives (${}^{\mathrm{roll}}_{\mathrm{LI}}s$) für die 180°- Linkskurven für alle Fahrer. Rechts in Abbildung 15 sind zusätzlich die Basiswerte der Regression (${}^{\mathrm{roll}}_{\mathrm{SL}}base$) des stationären Primitives von Fahrer 4 und 10 dargestellt.

[27] Basten, T.: Prädiktionsmodell (2021), a:S. 65; b: S.56, c: S. 70, d: S.71

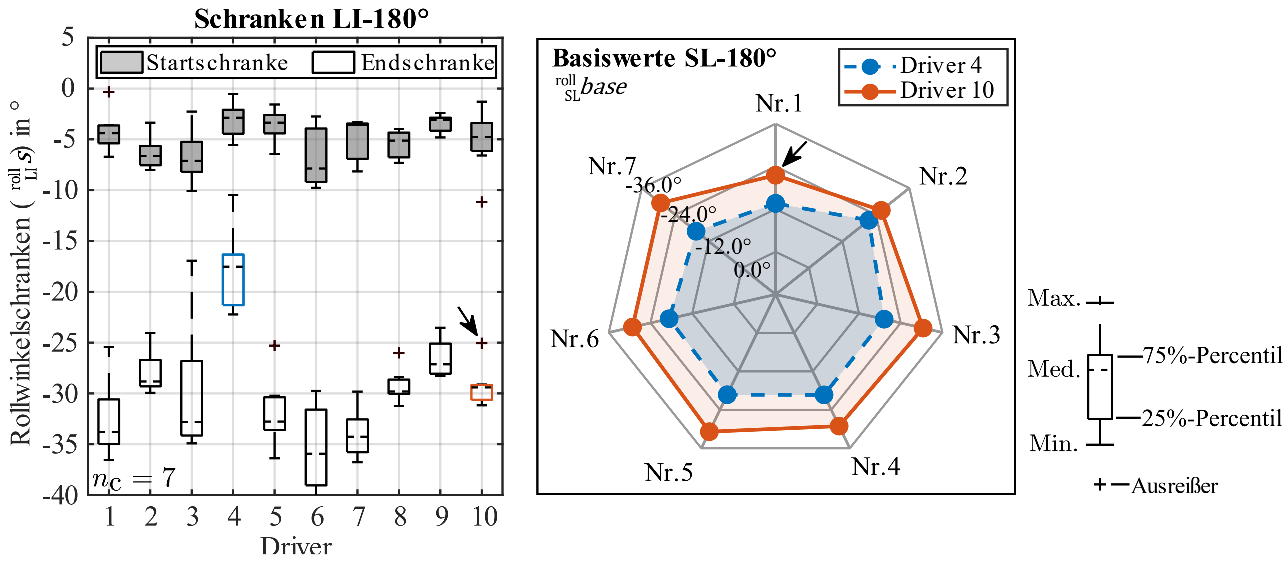

Abbildung 15: Rollwinkelschranken; 180°-Kurve; LI/RI-Primitiv[27c]

Die Startschranke (grau) bezeichnet hierbei den Schnittpunkt der Wachstumsfunktion mit der Ordinate und die Endschranke (weiß) den Unendlichkeitswert der Wachstumsfunktion (s. Tabelle 1). Es zeigen sich eindeutige Unterschiede der Start- als auch der Endschranken für das LI-Manöverprimitiv zwischen den einzelnen Fahrern. Die Endschranken des Primitivs korrelieren hierbei mit den Basiswerten des SL-Primitives. Anhand von Fahrer 4 und 10 zeigt sich diese Korrelation deutlich. Rechts im Bild sind die Netzplots der Basiswerte des SL-Primitives für Fahrer 4 und 10 dargestellt.

Neben den Schrankenwerten ist der Exponentenkoeffizient von besonderem Interesse, da dieser maßgeblich die Form der S-Funktion beeinflusst. In Abbildung 16 links und mittig sind die Exponentenkoeffizienten des Rollwinkels der Kurveneinleitung (${}^{\mathrm{roll}}_{\mathrm{LI}}b$) der 180°-Linkskurve der Fahrer 1, 4 und 8 dargestellt

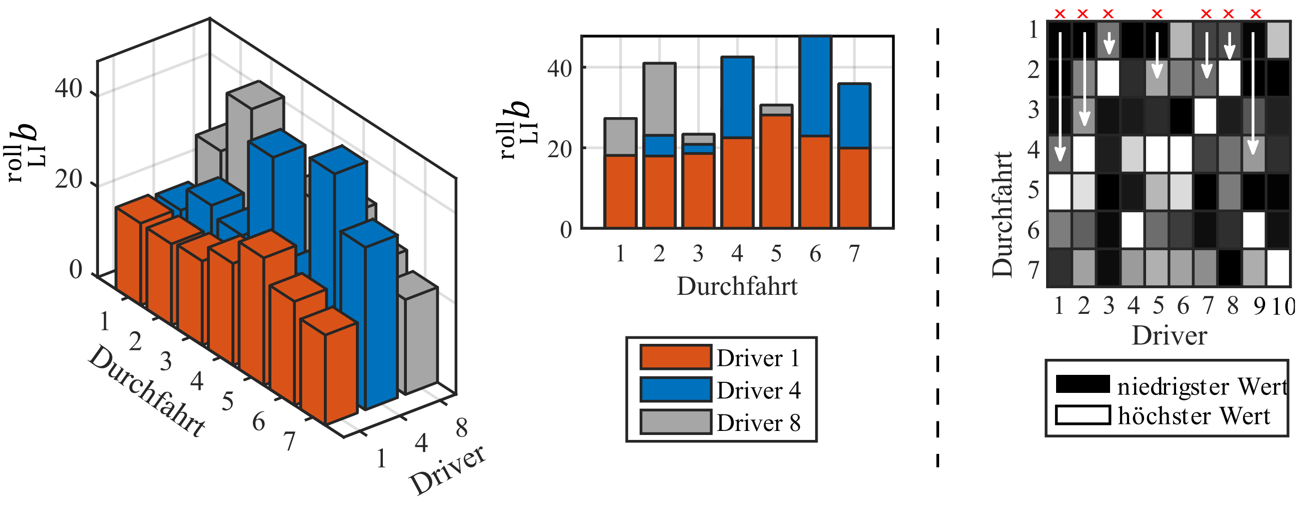

Abbildung 16: Rollwinkel-Exponentenkoeffizient 180°-Kurve; LI/RI-Primitiv-Detailansicht[27d]

Die Höhe der Exponentenkoeffizienten variiert fahrerspezifisch. Eine fahrerspezifische Abgrenzung ist für die vorliegende Linkskurve nicht möglich, da die Parameter durchfahrtsabhängig schwanken. In der Mitte von Abbildung 16 verdeutlicht sich, dass die Koeffizienten der Fahrer 1, 4 und 8 in der ersten Durchfahrt nicht den Maximalwert bzgl. aller Durchfahrten besitzen, sondern sich diesem mit zunehmender Anzahl an Durchfahrten annähern. In Abbildung 16 rechts sind die fahrerweise normierten Exponentkoeffizienten dargestellt. Die Normierung erfolgt anhand des höchsten Parameterwertes von allen Durchfahrten des jeweiligen Fahrers (weiß). Bei Betrachtung aller Fahrer (s. Abbildung 16 rechts) ist der beschriebene Effekt, des sich steigernden Exponentenkoeffizienten mit zunehmender Anzahl der Durchfahrten, bei sieben von zehn Fahrern zu beobachten (s. Pfeil). Bei den Rechtskurven ist ein entsprechender Effekt nicht zu erkennen.

Werden die Exponentenkoeffizienten der Fahrer des LI/RI-Primitives bzgl. der Kurvenrichtung miteinander verglichen, zeigen sich Unterschiede sowohl hinsichtlich der Parameterstreuung als auch der Höhe der Koeffizienten. Abbildung 17 zeigt die Exponentenkoeffizienten des Rollwinkelverlaufs des LI/RI- Primitives für die 180°-Rechts- und Linkskurven für alle zehn Fahrer.

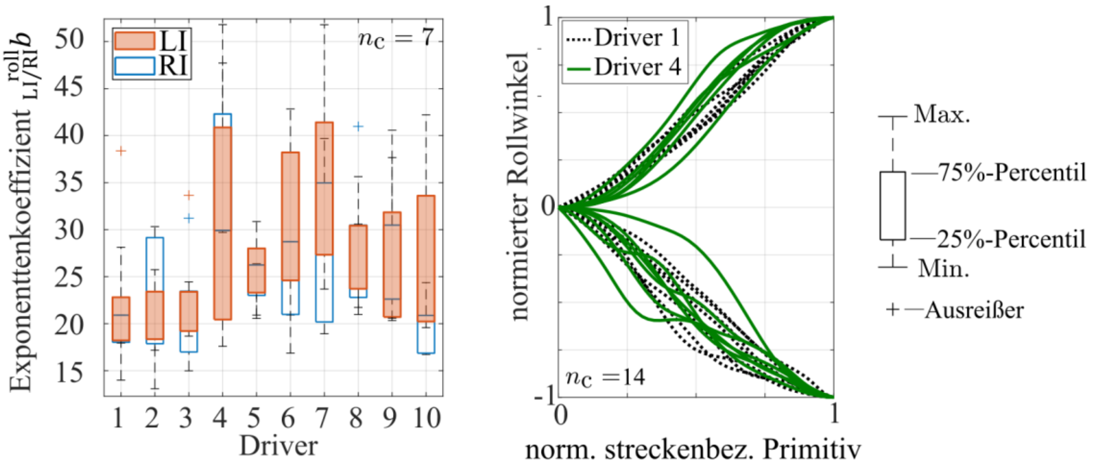

Abbildung 17: Rollwinkel-Exponentenkoeffizient 180°-Kurve; LI/RI-Primitiv-Übersicht[28a]

Rechts in der Abbildung sind die offsetbereinigten, normierten Rollwinkelverläufe über dem normierten streckenbezogenen Manöverprimitiv dargestellt. Am Beispiel von Fahrer 1 und 4 verdeutlicht sich, dass die Höhe der Exponentenkoeffizienten (s. Abbildung 17 links) mit der Form der Messdatenverläufe korreliert. So ist die Grundform der Rollwinkelverläufe von Fahrer 4 s-förmiger (${}^{\mathrm{roll}}_{\mathrm{LI/RI}}b$ hoch), während der Rollwinkelaufbau bei Fahrer 1 linearer erfolgt (${}^{\mathrm{roll}}_{\mathrm{LI/RI}}b$ niedrig). Es ist zu beachten, dass lediglich die Form der Verläufe miteinander verglichen wird. Aussagen über Absolutwerte sind in dieser Betrachtung nicht möglich. Weiterhin ist zu berücksichtigen, dass auch die übrigen Koeffizienten der Wachstumsfunktion die Steigung beeinflussen

Die Kurvenausleitung ist komplementär zur Kurveneinleitung. Daher wird für das LO/RO-Primitiv der identische Ansatz wie für das LI/RI-Primitiv gewählt.

Stationärphase

Der stationäre Teil der Kurvenfahrt weist häufig einen Trend des Rollwinkelsignals auf. Dieser Trend äußert sich in einer Zu-/ Abnahme des Rollwinkels. Zur Abbildung dieses Trends wird eine lineare Regression verwendet. Neben dem Trend sind insbesondere bei langen stationären Kurvenfahrten teils ausgeprägte Korrekturschwingungen festzustellen. Um diese zu berücksichtigen wird das Polynom ersten Grades mit zwei Sinusschwingungen überlagert. Diese repräsentieren die auftretenden Schwingungen. Formel (9) zeigt den Ansatz der gewählten mathematischen Approximation.

$$f(x) = base + g \cdot x + \tilde{a}_1 \cdot \sin\left(2\pi \cdot \tilde{f}_1 \cdot \left(x + \tilde{l}_1\right)\right) + \tilde{a}_2 \cdot \sin\left(2\pi \cdot \tilde{f}_2 \cdot \left(x + \tilde{l}_2\right)\right) \quad (9)$$

Allgemein gilt, dass mit zunehmender Aperiodizität des abzubildenden Signals die Exaktheit der Beschreibung mit einfachen mathematischen, interpretierbaren Funktionen abnimmt. Im Sinne der Nachvollziehbarkeit bzw. Interpretierbarkeit wurde sich dazu entschieden, keine weiteren Schwingungsterme zu überlagern. Abbildung 18 zeigt zwei beispielhafte Approximationen des SL/SR-Primitives zweier Fahrer.

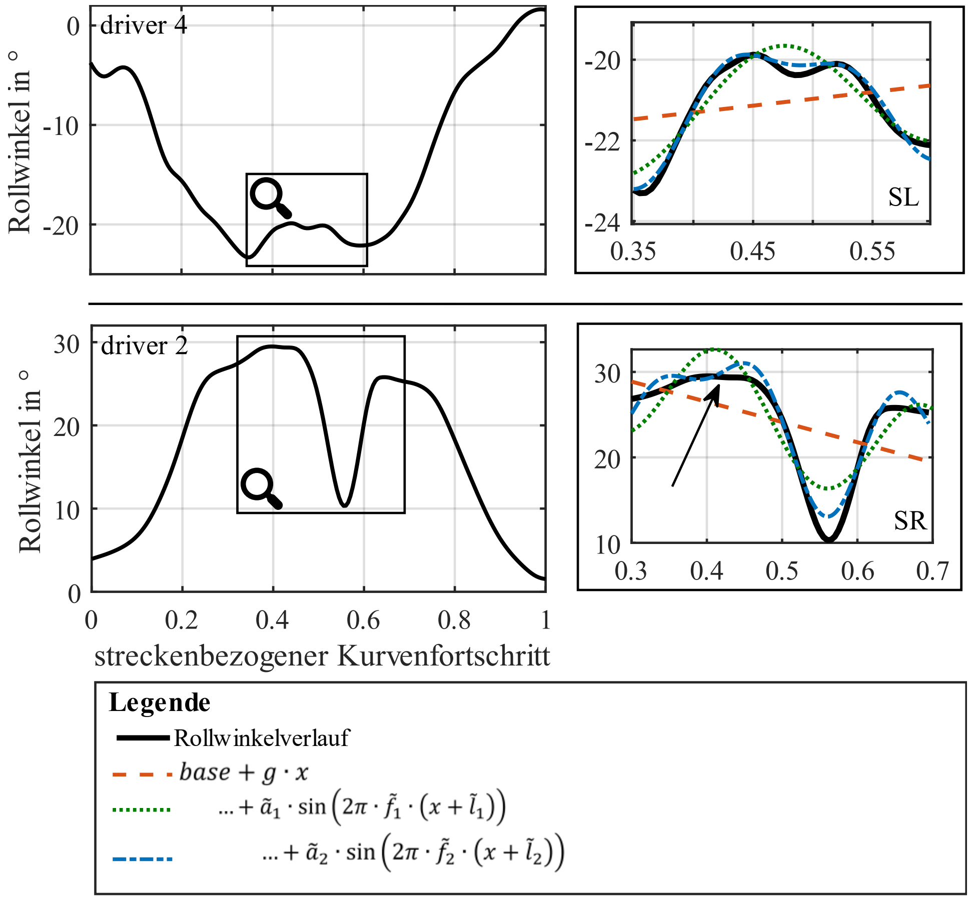

Abbildung 18: Approximation von Aperiodizitäten im stationären Primitiv[28b]

Der Messdatenverlauf ist für Fahrer 4 durch zwei überlagerte Schwingungen qualitativ passend approximierbar. Fahrer 2 weist in der betrachteten Phase ebenfalls ein schwingendes Verhalten des Rollwinkels auf, allerdings zeigen sich im betrachteten Abschnitt am Anfang und Ende unterschiedliche Frequenzen (s. Pfeil). Mit zwei überlagerten Schwingungen der linearen Regression ist der Grundverlauf von Fahrer 2 abbildbar, jedoch zeigen sich im Vergleich zu Fahrer 4 stärkere Abweichungen zwischen approximiertem und gemessenem Verlauf.

Abbildung 19 zeigt die Netzdiagramme der Rollwinkelgradienten des Primitives SL/SR (${}_{\mathrm{SL/SR}}^{\mathrm{roll}}g$) von drei Fahrern. In der Abbildung oben links sind zusätzlich die Rollwinkelverläufe dargestellt.

[28] Basten, T.: Prädiktionsmodell (2021), a: S.72, b:S. 58; c: 66, d: S.67, e: S. 68

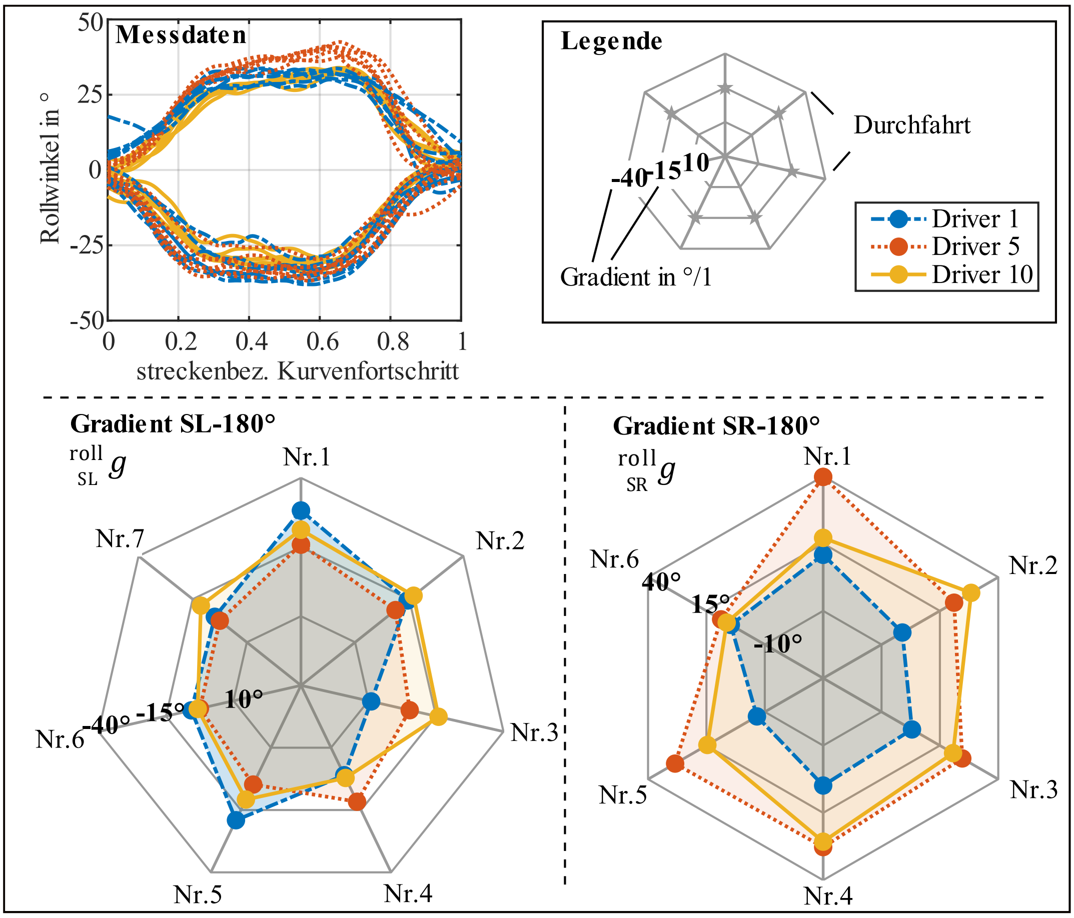

Abbildung 19: Rollwinkelgradient; 180° Kurve; SL/SR-Primitiv[28c]

Die Netzdiagramme ermöglichen es, die Entwicklung der Rollwinkelgradienten eines Fahrers mit zunehmender Durchfahrtsanzahl darzustellen und erlauben gleichzeitig eine relative Einordnung mit den übrigen Fahrern. Anhand der Diagramme zeigt sich, dass sich die Rollwinkelgradienten sowohl bzgl. der Fahrer als auch der Kurvenrichtung unterscheiden. Die Rollwinkelgradienten der Rechtskurven weisen hierbei, verglichen mit den Linkskurven, größere Unterschiede auf. Von den betrachteten Fahrern weist Fahrer 4 bei allen Rechtskurven die geringsten Gradienten auf, Fahrer 5 und 10 sind nicht in eine eindeutige Reihenfolge bzgl. der Gradientenwerte zu bringen. Insbesondere bei Fahrer 5 fallen die Absolutwerte der Gradienten in den Linkskurven geringer aus, verglichen mit den Rechtskurven. Eine Korrelation zwischen Durchfahrtsnummer und dem Gradientenwert ist nicht feststellbar. Der Vergleich der Gradienten mit den kurvenfortschrittsbezogenen Messdaten (Abbildung 19 oben links) bestätigt, dass die Gradienten den Trend der Rollwinkelentwicklung während der stationären Phase der Kurvenfahrt abbilden.

Einen weiteren Koeffizienten stellen die Basiswerte der linearen Regressionen dar. In Abbildung 20 sind die Basiswerte des SL/SR-Primitives des Rollwinkels (${}_{SL/SR}^{roll}base$) der 180°-Kurven für drei beispielhafte Fahrer dargestellt.

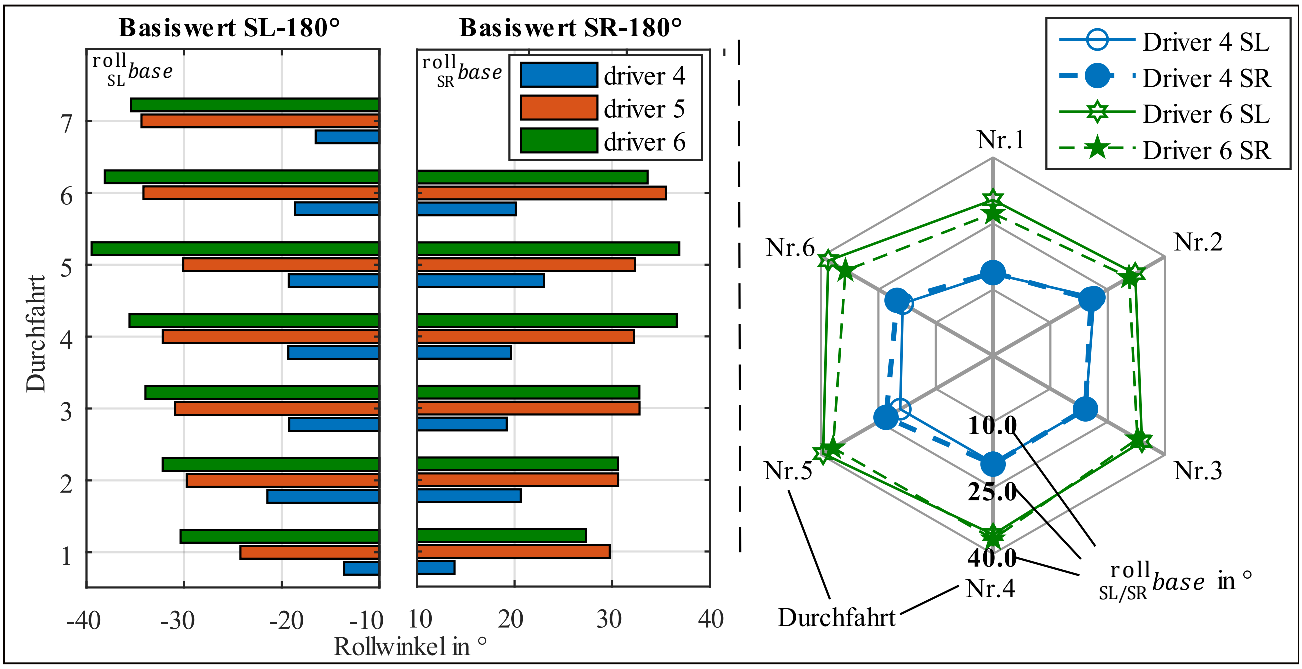

Abbildung 20: Rollwinkelbasiswert; 180° Kurve; SL/SR-Primitiv[28d]

Die Basiswerte weisen fahrerspezifische Unterschiede auf. Der Basisrollwinkel von Fahrer 4 liegt betragsmäßig, unabhängig von der Kurvenrichtung, unter den Werten der beiden anderen Fahrer. In Abbildung 20 links zeigt sich, dass die Basiswerte von Fahrer 5 und 6 mit steigenden Durchfahrten einen zunehmenden Trend aufweisen. Rechts in Abbildung 20 sind die Netzplots der betragsmäßigen Basiswerte von Fahrer 4 und 6 dargestellt. Die Werte von Fahrer 6 liegen in den Linkskurven, bis auf eine Ausnahme, über denen der Rechtskurven. Bei Fahrer 4 ist kein Muster zwischen den Basiswerten und der Kurvenrichtung erkennbar. Lediglich in der vorletzten Durchfahrt (Nr.5) unterscheiden sich die Basiswerte der Links- und Rechtskurve von Fahrer 4.

Im Folgenden werden die Parameter $\tilde{a}_1, \tilde{f}_1$ und $\tilde{l}_1$ der ersten überlagerten Schwingung der linearen Regression (Primitiv SL/SR) des Rollwinkelverlaufes der 180°-Rechts- und Linkskurven untersucht.
Abbildung 21 zeigt die Koeffizientenpaare aus Frequenz ($\tilde{f}_1$) und Amplitude ($\tilde{a}_1$) und deren 90 %-Vertrauensintervall für die Fahrer 4, 6 und 8.

Die Amplituden- und Streuungsbereiche von Fahrer 4 weisen kurvenrichtungsabhängige Unterschiede auf. Weiterhin treten bei der Rechtskurve zwei auffällig hohe Amplituden auf (s. Pfeil). Diese sind auch in den realen Messdaten erkennbar (s. Abbildung 21 oben rechts). Die Schwingungsparameter von Fahrer 6 weisen in der Rechtskurve im Vergleich zur Linkskurve einen größeren Streuungsbereich auf. Fahrer 8 besitzt von den dargestellten Fahrern die geringsten Amplituden, unabhängig von der Kurvenrichtung. Da dieser Fahrer die längste Fahrerfahrung aller Probanden aufweist wird davon ausgegangen, dass sich die Erfahrung und das Können in kleinen Korrekturamplituden bei gleichzeitig hohen Korrekturfrequenzen widerspiegeln.

Auf eine detaillierte Vorstellung der Parametrierung des Geschwindigkeitssignals wird im Rahmen dieses Papers verzichtet. Hierfür werden dieselben Ansatzfunktionen mit anderen Randbedingungen genutzt.

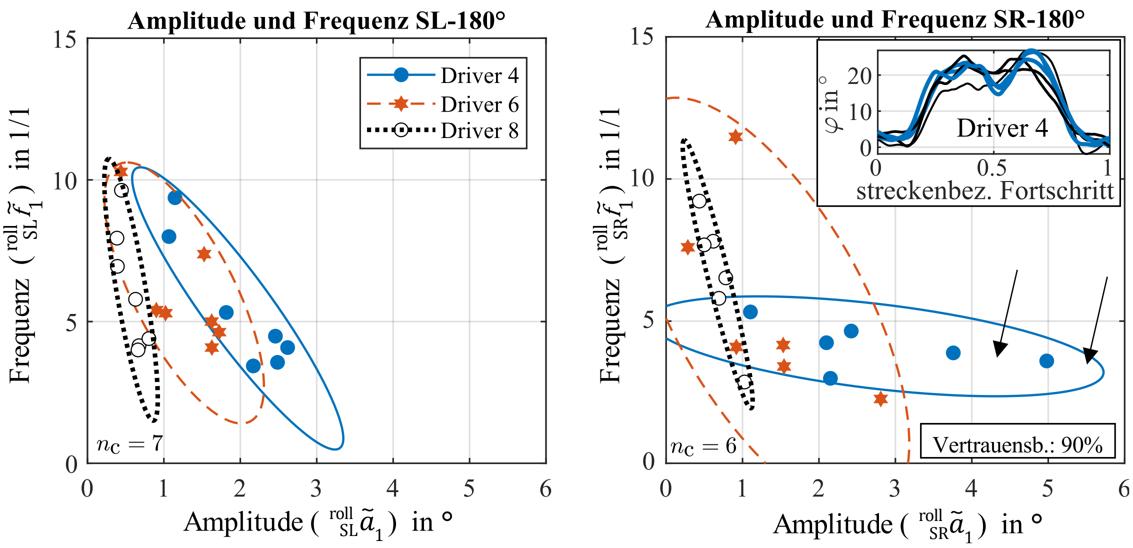

Abbildung 21: Rollwinkelhauptschwingung Amplitude/Frequenz;180° Kurve; SL/SR-Primitiv[28e]

4 Trajektorienprädiktion

Die Berechnung der Trajektorie eines Motorrades ist zum Beispiel anhand des Gierwinkels und der Fahrzeuggeschwindigkeit möglich. Ziegler[29], Laumond[30] und Bittel[31] beschreiben die Trajektorie für den vereinfachten Fall eines rollenden Rades mit Hilfe der Differentialgleichung (10).

$$\dot{x}\cos(\vartheta) + \dot{y}\sin(\vartheta) = 0 \tag{10}$$

Die Parameter $\dot{x}$ und $\dot{y}$ sind die Einträge des ebenen Geschwindigkeitsvektors und ϑ repräsentiert den Winkel zwischen der Bewegungsrichtung und Abszisse. Die diskrete Darstellung unter Beachtung der Gierwinkelkonvention ist in Gleichung (11) dargestellt.

$$ {}^{\mathrm{e}}\begin{pmatrix} x \\ y \end{pmatrix}_{i+1} = {}^{\mathrm{e}}\begin{pmatrix} x \\ y \end{pmatrix}_{i} + {}^{\mathrm{hor}}v_{x_i} \cdot \Delta t \cdot \begin{pmatrix} -\sin\left(\psi_i + {}^{\mathrm{hor}}\dot{\psi}_i \Delta t\right) \\ +\cos\left(\underbrace{\psi_i + {}^{\mathrm{hor}}\dot{\psi}_i \Delta t}_{\psi_{i+1}}\right) \end{pmatrix} \tag{11}$$

Bei dem Ansatz handelt es sich um ein Anfangswertproblem, bei welchem ausgehend von einem Startwert in aufeinanderfolgenden Schritten in Abhängigkeit des gegebenen zukünftigen theoretischen Rollwinkel- und Geschwindigkeitsverlaufes die Fahrspur berechnet wird. Als Startwerte zum Zeitpunkt (ZP) t=0 sind die Startposition $[x_0; y_0]^{\mathrm{T}}$ und der Gierwinkel ψ_0 bekannt. Es ist zu beachten, dass das Verfahren den theoretisch wirksamen Rollwinkel betrachtet. Weiterhin nutzt das Verfahren zur Berechnung des Zusammenhanges zwischen Rollwinkel und Gierrate die Bedingung der stationären Kurvenfahrt.

Nachfolgend werden die Punkte aufgezählt, an denen die Annahme der stationären Kurvenfahrt fehlerbehaftet ist:

[29] Vgl. Ziegler, J.: Dissertation, Optimale Bahn- und Trajektorienplanung für Automobile (2015), S. 7.
[30] Vgl. Laumond, J.-P. et al.: Robot Motion Planning and Control (1998), S. 4.
[31] Vgl. Bittel, O.: Roboterkinematik (2016), S. 18.

a) Kräftegleichgewicht durch Annahme der stationären Kurvenfahrt

Die stationäre Kurvenfahrt basiert auf der Annahme, dass ein Kräftegleichgewicht herrscht. Dieses äußert sich darin, dass die resultierende Kraft aus Gewichts- und Fliehkraft am Gesamtschwerpunkt des Fahrzeuges angreifend durch die Reifenaufstandslinie verläuft. Wird die Annahme der stationären Kurvenfahrt auf einen zeitlich veränderlichen Rollwinkelverlauf angewendet, ergibt sich insbesondere an Kurvenein- als auch Ausgängen ein zu schneller Gierratenaufbau bzw. Abbau, da die Formel die Trägheit des Gesamtprozesses des Einrollvorganges nicht berücksichtigt.

b) Countersteering

Der Effekt des Countersteerings äußert sich insbesondere beim Einleiten in eine Kurve. Je nach Ausprägung ist das Countersteering sowohl im Rollwinkel- als auch im Gierratensignal beobachtbar.

c) Messwertbedingte Ungenauigkeiten

Die berechnete Gierrate nutzt das Rollwinkel- und Geschwindigkeitssignal als Eingangsgrößen. Der zur Berechnung genutzte Rollwinkel ist der theoretische Rollwinkel, sodass das Rollwinkelsignal sowohl durch die Reifenbreite als auch eine mögliche außerhalb der Fahrzeugsymmetrieebene liegende Schwerpunktlage beeinflusst wird. Die Korrektur der Reifenbreite ist anhand von typischen Erfahrungswerten möglich. Die Oberkörperposition des Fahrers hingegen ist mit den gegebenen Messmöglichkeiten nicht direkt erfassbar. Weiterhin sind motorradbauartbedingte Einflüsse zu berücksichtigen. Hierzu zählen bspw. freie Motormomente, welche, je nach Motoreinbaulage, eine leichte dauerhafte Schräglage des Fahrzeuges auch bei Geradeausfahrt bewirken.

d) Trägheiten

Sowohl der Rollwinkel- als auch der Geschwindigkeitsverlauf weisen, verglichen mit der Volatilität einer Drehrate, eine deutlich niedrigere Dynamik auf. Die Rollrate dient als anschauliches Beispiel. Während der Rollwinkelverlauf geglättet wirkt, besitzt die dazugehörige Rollrate eine höhere Dynamik.

e) Lenkwinkel/ -momente

Die Lenkbewegungen des Fahrers sind unter dem gegebenen Untersuchungsrahmen nicht bekannt. Besonders im Niedriggeschwindigkeitsbereich wirken Lenkeingaben des Fahrers stabilisierend, da die Kreiselstabilisierung erst bei höheren Geschwindigkeiten durch Zunahme der Kreiselkräfte wirkt. Somit ist die Begrenzung des zulässigen Geschwindigkeitsbereichs mit einer unteren Grenze zielführend[32], sodass die Effekte der Fahrzeugstabilisierung durch starke Lenkbewegungen als vernachlässigbar gering angesehen werden.

Die aufgeführten Einflüsse sind zur Verdeutlichung in Abbildung 22 dargestellt. In der oberen Abbildung ist die gemessene horizontierte Gierrate (${}^{\mathrm{hor}}\dot{\psi}_{\mathrm{meas}}$) und die auf Basis der stationären Kurvenfahrt berechnete Gierrate (${}^{\mathrm{hor}}\dot{\psi}_{\mathrm{stat}}$) dargestellt. Unten in der Abbildung ist die Differenz beider Signale aufgetragen.

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[32] Untere Grenze: 4 m/s; bsph. Szenario: Haarnadelkurve auf einer Landstraße

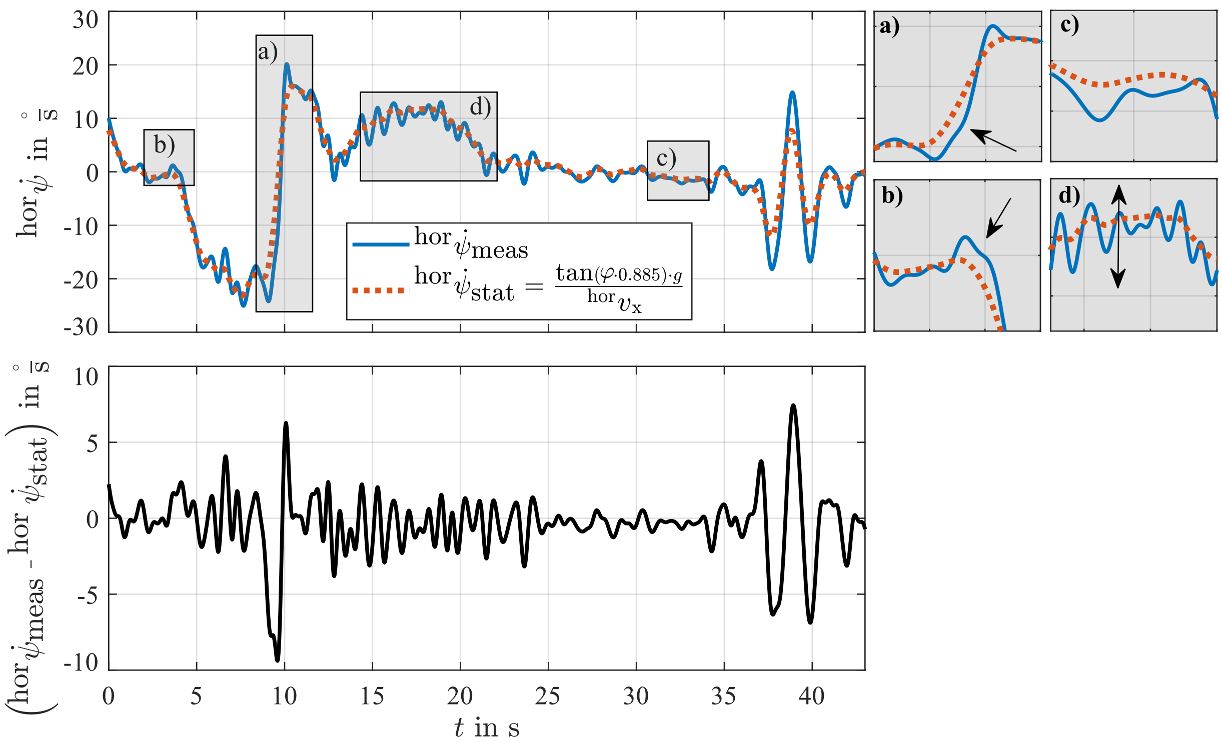


Abbildung 22: Annahme der stationären Kurvenfahrt: Optimierung[34a]

Die grau schattierten Bereiche in Abbildung 22 markieren Gebiete, in welchen sich die aufgeführten Fehlerursachen erkennbar widerspiegeln. Die Nummerierung der Bereiche orientiert sich an der Nummerierung der vorangegangenen Aufzählung möglicher Verletzung der stationären Bedingung. Der Effekt des Countersteerings ist zu Beginn der ersten Kurveneinleitung erkennbar (s. Pfeil bei b)). Unmittelbar vor Einleitung der Rechtskurve ist eine positive Gierrate erkennbar.
Die Abweichung aufgrund der Verletzung des Kräftegleichgewichts zeigt sich während des Richtungswechsels in der S-Kurve (siehe a)) deutlich. So beginnt die Kurvenausleitung basierend auf der stationär berechneten Gierrate im Vergleich zur messtechnisch erfassten horizontierten Gierrate zu früh. Die geringere Volatilität des berechneten Signals ggü. dem gemessenen Signal ist größtenteils getrennt von anderen Effekten im Bereich d) erkennbar. Es liegt eine deutliche Diskrepanz der beobachtbaren Amplitudenhöhen vor.

Während der Geradeausfahrt im Gebiet c) ist für eine Dauer von über 5 s eine Abweichung der Signale ohne Vorzeichenwechsel zu erkennen. Dies deutet z.B. auf eine außermittige Sitzposition des Fahrers während der Geradeausfahrt hin.

Aus dem unteren Graphen in Abbildung 22 wird deutlich, dass insbesondere in dynamischen Bereichen (t = 7 - 11 s) die Abweichungen zwischen berechneter stationärer und gemessener horizontierter Gierrate stark (bis zu 10°/s) ausgeprägt sind. Da für die Positionsberechnung vor einem Manöver insbesondere die Dynamik während der Kurveneinleitung einen großen Einfluss auf das Ergebnis hat, ist es erstrebenswert, die durch die Annahme der stationären Kurvenfahrt bedingten Gierratenfehler zu minimieren.

Aufgrund der Klassifizierbarkeit der Fehler wird eine Fehlerkompensation entwickelt, welche die abschätzbaren Fehler (s. Übersicht) berücksichtigt und kompensiert. Dies entspricht einer Vorsteuerung, da bekannte und abschätzbare Fehlerursachen von Beginn an Berücksichtigung finden. Formel (12) zeigt die verwendete Struktur des Kompensationsgliedes.

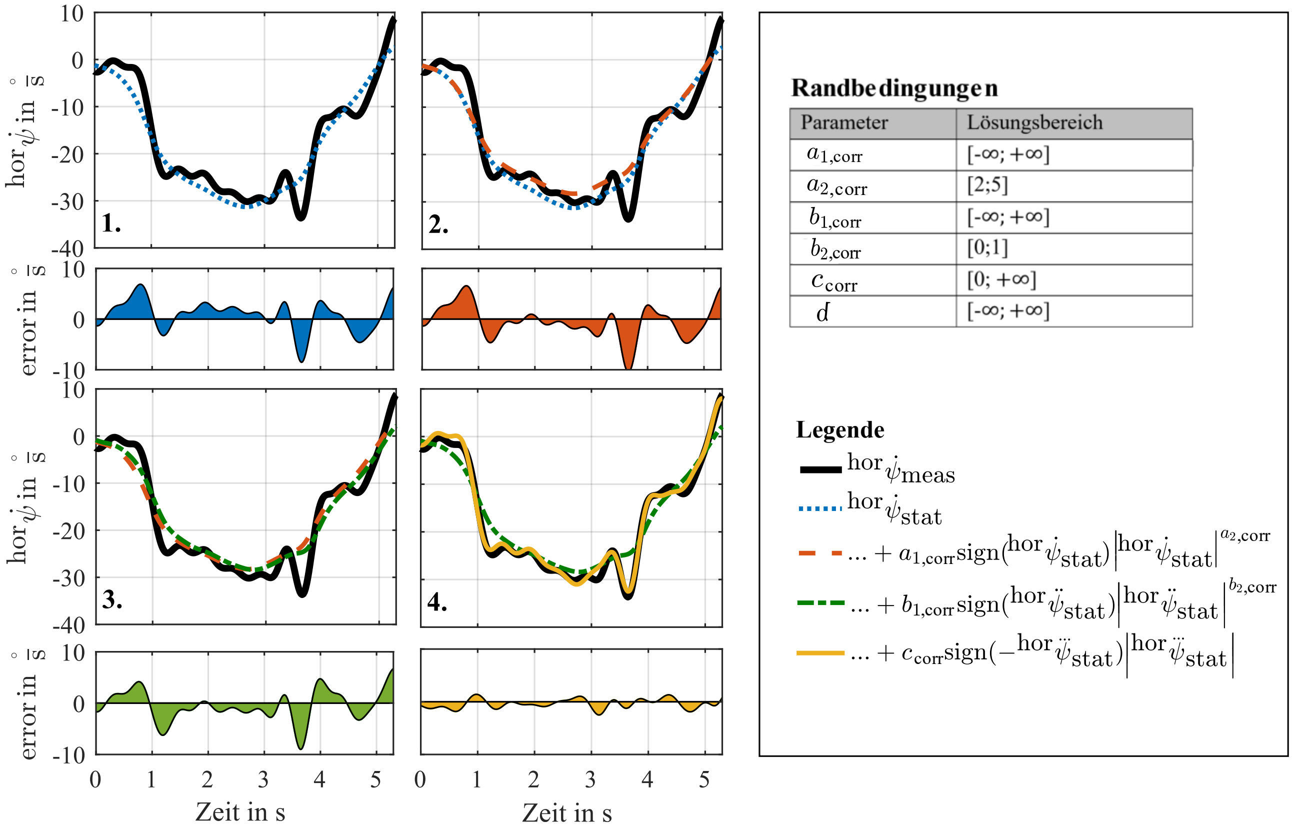
$$
\begin{aligned}
{}^{\mathrm{hor}}\dot{\psi}_{\mathrm{corrected}} = {} & \underbrace{\frac{\tan(\varphi)\cdot g}{{}^{\mathrm{hor}}v_{\mathrm{x}}}}_{{}^{\mathrm{hor}}\dot{\psi}_{\mathrm{stat}}} + \cdots \\
& \dots a_{1,\mathrm{corr}} \cdot \mathrm{sign}\left({}^{\mathrm{hor}}\dot{\psi}_{\mathrm{stat}}\right) \cdot \left|{}^{\mathrm{hor}}\dot{\psi}_{\mathrm{stat}}\right|^{a_{2,\mathrm{corr}}} + \cdots \\
& \dots b_{1,\mathrm{corr}} \cdot \mathrm{sign}\left({}^{\mathrm{hor}}\ddot{\psi}_{\mathrm{stat}}\right) \cdot \left|{}^{\mathrm{hor}}\ddot{\psi}_{\mathrm{stat}}\right|^{b_{2,\mathrm{corr}}} + \cdots \\
& \dots c_{\mathrm{corr}} \cdot \mathrm{sign}\left(-{}^{\mathrm{hor}}\dddot{\psi}_{\mathrm{stat}}\right) \cdot \left|{}^{\mathrm{hor}}\dddot{\psi}_{\mathrm{stat}}\right| + d_{\mathrm{corr}}
\end{aligned}
\qquad (12)
$$

Für eine zuverlässige Lösungsfindung und Vergleichbarkeit der Parameter werden Grenzen für die Parameter gewählt. Diese sind der Abbildung 23 rechts oben zu entnehmen. Zusätzlich sind in Abbildung 23 die einzelnen Schritte der Fehlerkompensation und deren Auswirkung visualisiert. Die Basis der Exponenten wird entdimensioniert mit $\frac{\mathrm{rad}}{\mathrm{s}}$ für $\left|{}^{\mathrm{hor}}\dot{\psi}_{\mathrm{stat}}\right|$, mit $\frac{\mathrm{rad}}{\mathrm{s}^2}$ für $\left|{}^{\mathrm{hor}}\ddot{\psi}_{\mathrm{stat}}\right|$ sowie mit $\frac{\mathrm{rad}}{\mathrm{s}^3}$ für $\left|{}^{\mathrm{hor}}\dddot{\psi}_{\mathrm{stat}}\right|$ .Somit besitzen die Koeffizienten $a_{1,\mathrm{corr}}, b_{1,\mathrm{corr}}, c_{\mathrm{corr}}$ und d_{corr} die Einheit der Gierrate (rad/s).

Mit dem hier vorgestellten Modell kann rein aus der Bekanntheit eines Rollwinkel und Geschwindigkeitsverlaufes eine Trajektorie generiert werden. In Kombination mit dem in Kapitel 3 vorgestellten Fahrendenmodell ist somit eine individuelle Prädiktion der Trajektorie in Abhängigkeit des typischen Verhaltens möglich.

Die Koeffizienten $a_{1,\mathrm{corr}}$ und $a_{2,\mathrm{corr}}$ ermöglichen eine gierratenproportionale Anpassung der stationär errechneten Gierrate. Somit spiegelt dieser Parameter bspw. die Oberkörperneigung des Fahrers während der Kurvenfahrt wider. Der zulässige Lösungsbereich des Exponenten $a_{2,\mathrm{corr}}$ setzt voraus, dass der Einfluss der Fahreroberkörperneigung bei höheren Gierraten (und Rollwinkeln) stärker ausgeprägt ist. Bezogen auf die Manöverprimitive bedeutet dies, dass insbesondere im stationären Manöverprimitiv der Einfluss der Oberkörperhaltung als signifikant angesehen wird. Das Vorzeichen von $a_{1,\mathrm{corr}}$ gibt an, in welche Richtung der Oberkörper geneigt ist. Entsprechend der Konvention des fahrzeugfesten Koordinatensystems zeigt ein positives Vorzeichen eine Körperhaltungstendenz nach links und ein negatives Vorzeichen eine Körperhaltungstendenz nach rechts an. In Abhängigkeit der Kurvenrichtung liegt somit ein lean in/out vor. Der Einfluss der beiden Parameter verdeutlicht sich in Abbildung 23 im 2. Schritt.

Die Koeffizienten $b_{1,\mathrm{corr}}$ und $b_{2,\mathrm{corr}}$ und der zugehörige Summand haben eine dämpfende Wirkung auf den Verlauf des Gierratensignals. Diese kommt insbesondere bei der Kurvenein- und ausleitung zum Tragen. Besonders bei großen und langanhaltenden Gierratenänderungen ist die Annahme der stationären Kurvenfahrt fehlerbehaftet. Der Exponent $b_{2,\mathrm{corr}}$ bewirkt, dass insbesondere in dynamischen Bereichen eine Berücksichtigung des nicht ausgebildeten Kräftegleichgewichts stattfindet. Dies tritt überwiegend während der Primitive LI/RI bzw. LO/RO auf. Im 3. Schritt in Abbildung 23 ist zu sehen, dass die Parameter besonders während der Kurvenein- und ausleitung eine Verzögerung des Signals bewirken, was den dämpfenden Effekt widerspiegelt.



Parameter	Lösungsbereich
$a_{1,corr}$	[-∞; +∞]
$a_{2,corr}$	[2;5]
$b_{1,corr}$	[-∞; +∞]
$b_{2,corr}$	[0;1]
c_{corr}	[0; +∞]
d	[-∞; +∞]

Abbildung 23: Einfluss der Korrekturfaktoren[34b]

Der Parameter c_{corr} dient zur Berücksichtigung der unbekannten Trägheiten. Es wird angenommen, dass diese Trägheiten als linear abhängig von der zweifachen Ableitung der Gierrate ($^{hor}\ddot{\psi}_{stat}$) modelliert werden können, da der Einfluss der Trägheiten unabhängig vom gefahrenen Kurvenprimitiv ist. Im 4. Schritt der Abbildung 23 zeigt sich, dass das additive Glied von Parameter c_{corr} die Volatilität des korrigierten Signals erhöht und dieses dem Grundverlauf der gemessenen Gierrate folgt.

Der Parameter d_{corr} (nicht in Abbildung 23 dargestellt) ist in der Lage, zwei weitere Unbekannte des Systems zu optimieren und sorgt für eine vertikale Verschiebung des Graphen. Einerseits besteht die Möglichkeit der Offsetkorrektur des Geschwindigkeitssignals, andererseits findet auch ein dauerhafter Offset im Rollwinkelsignal Berücksichtigung. Bei Letzterem ist es hierbei unerheblich, ob eine fehlerhafte Einbaulage des Messsystems vorliegt oder der Fahrer permanent mit leichtem Rollwinkel fährt.

Die Koeffizienten werden so parametriert, dass die Abweichung zwischen berechneter stationärer Gierrate und messtechnisch erfasster horizontierter Gierrate minimiert wird. Die Bestimmung der Koeffizienten erfolgt fahrendenindividuell und kurvenspezifisch, sodass eine bestmögliche Fehlerkompensation stattfindet.

5 Modellbewertung

Nach der Vorstellung der Modellbestandteile, wird nachfolgend die Gesamtgenauigkeit des Modells bewertet. Hierzu wird ein Datensatz verwendet, welcher im Zuge einer Studie zur Genauigkeitsbewertung der Messdatenerfassung per ADMA [33]aufgezeichnet wurde. Die im Folgenden untersuchte Gesamtungenauigkeit beinhaltet hierbei alle Ungenauigkeiten der einzelnen Vereinfachungsschritte und drückt sich in Form des Positionsfehlers zwischen realer gemessener und geschätzter Trajektorie aus. Als Gütekriterium dient der Querversatz zwischen geschätzter und realer Trajektorie. Die geschätzte Trajektorie ergibt sich aus dem approximierten Messdatenverlauf des Rollwinkel- und Geschwindigkeitssignals, den Korrekturfaktoren aufgrund stationärer und dynamischer Kurvenfahrt und der Manövereinteilung. Abbildung 24 verdeutlicht das angewandte Gütekriterium und gibt einen Überblick über die relevanten verwendeten Eingangsgrößen. Rechts in der Abbildung ist der laterale Versatz zwischen gemessenem und approximierten Positionsverlauf dargestellt. Der laterale Versatz beschreibt den minimalen Abstand zwischen gemessener und geschätzter Trajektorie und ist daher unabhängig vom jeweiligen Zeitpunkt des Erreichens der Position.

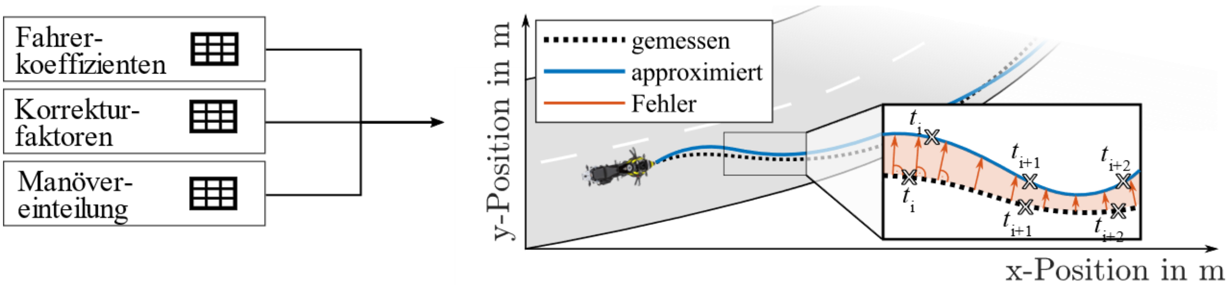


Abbildung 24: Gesamtbewertung- Gütekriterium[34c]

Abbildung 25 zeigt die Ergebnisse für eine Kurvendurchfahrt. In der Abbildung links sind die gemessenen SP[35]-Positionen und die berechnete SP-Trajektorie (blau) dargestellt. Zusätzlich ist die Verbindungslinie der Reifenaufstandspunkte (rot) eingezeichnet. Zu Manöverbeginn werden die aktuelle Position und die Orientierung des Fahrzeuges als bekannt vorausgesetzt. Ausgehend von den Startwerten wird die zukünftige Position auf Basis der fahrerspezifischen Koeffizienten berechnet. In der Mitte der Abbildung 25 sind der gemessene Rollwinkel- /Geschwindigkeitsverlauf und die Approximationen basierend auf der mathematischen Beschreibung dargestellt. Ebenfalls ist die berechnete und die gemessene horizontierte Gierrate zu sehen. Für die vorliegende Kurve ist der laterale Fehler über das gesamte Manöver < 0,2 m. Die Referenzierung des Fehlers auf die zurückgelegte Strecke setzt den lateralen Fehler in ein räumlich interpretierbares Verhältnis. Der maximale relative laterale Positionsfehler ist < 0,7 %.

[33] Automotive Dynamic Motion Analyzer der Firma Genesys, hochpräzise Fahrdynamikmesstechnik
[34] Basten, T.: Prädiktionsmodell (2021), a: S.100, b:S. 102; c: S.120, d: S. 121, e: S. 122
[35] Schwerpunkt

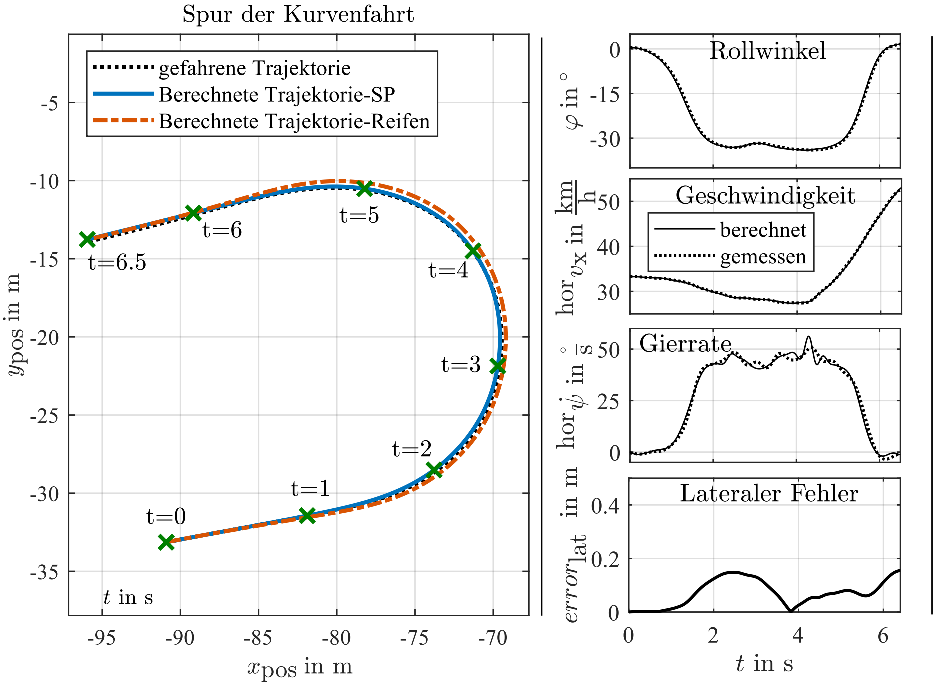


Abbildung 25: Trajektorienberechnung-Simulationsausgabe[34d]

Der laterale Fehler aller 180°- Rechts- bzw. Linkskurven zweier beispielhafter Fahrender ist in Abbildung 26 dargestellt.

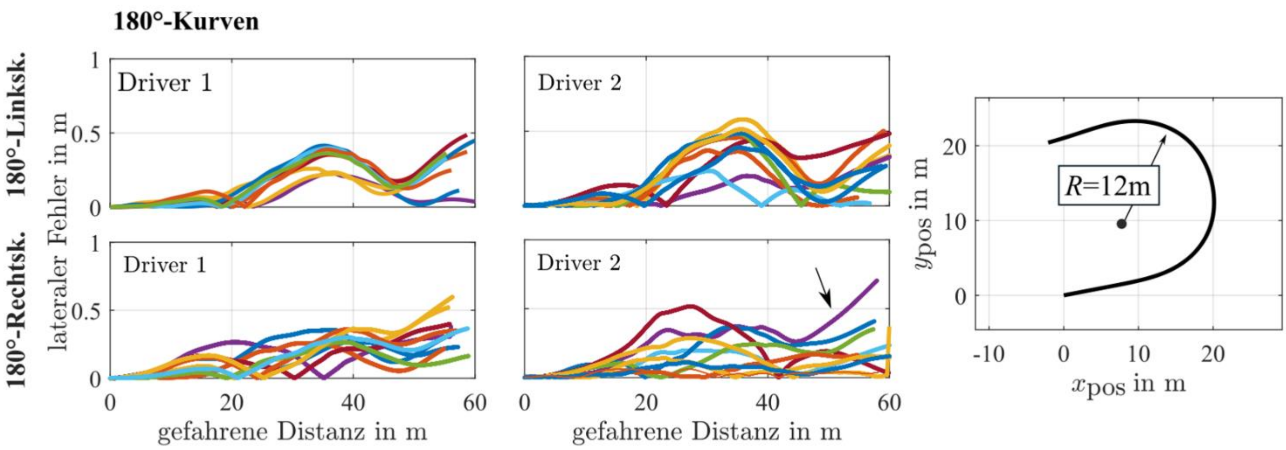


Abbildung 26: Gesamtgenauigkeitsbewertung 180°-Kurven[34e]

Die lateralen Fehler steigen mit zunehmender Vorhersagedauer. Der Maximalfehler aller Durchfahrten der 180°-Kurven ist für Fahrer 1 <0,6 m bzw. für Fahrer 2 <0,7 m. Bei 97 % der Kurvendurchfahrten ist der Versatzfehler vor Beginn der Kurvenausleitung fahrerunabhängig <0,5 m. Bei einer Rechtskurve von Fahrer 2 wächst der Versatzfehler am Ende stärker an im Vergleich zu den übrigen Durchfahrten (s. Pfeil). Die betroffene Durchfahrt ist in Abbildung 27 dargestellt.

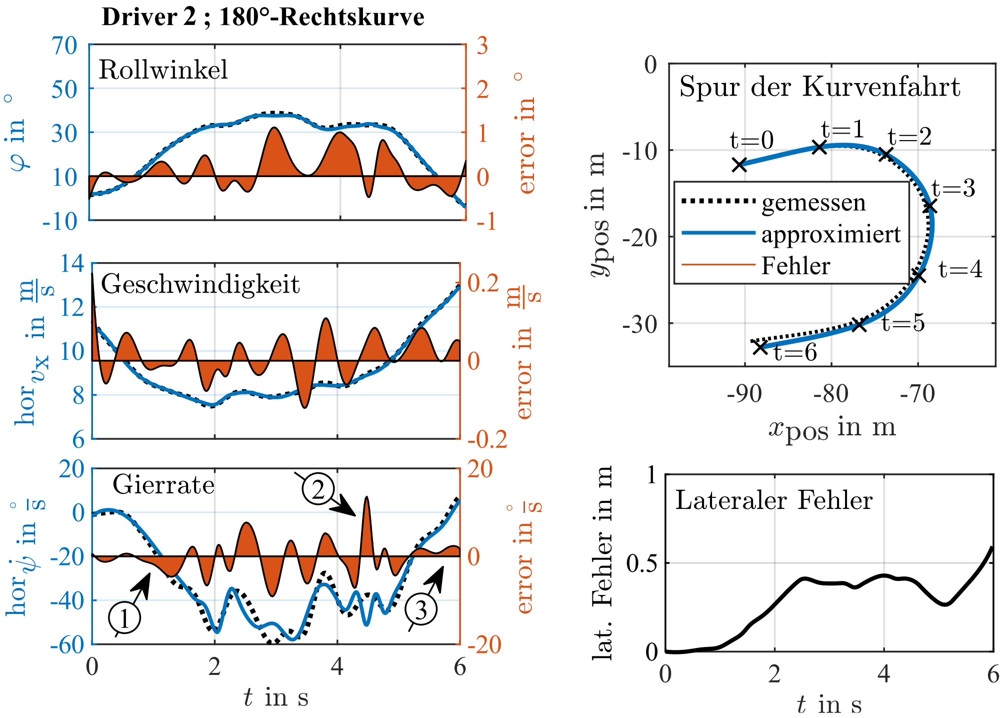


Abbildung 27: Detailbetrachtung Maximalfehler der 180°-Kurve[34e]

Links in Abbildung 27 sind der approximierte Rollwinkel-/ Geschwindigkeitsverlauf und die daraus berechnete Gierrate sowie deren Fehler dargestellt. Rechts oben ist die gemessene und geschätzte Trajektorie zu sehen. Die Approximationsfehler des Rollwinkel- und Geschwindigkeitssignals sind gering. Die Untersuchung der Gierrate zeigt jedoch, dass insbesondere bei der Kurveneinleitung ein nicht um die Nulllage schwankender Gierratenfehler auftritt (s. Pfeil Nr. 1). Infolgedessen wächst der Positionsfehler bereits bei der Kurveneinleitung. Über den stationären Kurventeil bleibt der Lateralversatz annähernd konstant. Am Ende der stationären Phase und am Übergang zur Kurvenausleitungsphase treten höhere Gierratenfehler im Vergleich zu den übrigen Bereichen auf (s. Pfeil Nr.2). Dies ist auf Näherungsungenauigkeiten des Rollwinkel- und Geschwindigkeitsverlaufes zurückzuführen. Weiterhin bedingen die Segmentübergänge der approximierten Verläufe eine fehlerhafte Dynamik. Am Ende des Gesamtmanövers (ab $t = 5$ s) zeigt der Gierratenfehler einen positiven Trend (s. Pfeil Nr. 3), welcher zu einer Verringerung des lateralen Fehlers führen müsste. Da die Betrachtung des lateralen Positionsfehlers zwischen realer und berechneter Trajektorie jedoch unabhängig von dem Zeit-Ort-Bezug des berechneten Signals ist und mit zunehmender Simulationsdauer die zurückgelegte Wegdifferenz zwischen realer und approximierter Kurvendurchfahrt zunimmt, ist insbesondere am Manöverende der Zusammenhang zwischen zeitlichem Gierratenfehler und der Positionsabweichung nicht mehr direkt erkennbar.

6 Zusammenfassung und Ausblick

In diesem Paper wird ein Modell vorgestellt, welches die Vorhersage von Fahrdynamikdaten, unter Berücksichtigung des Fahrendeneinflusses, ermöglicht. Dabei werden keine, nicht allgemein zugänglichen, fahrzeugspezifischen Parameter genutzt.

Zur Identifizierung der Fahrerspezifität eignen sich besonders der Rollwinkel- und der Geschwindigkeitsverlauf. Für die Erfassung der Fahrerindividualität innerhalb dieser beiden Signale werden parametrierbare Ansatzfunktionen definiert. Die Parameter der Ansatzfunktionen ergeben sich aus der Approximation der realen Messdatenverläufe. Zur Gewährleistung der Vergleichbarkeit mehrerer Messschriebe eines Manövers, erfolgt eine Betrachtung der Messdatenverläufe bzgl. des relativen Streckenfortschrittes. Es wird nachgewiesen, dass die Koeffizienten der Ansatzfunktionen Fahrer- und Manöverspezifität besitzen. Es sind sowohl fahrertypische Muster während der stationären Bereiche der Kurvenfahrten als auch anhand der Parameter der Wachstumsfunktion während der Kurveneinleitung und -ausleitung erkennbar. Die berechneten Koeffizienten ermöglichen ferner eine Beurteilung der dynamischen Parameter bzgl. der Reproduzierbarkeit einer Kurvenfahrt. Bereits bekannte Frequenzunterschiede zwischen den Fahrern aus dem Zeitbereich sind auch bei der streckenbezogenen Betrachtung eindeutig klassifizierbar. Auf Basis der Parameter der Ansatzfunktionen besteht die Möglichkeit, die Rollwinkel- und Geschwindigkeitsverläufe für ein vorliegendes Manöver zu rekonstruieren.

Für die Schätzung der zukünftigen Positionen wird ein Ansatz entwickelt, welcher, basierend auf der Annahme der stationären Kurvenfahrt, aus dem rekonstruierten Rollwinkel- und Geschwindigkeitsverlauf die horizontierte Gierrate berechnet. Hierbei werden kalkulierbare Ungenauigkeiten der stationären Annahme mit Hilfe von Korrekturparametern berücksichtigt. Diese Parameter werden, analog zu den Fahrerkoeffizienten, manöverindividuell bestimmt. Die Korrekturparameter ermöglichen bspw. Rückschlüsse auf die Oberkörperhaltung des Fahrers während eines Manövers. Die Korrekturparameter führen zu einer signifikanten Verbesserung der Positionsschätzung, da die geschätzte Gierrate realitätsnah an die gemessene Gierrate angenähert wird.

Die Approximationsgüte der Ansatzfunktionen wird, trotz der einfachen und interpretierbaren mathematischen Struktur, als hoch eingestuft. Die maximalen Abweichungen zwischen realen und approximierten Messdatenverläufen von über 600 Kurvendurchfahrten sind gering.

Die Ungenauigkeit der Positionsvorhersagen liegt für den überwiegenden Teil der betrachteten Manöver über die gesamte Manöverlänge bei unter 0,6 m (auf Basis des für die Untersuchung genutzten Datensatzes).

Abschließend ist festzustellen, dass das entwickelte Konzept die Möglichkeit bietet, Fahrdynamikdaten zuverlässig zu beschreiben, zu interpretieren und darauf basierend vorherzusagen. Mit Hilfe der mathematischen Beschreibung der Messdatenverläufe ist es möglich, diese zu rekonstruieren und darauf basierend eine Berechnung der zukünftigen Positionen vorzunehmen.

Ausblick

Das in diesem Paper entwickelte Modell besitzt Weiterentwicklungspotential. Eine Möglichkeit zur Optimierung der Positionsberechnung basiert auf der Verbesserung der Beschreibung der Geschwindigkeitsverläufe. Die Auswertung ergibt, dass insbesondere in der Kurveneinleitung Geschwindigkeitsfehler einen relevanten Einfluss auf die berechneten Positionen haben. Ursächlich hierfür ist die Nutzung des Geschwindigkeitssignals, sowohl bei der Berechnung der Gierrate als auch bei der Trajektorienberechnung. Da die Geschwindigkeitsverläufe aktuell mit den identischen

Ansatzfunktionen wie die Rollwinkelverläufe beschrieben[36] werden, besteht in einer Optimierung der Ansatzfunktionen ein mögliches Verbesserungspotential. Hierbei sind jedoch die wachsende Komplexität und die schwieriger werdende Interpretierbarkeit der Parameter zu beachten. Weiterhin ist zu berücksichtigen, dass der Rollwinkelverlauf durch ein vorgegebenes Manöver gut eingrenzbar ist, die Geschwindigkeitsentwicklung jedoch variabler und weniger stark an den Manöververlauf gekoppelt ist. Dies gilt besonders für die Kurveneinleitung.

Die entwickelte mathematische Approximation der Messdatenverläufe mittels Ansatzfunktionen bietet die Möglichkeit, das Fahrverhalten einzelner Fahrer manöverspezifisch zu beschreiben und zu klassifizieren. Die Parameter sind direkt interpretierbar. Daher besteht die Möglichkeit, die Koeffizienten als Basis für einen kurvenbasierte Fahrstilanalyse zu nutzen. Da die Erkennung kritischer Manöver anhand der Koeffizienten zuverlässig möglich ist, besteht außerdem die Möglichkeit kritische Situationen im Nachhinein mit den Fahrenden nach- bzw. aufzubereiten. Auch die Identifikation fahrerischer Defizite ist, sofern ausreichend Trainingsdaten vorhanden sind, möglich.

Zuletzt können die hier gewonnen Erkenntnisse bei der Weiterentwicklung von Fahrassistenzsystemen für Motorräder verwendet werden.

[36] Mit angepassten Randbedingungen.

Disclaimer

Diesem Beitrag liegt das im Auftrag des Bundesministeriums für Verkehr und digitale Infrastruktur, vertreten durch die Bundesanstalt für Straßenwesen, unter FE 82.0710/2018 laufende Forschungsprojekt zugrunde.

Die Verantwortung für den Inhalt liegt allein beim Autor.

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The author is solely responsible for the content.

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Titel:

Motorcycle riding in groups - known accident patterns?

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1. Introduction

Riding a motorbike in Germany is associated with a high risk. About 20% of those killed in road accidents are drivers of motorised two-wheelers. The risk of being killed as a motorbike driver is more than 20 times higher than that of a passenger car driver in relation to the mileage. The aim of successful prevention work must therefore be to understand all aspects of accidents involving motorcyclists in order to develop appropriate measures. This also includes understanding riding in motorbike groups and the corresponding accident patterns. The results described below were published in the series "compact accident research" by the Insurers Accident Research in October 2020.

2. Approach

2.1 UDB

The accident database of the German Insurers Accident Research (UDB) is representative of the motor vehicle liability claims of German insurers. The UDB only records liability claims with at least one injured person and a claim expenditure of at least € 15,000. The database with more than 10,000 accidents is continuously growing. The UDB records 2,345 accidents involving motorcyclists. These accidents were analysed in detail for the present study.

2.2 Accident occurrence

In the 2,345 accidents analysed, a total of 2,849 motorcyclists were involved. The analyses confirmed the obvious assumption that not only motorcyclists riding alone were involved in accidents, but also motorcyclists riding together in a group (Fig. 1-2).

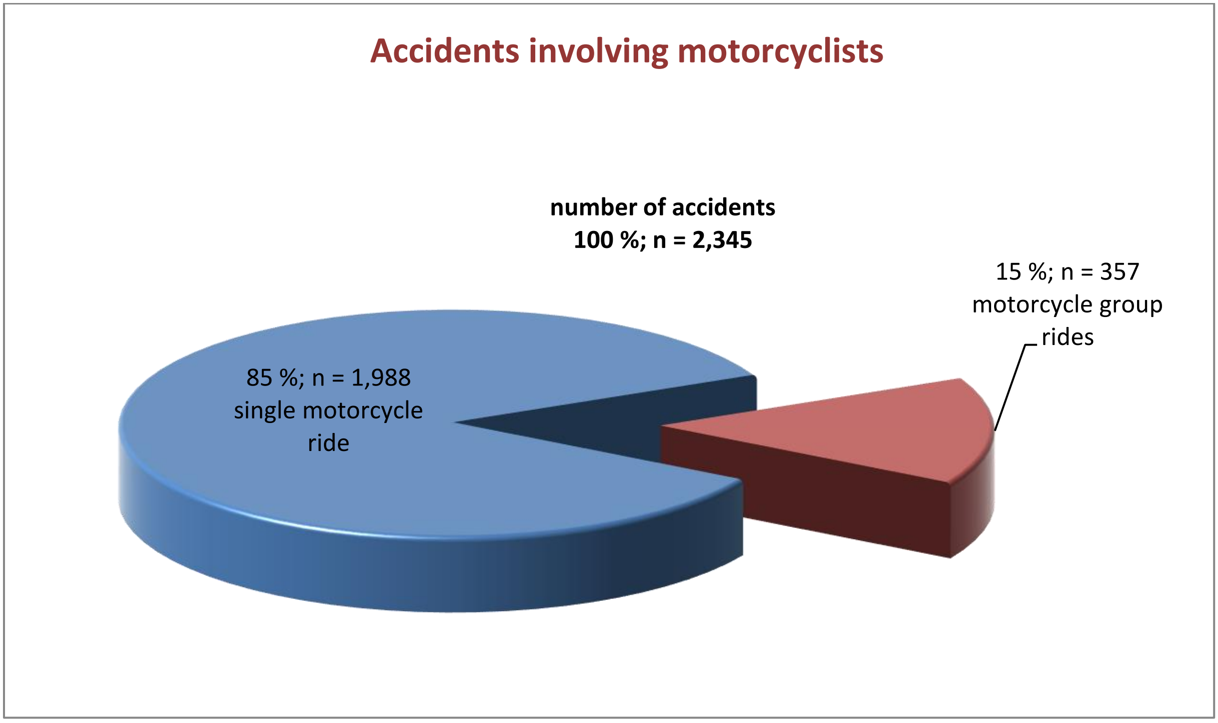

Fig. 1: Accidents involving motorcyclists

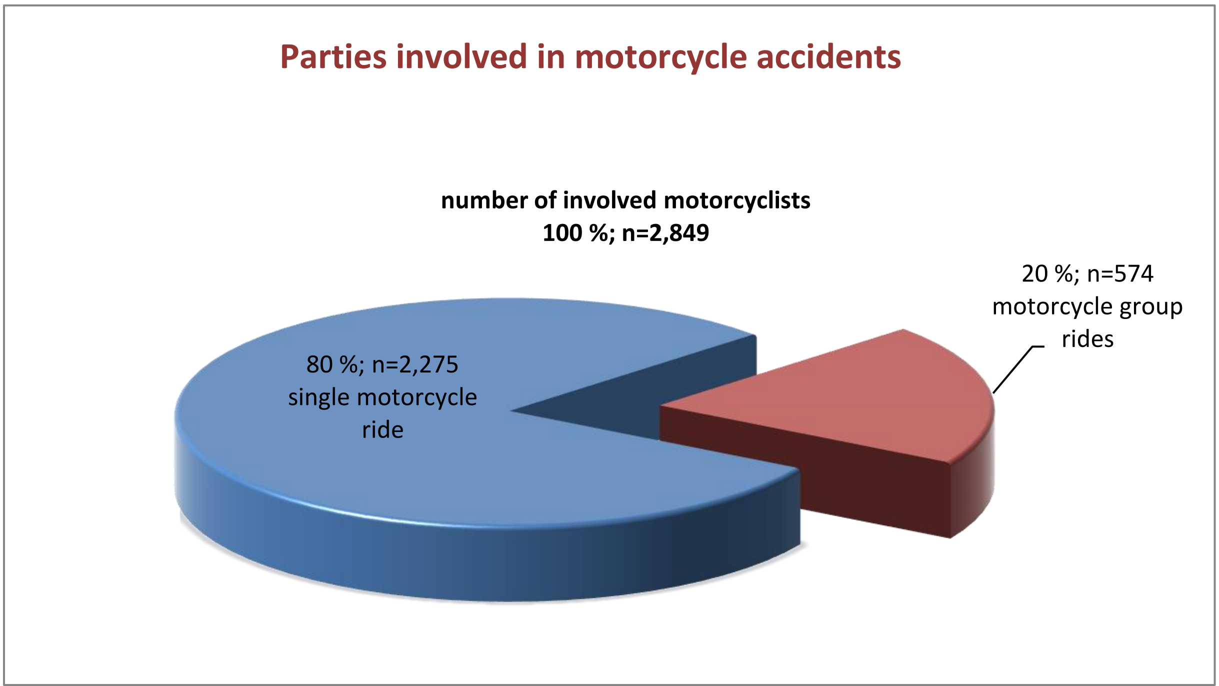

Fig. 2: Parties involved in motorcycle accidents

3. Results

In order to find out whether and to what extent the accident occurrence differs between group rides and solo rides by motorcyclists, detailed analyses were carried out between the comparison groups.

The most striking differences are listed below. Starting with the analysis of accidents by location, it was noticeable that 74% of accidents involving groups of motorcyclists occurred outside built-up areas, while the proportion in the comparison group of solo or single riders was only 44% (Fig. 3-4). This most likely reflects the choice of route for group rides, which are almost exclusively leisure rides.

In contrast, the accident locations for single rides reflect the entire spectrum of use of a two-wheeler - i.e. also as a commuter vehicle in the city or similar.

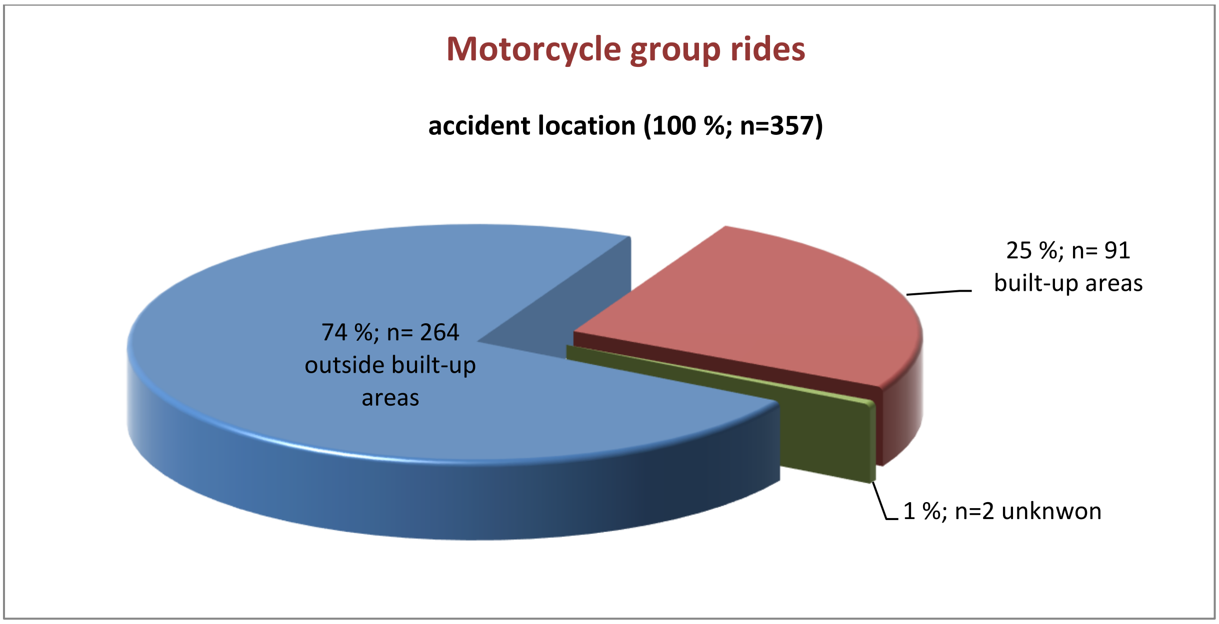

Fig. 3: Motorcycle group rides: accident location

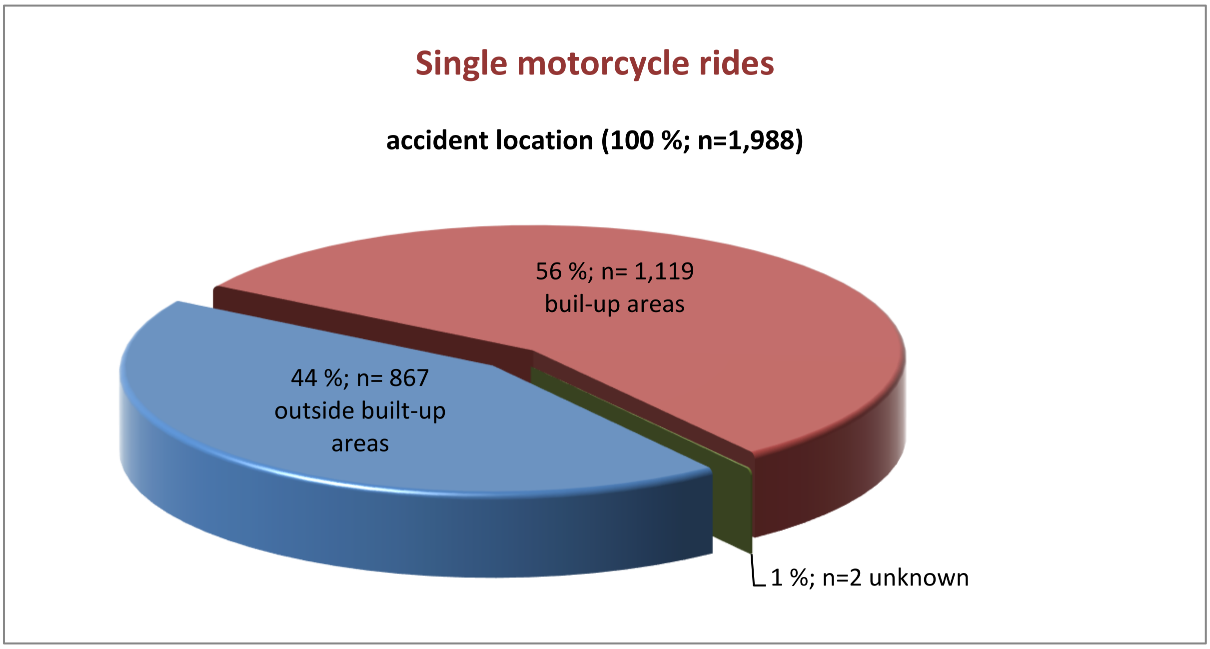

Fig. 4: Single motorcycle rides: location

Differences are also evident in the two-wheeled models involved in accidents.

While scooters were the most common model involved in accidents on individual trips (24%), sporty motorcycles accounted for 24% of group trips. In general, a shift towards fun-oriented or larger motorbike models is noticeable here compared to the individual rides (Fig. 5).

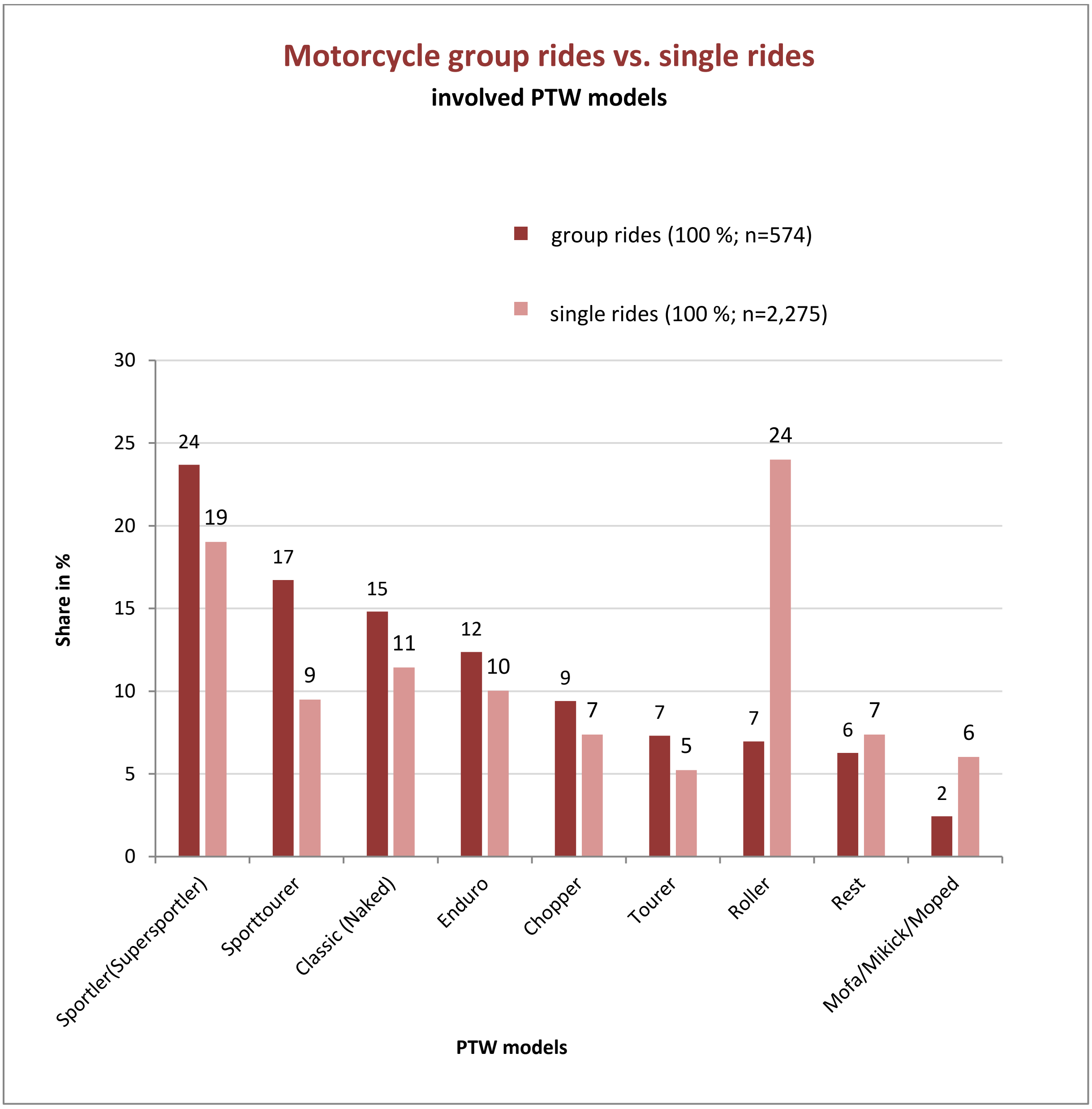

Fig. 5: Motorcycle group rides vs. single rides: PTW models involved

In principle, however, this analysis does not allow any statements to be made on the usage behaviour of group rides. Rather, it can only evaluate the accident occurrence and give indications of possible usage behaviour regarding PTW models.

Based on these first clear differences, the analysis was further deepened with regard to accidents outside built-up areas in order to be able to describe the typical accident scenarios for group rides with motorbikes.

The difference in the respective collision opponents in the accidents is striking.

In the accidents involving groups of motorbikes, 59% of the collision opponents were other two-wheelers. In comparison, in the accidents involving individual journeys, 76% were multi-track vehicles (Fig. 6).

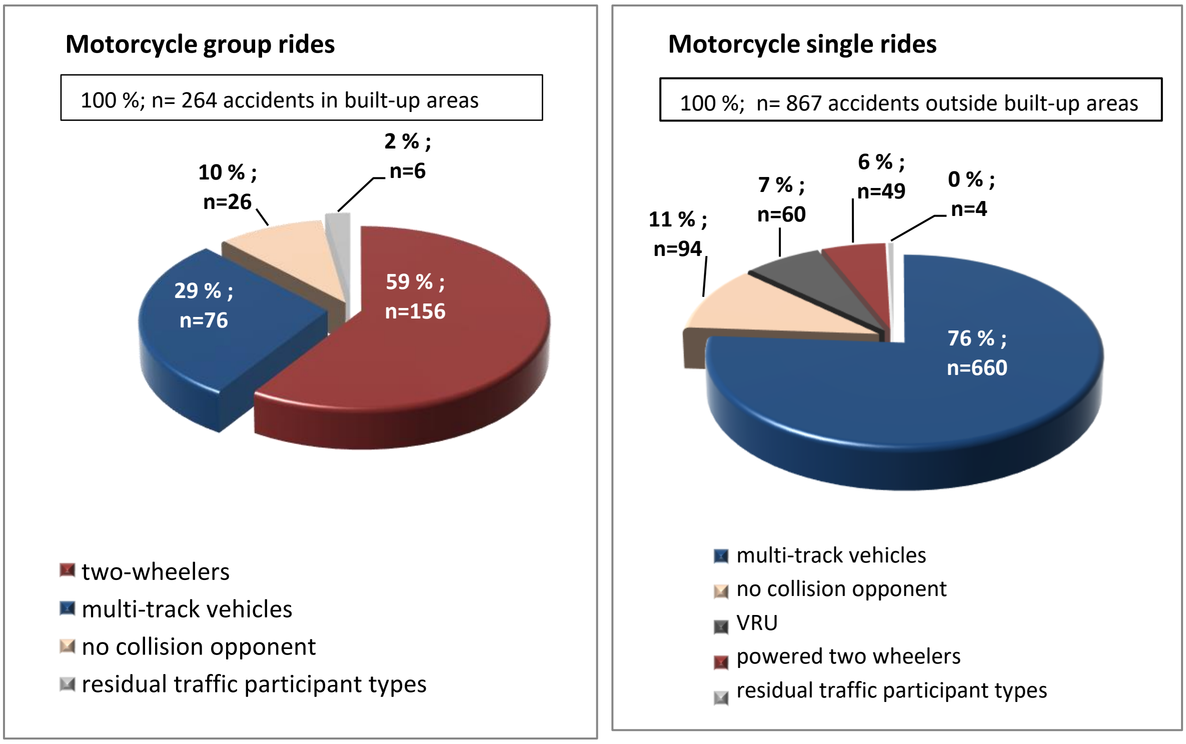

Fig. 6: Comparison of motorcycle accidents: collision opponents and accident location

The very high proportion of motorcyclists as collision opponents in group rides indicates that there are other group members involved in these accidents and, on closer analysis, appears to be a salient feature of group rides.

Comparing the age distribution of all riders outside built-up areas, the share of 42-47 years old group riders is 21 percent compared to 14 percent of all other two-wheelers involved in individual rides (Fig. 7). Compared to individual riders, the proportion of older riders aged 42 and over is higher for group riders. On the other hand, the proportion of younger casualties up to 42 years of age is higher among single riders. Supported by general empirical values, one can deduce here indications for the higher attractiveness of group rides as a leisure activity among older motorbike users.

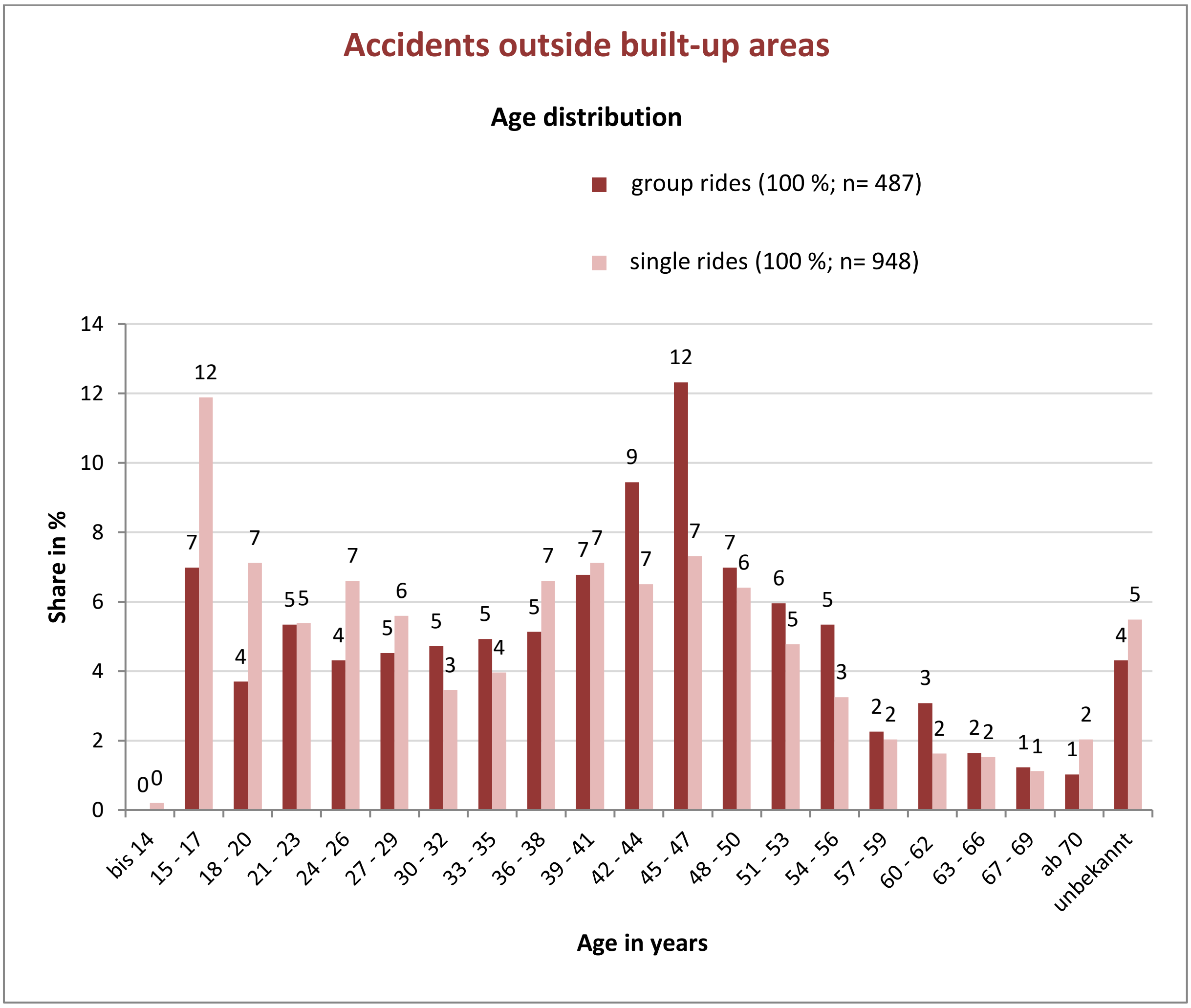

Fig. 7: Motorcycle group rides vs. single rides accidents outside built-up areas: age distribution

At the accident level, if we look at the conflict situation that led to an accident (accident type), the driving accident (36%) and the longitudinal accident (32%) stand out among the group journeys (Fig. 8). A driving accident is when the driver loses control of his vehicle, whereas the conflict in a longitudinal accident is characterised by vehicles moving in the same or opposite direction. In the accidents of the three most frequent accident types (n=225), a total of 360 motorcyclists and passengers of the motorbike groups were involved in accidents.

Accidents during individual journeys show a more even distribution of accident types, without one accident type dominating. The proportion of accidents during turning or turning/crossing is higher here than for group journeys. One reason may be the choice of route: On a group trip as a purely leisure trip, one is freer in the choice of route and would tend to avoid complex intersections or high traffic volumes, etc. This is not possible for individual journeys, e.g. daily commuting between home and work.

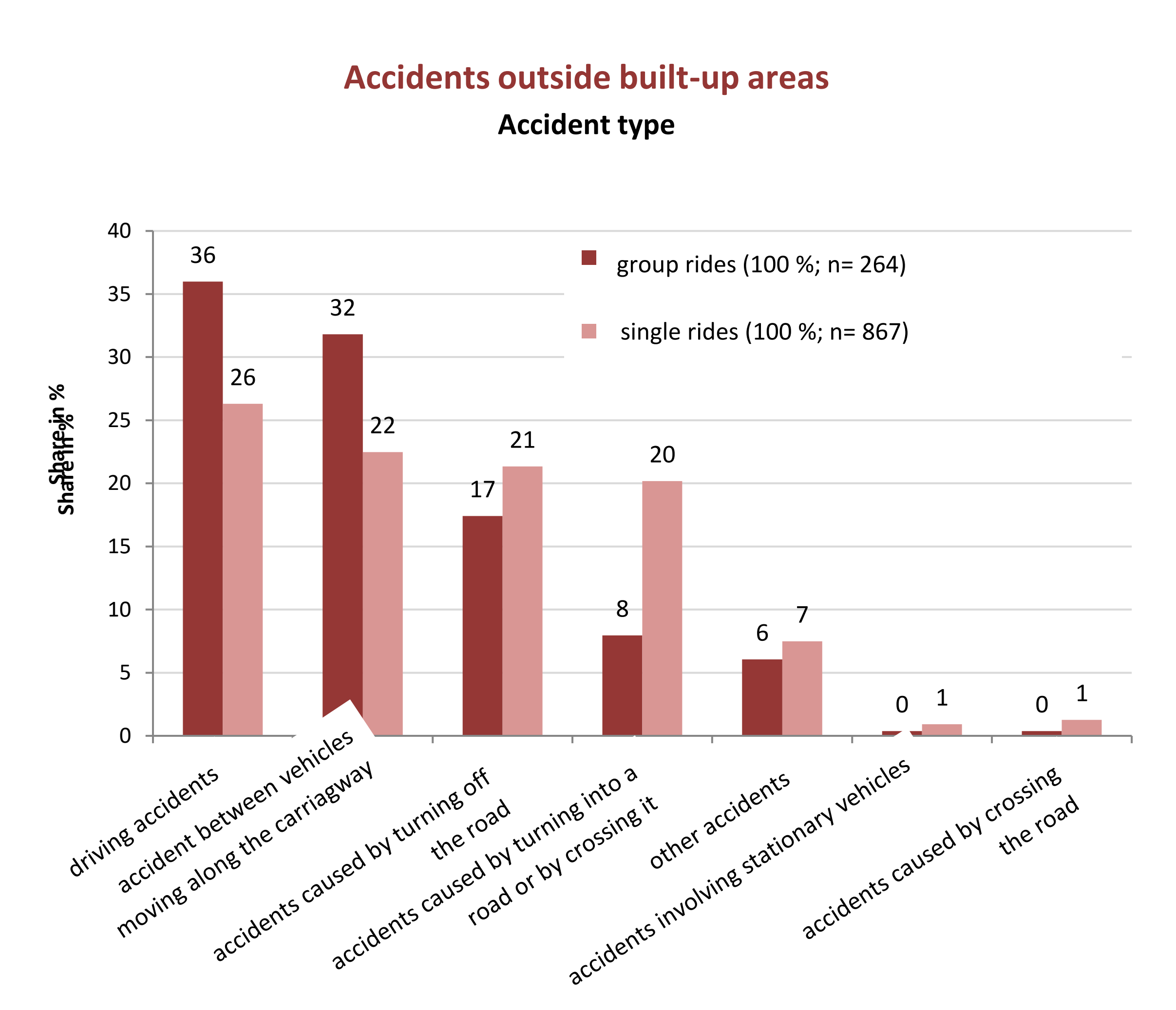

Fig. 8: Accidents outside built-up areas involving motorcycle group rides vs. single rides: accident types

The detailed examination of driving accidents during group rides revealed a high proportion (61 %) of collisions with oncoming vehicles. In the comparison group, by contrast, the proportion is 50 % and the proportion of accidents involving leaving the lane is comparatively high (Fig. 9).

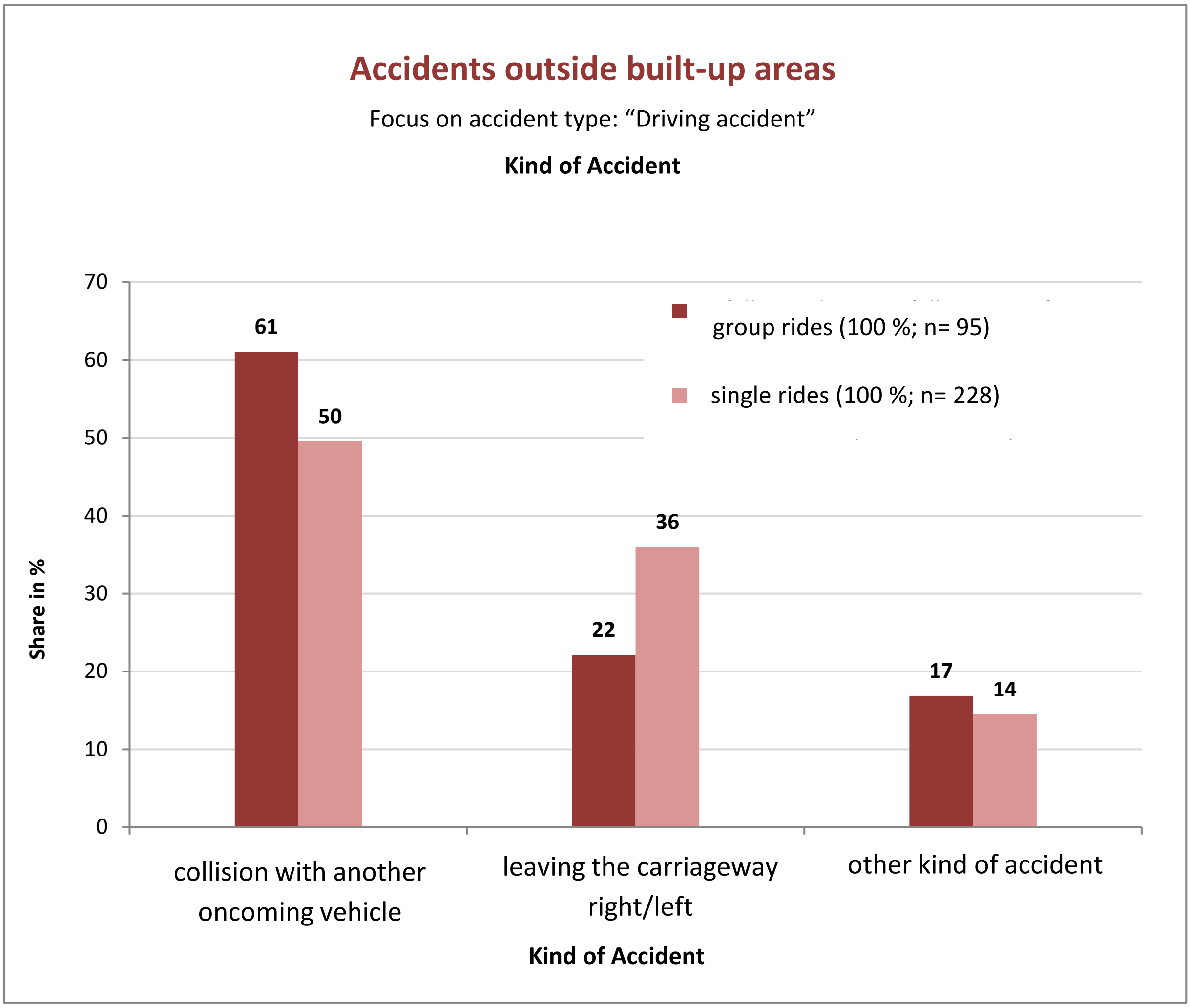

Fig. 9: Accidents outside built-up areas involving motorcycle group rides vs. single rides for the type of accident “driving accident”

This high proportion of the accident type “driving accidents” during group rides and the collision with oncoming vehicles requires a closer look. What is striking here is the misbehaviour of riders in motorbike groups with regard to their choice of speeds, road use and overtaking (Fig. 10).

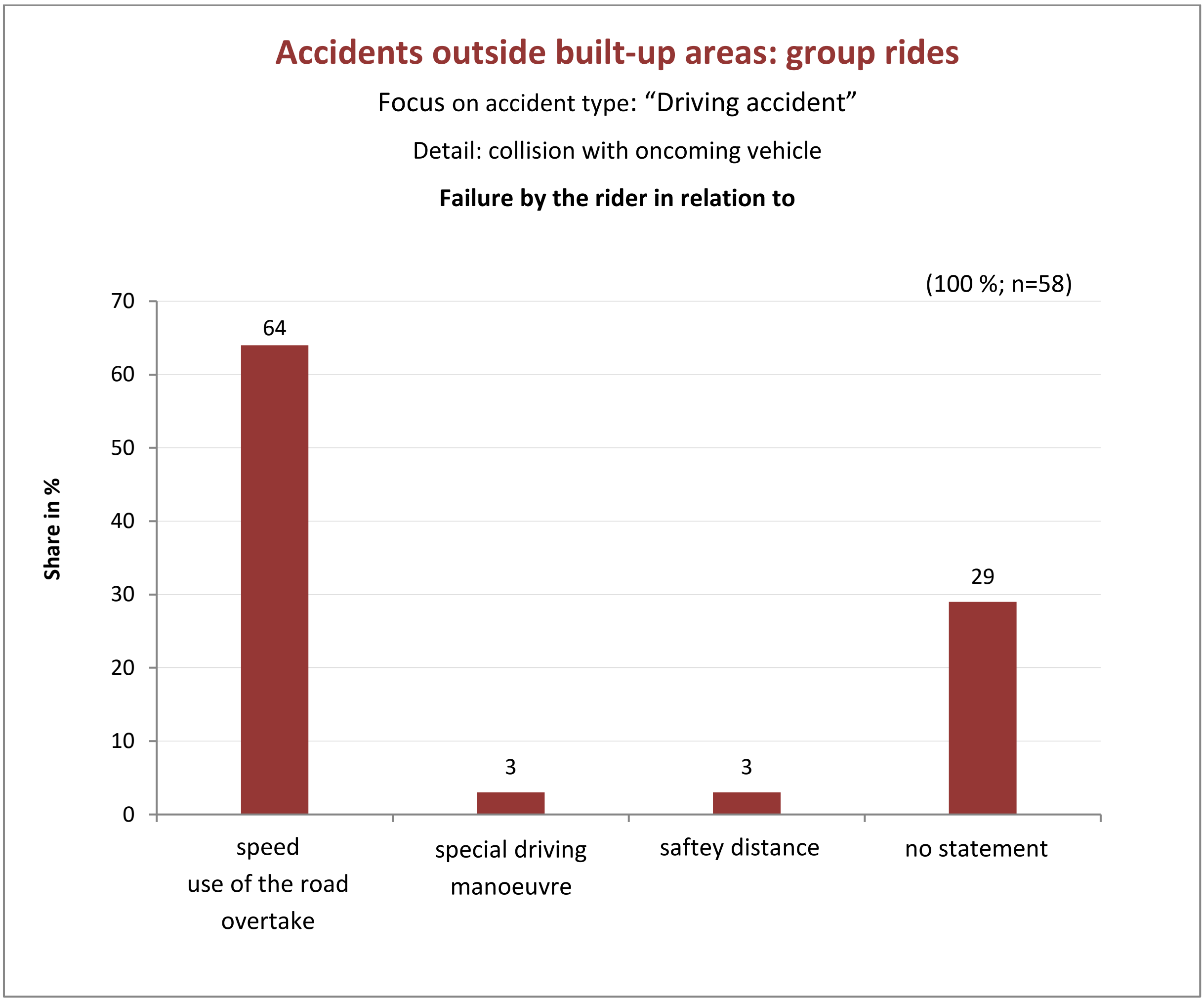

Fig. 10: Accidents in motorcycle group rides and collisions with oncoming vehicles by mistake of the rider for the accident type "driving accident".

A similar picture emerges for the misbehaviour of riders in motorbike groups in accidents of the accident type "driving accident" in combination with lane departure. Here, too, the rider's misconduct in terms of choice of speeds, distances and road use (67 %) is striking (Fig. 11).

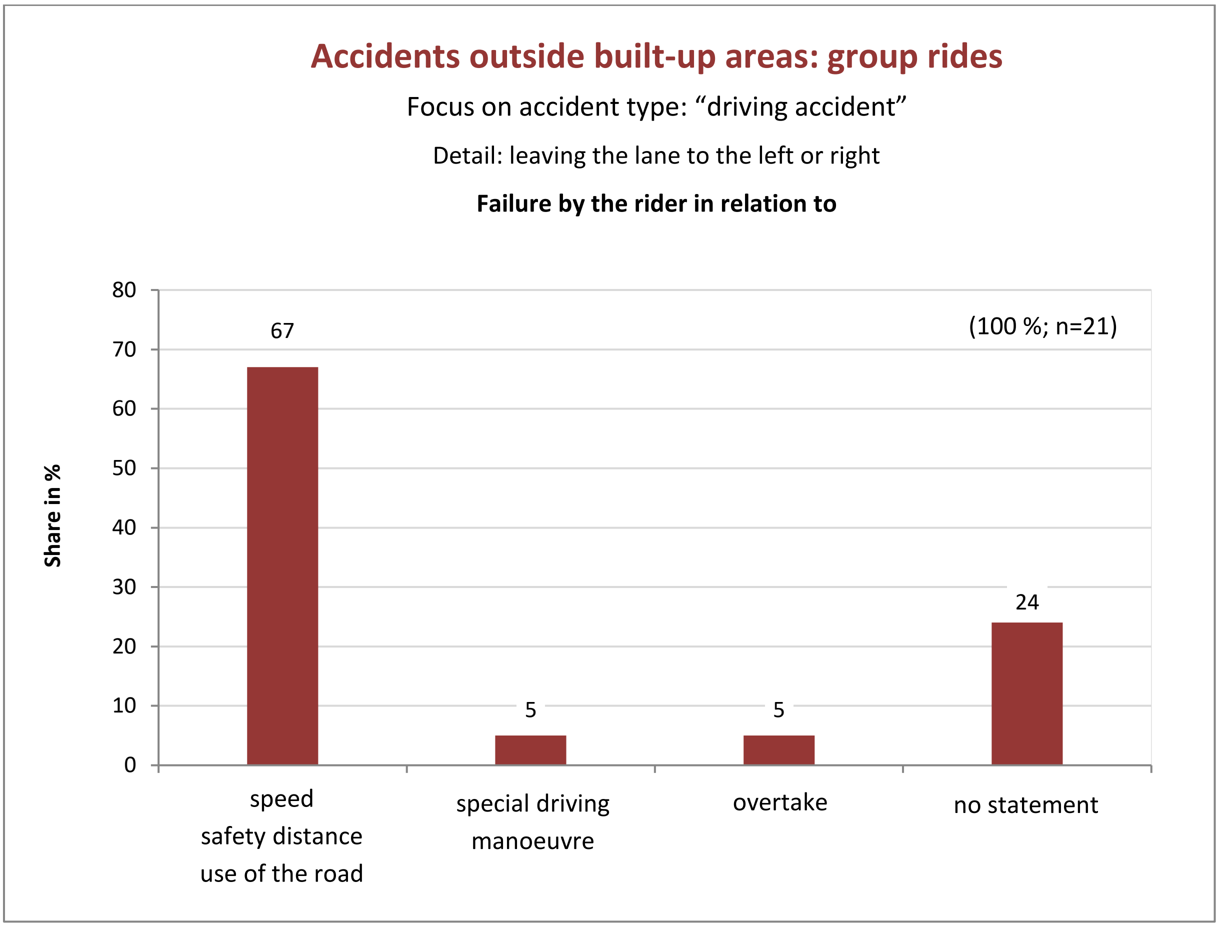

Fig. 11: Accidents in motorcycle group rides outside built-up areas involving lane departure to the right or left, broken down by mistake of the rider for the accident type “driving accident”

3.1 Typical accident sequences

Following individual case analyses of accidents in the UDB, typical accident sequences and causes in accidents involving groups of motorbikes can be summarised, which support and illustrate the general statements made on the previous pages. Above all, excessive speed and insufficient safety distance can be identified as causes of accidents when travelling in motorbike groups. From the point of view of prevention work, the main solution here - as is so often the case with accidents involving motorcyclists - seems to be the education of motorcyclists, but also of all other road users, and not just technical measures in infrastructure or vehicle technology.

- Speed
  If the motorbike group or individual group members are travelling at excessive speed, the motorcyclists are carried out of their optimal lane and thus reach across the centre line. This results in a collision with oncoming traffic.

  Oncoming traffic, including group members of another motorbike group, react by straightening their machines when they recognise the dangerous situation, which in turn leads to a collision, e. g. by the group members following them driving up, braking or swerving. As a result of the fallen motorcyclists, their riderless machines either slide into oncoming traffic or cause risky driving manoeuvres by following group members, which in turn lead to further accident consequences.

- Overtake
  Group members overtake and get into oncoming traffic, e. g. motorcyclists, which is usually difficult to see.

This leads to frightening situations as a result of which, for example, the reaction is to straighten up the machine in the bend. This in turn leads to being carried out of the lane.
Furthermore, when overtaking one's own group members, the lateral, front and rear distance to the following group member is often too small. Overestimating the performance of one's own machines, especially when overtaking, also leads to risky driving manoeuvres.

- Safety distance
  Insufficient safety distance often results in the following group member noticing the driving manoeuvre or the change in direction of the group member in front too late, resulting in abrupt driving manoeuvres which then lead to an accident. Similarly, this small safety distance does not allow an motorcyclist to re-engage in the event of an aborted overtaking manoeuvre with the corresponding accident consequences.

- Group behaviour and inattention
  Among others, the lack of coordination between the group members and the inattention of the following group members, especially when the group members ahead of them are turning, can be observed in the accidents.

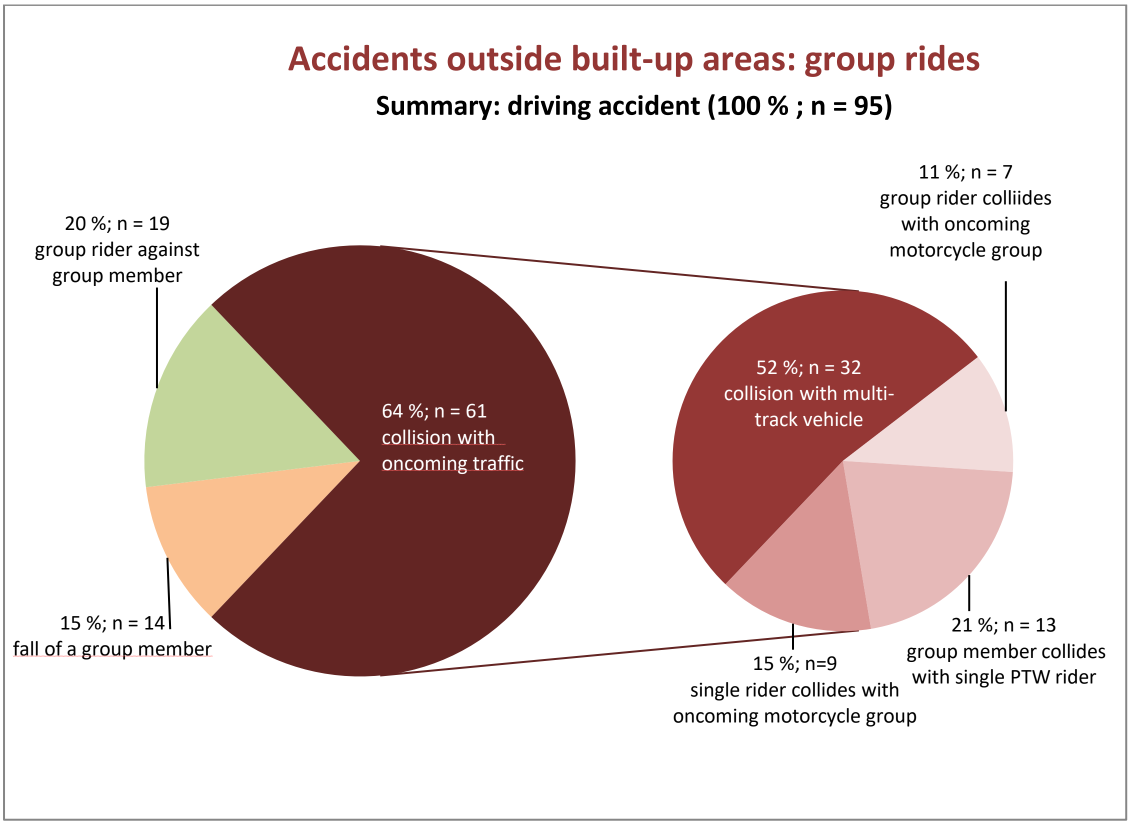

Fig. 12: Accidents of motorcycle group rides outside built-up areas: summary for the accident type “driving accident”

4. Summary

Group motorbike rides have special features in terms of accident occurrence and differ from the known accident patterns for individual motorbike rides. One striking difference is the very high proportion of group members involved and involved in accidents.
In all 225 accidents, a total of 360 riding members of the motorbike groups were involved. Unfavourable group dynamics as well as the motorcyclists' misjudgment of their chosen speed, safety distance and their own inattention appear to be causal factors in these accidents.

The following measures can help to reduce these accidents in the future.

- Avoidance of excessive and inappropriate speeds
- Keeping a safe distance from the group members in front.
- Avoid side-by-side driving by group members
- Only initiate overtaking manoeuvres if the traffic situation allows it.
- Better and unambiguous coordination between group members