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Evaluation of rider's support systems in Power Two Wheelers (PTWs)

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Abstract

The study aimed to investigate the potential of In-Vehicle Information Systems (IVIS) integration on motorcycles for the most crucial functionalities and develop efficient and rider-friendly interfaces and interaction elements for riders comfort and safety. The main objectives were to estimate the safety impact and user acceptance of the prototypes in a series of pilot applications within the SAFERIDER project.
Field tests were conducted with a Piaggio MP3 Hybrid. The On-Bike Information System (OBIS) evaluated was the Navigation and Route guidance (NV, RG) with three different HMIs: Visual (display) Acoustic & Haptic (Smart Helmet). 18 riders (37 ±8.5 years old) participated in the field tests and completed a questionnaires' battery on workload and user acceptance for each condition (i.e. HMI).
Higher values were observed for the haptic HMI (5.5±1.21), then for the audio (4.51±0.84) and the lower for the visual display of the navigator (3.87±0.79) for both usability and acceptance. Sensory load is increased with the visual and audio HMI and decrease significantly ($p<.05$) with the vibration signals within the helmet. Moreover, the NV+RG experience was perceived as more stressful than the audio and haptic; with the latter being of significant magnitude ($p<.05$). Statistically significant higher physical activity is required in the visually demanding condition (Navigation and Route Guidance display) compared to the haptic signalling condition ($p=.015$). Safety, performance and derived enjoyment by the riding experience are increased and perceived risk is decreased.
Overall, the haptic HMI was the most preferred and was perceived as safer for the Navigation and Route Guidance system. Moreover, most participants believed that they would use it in urban and unfamiliar traffic environments as it was more appealing and pleasant.

Keywords: PTW; HMI; navigation; OBIS; information system; visual; acoustic; haptic

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1. Introduction

Fundamental differences between Power Two-Wheelers (PTWs) and passenger cars exist and are evident in accident statistics for both vehicle types. PTWs have low visibility, are less stable when compared to passenger cars and riders are extremely vulnerable to accidents and falls. The protection provided by the PTW to the rider is very limited in case of an accident. It is evident from research findings that riders are involved in a disproportionately high percentage of fatal and serious accidents, most of which are in cities and caused by human error. Motorcycle and moped fatalities accounted for 17.8% of the total number of road accident fatalities in 2003, in EU-14 member countries.

According to the US National Center for Statistics & Analysis fatality rates have increased the last years in US which implies that the rate of increase in fatalities has outpaced the rate of increase in motorcycle exposure. Specifically, fatalities per 100 million PTWs are 33.96, up from 20.99 in 1997 (61% increase) and per 100,000 registered vehicles 64.82, up from 55.30 in 1997 (17% increase). A motorcycle rider is 26 times more likely to die in a crash compared to a driver of a passenger car; whilst taking into account mileage driven (NCSA, 2004).

Current research highlights that cars are the principal cause of road traffic deaths of pedestrians, cyclists and motorcyclists (MAIDS 2004; ETSC, 2003). PTW riders are vulnerable road users and have a high risk of injury, however they are not involved in more ‘unwanted’ road traffic accidents than four-wheel vehicles and therefore are not ‘careless’ road users when comparing to four-wheel vehicle drivers (FEMA, 2006).

These findings were taken into serious considerations during the development phase of the proper ARAS/OBIS functionalities in relation to riders’ safety and PTW accident reduction target through their implementation. The adaptation and implementation of appropriate ADAS/IVIS technologies in PTWs might contribute to the significant enhancement of riders’ safety. Most countries have a large proportion of motorcycle fatalities among riders aged 25 years and older. Hence, new types of technologies could productively (i.e. safety-wise) attract this young rider groups.

Experimental devices have been developed in order to prevent or minimise injuries (e.g. airbags, ABS/CBS brake systems etc.). Many devices and entertainment systems already fitted to passenger cars have started also to emerge for PTWs. The rider’s vulnerability demands the use of assistive systems and devices that would minimise their interference with the riding task. In other words, the transferability of some systems from passenger cars to PTWs may be diminished by the inherent limitations of the riding experience. Navigation systems can be found abundantly in market nowadays. Improvements and enhancements of PTWs have led the way to many more users to take longer trips to unfamiliar places (i.e. using their PTW for long-distance travelling and leisure purposes). Therefore the application of navigation systems should interfere as less as possible in the riding task itself as the skills involved in riding are more complex and demanding when compared to driving a passenger car. It should be mentioned that visual in-vehicle navigation and/or traffic information displays have been shown to have negative effects on traffic safety (Janssen, Kaptein, & Claessens, 2000; Liu, 2001). Change of eye gaze direction to check the status of route guidance for a rider to be visual load of increased impact when compared to the same task for a passenger car. These safety impact aspects were taken into consideration when designing and testing the systems developed for the undertaken field study.

This study was conducted within the framework of the Collaborative Project SAFERIDER which was a 3-year EC co-funded project aiming at enhancing motorcycle rider safety by extending and adapting ADAS/IVIS “know-how” and technologies from the automotive sector to develop novel Advanced Rider Assistance Systems (ARAS) and optimise the interface of On Bike Information Systems (OBIS) for the general population of riders and all motorcycle types.

The systems developed were functionally tested and verified prior the field tests tool place. Beyond any types of objectification it was crucial to gather data and translate them into beliefs and attitudes

representing riders as a group of road users that are recipients of new and innovative assistive systems. Thus, a user-centered approach was adopted for this study.
Therefore, the main objectives were to investigate the satisfaction of the user by the system tested and involved HMIs (e.g. haptic or auditory), the easiness of the application (e.g. learnability) and usability. All these key subjective parameters might be translated -for inferences purposes-to the successfulness of applying this type of system in riders' travelling riding regime (e.g. every time they are on holidays). The subjective assessment comprises the following clusters:

- Workload and safety evaluation: investigation of the impact of the system on riding.
- Acceptability evaluation: investigation of the system acceptability in terms of social
- Acceptability and practical acceptability (e.g. usefulness, cost).

Besides, the user-centred view covers the usability and attractiveness of the system perceived by the users. It deals with attributes the riders associate to the system and to riding with the system (including feelings of safety and enjoyment). Finally, the riders' acceptance of the system plays a decisive role in the system evaluation; it is strongly linked to the rider's intention to use the system, as well as the willingness to own the system and to spend money for acquiring it. Including the users' opinions is therefore an extremely important aspect when evaluating a new system and when preparing its entrance to the market.

In the present document, the results from the evaluation of the Navigation and Route Guidance system are presented from the user tests carried out in Greece. Navigation & Route Guidance provides a key function for novice riders and tourist by integrating On-BIKE System and positioning data. Two facts were important for the applicability of these findings. Firstly, the use of Power Two Wheelers (PTWs) is abundant in southern Europe. Greece has the highest ownership rate with 150 mopeds and 100 motorcycles per 1000 inhabitants. Secondly, good weather conditions in Greece allow for long and leisure oriented travelling with PTWs.

2. Methods

2.1. Participants

Participants were recruited via a driving/riding training centre and were not professional drivers or individuals associated with the research institute. The following criteria applied:

- Inclusion criteria: riding experience ≥ 3 years
- Exclusion criteria: physical and cognitive limitations that would endanger the participant's safety

Gender issues were taken into serious consideration, however the response was not as expected (i.e. higher number of male riders responded).

The following table gives an overview of the sample's demographic characteristics based on the Riding Profile Questionnaire.

Table 1. Demographic characteristics of field tests' sample

Gender	*Age*	*Riding experience*	*Km ridden per year*	*Km ridden since license*	*Bike type*
15M/3F	37.1±8.5	21.33±14.7	11583.3±8765.3	183823.5±107143.7	Majority Touring (34%)

All participants ride on a daily basis for commuting purposes at urban traffic environments most of the time and all year round. The prominent type of motorcycle was touring (34%). High standard deviations were obtained due to two participants riding for less than three years. However, all participants were experienced riders with regard both riding years since license was obtained and distance ridden per year. Particularly in this evaluation, riders were asked if they have been using navigator systems as drivers and/or riders. Only six participants (33%) are using on a regular basis a navigator system in their own vehicle and that is their passenger car. The latter was taken into account when the system and the display (HMI) were explained and described to them (briefing session) and, also, during evaluation. The number of participants sufficed in order to reveal significances in a within-participants' condition (Cohen, 1988).

2.2. Instrumentation

Field tests at HIT were conducted with the Piaggio scooter shown below (fig. 1). The Piaggio MP3 Hybrid uses a 125cc four-stroke engine, and a battery-driven 2.6 kW (3.5 hp, 15Nm max torque) electric motor, with a regenerative braking system. The vehicle has three user-selected variants of hybrid drive to create a vehicle capable of up to 1.67 L/100km and 0–97 km/h in 5 seconds when both methods of propulsion are used. In electric-only mode the MP3 can travel a distance of 18 km at a maximum speed of 32 km/h. When both power sources are used the MP3 can run for a maximum of 25 minutes, with performance equivalent to a 250 cc scooter. When powered solely by the petrol engine the MP3 is slower than other 125cc machines due to its weight (249 kg) compared with 208kg for the petrol-only MP3 model. The MP3 Hybrid is equipped with a generator of 1.5 kW max power.

Fig. 1. MP3 Hybrid (CERTH) and the Navigation and Route Guidance system

The route was chosen because of its proximity to the HIT premises and its inherent potentials for testing the systems. Each route lasted approximately 20 minutes and duration depended on traffic volume.

2.3. Subjective scales

Subjective scales were applied in order to evaluate the criteria set. The questionnaires applied were translated in native language and back translated to ensure content validity. The following table presents the questionnaires, scales, and open ended interview used as proposed.

The procedure to set up the Driving Activity Load Index (DALI) (Pauzié, 2008) was to ask various experts involved in the driving task studies to define which were, in their opinion, the main factors inducing mental workload for people driving a vehicle equipped with an on-board system (car phone, driving aid system, radio, etc.). This investigation leads to the following definitions for the 6 workload dimensions for the DALI: Effort of attention, Visual demand, Auditory demand, Temporal demand, Interference & Situational stress. After discussion with experts in the area of riding, we propose to adapt this tool to the riding context, the same way it has been done for the NASA-TLX being adapted to the driving context. We propose the first version of the RALI to have the following factors: Visual Demand, Auditory Demand, Temporal Demand, System Interference, Effort of Attention, Situation Own Coping, Situational Stress, Emotions Handling Vehicle. The two main factors added as they seem to be typical from the riding context are: “SITUATION OWN COPING” for “To evaluate the workload induced for coping with the other vehicles and with the complexity of the environment” and “EMOTIONS HANDLING VEHICLE” for “To evaluate the level of negative emotions linked to the control and the handling of the motorbike.” (Lot et al., 2009).

Overall evaluation of the ride was based on a 9-item questionnaire on a five point scale (from 1:low to 5:high). The system evaluation questionnaire comprised 18 items with pair representing extreme contrasts (i.e. 7 scale; weak to strong). The possibilities between the extremes enabled the participant to describe the intensity of the quality they choose (clustered in three major qualities: Ergonomic, Hedonic, and Appeal) (Lot et al., 2009). In addition, the willingness to have and pay for the tested systems, functionalities and HMIs was investigated by the administration of simple and straightforward questionnaires.

Table 2. Overview of materials during the tests

Evaluation focus	***Materials***	
	Questionnaires	*Interview* and *experimenter notes* clustered on topics
Workload	Evaluation of ride respective items, RALI	
Acceptance	HMI items on and attrakdiff items (hedonic and appeal qualities composite ratings)	
WtH and WtP	Respective questions on the marketability perspectives	

The questionnaire set specifically adapted for OBIS systems was applied in all conditions. Materials, data gathering, storing, coding, analyses and safe keeping were used and implemented according to Ethical guidelines defined by the Regional Ethics Committee.

The study focus was to investigate the subjective perception of acceptance and perceived usefulness of the proposed functions and developed HMIs, therefore no objective data were gathered.

2.4. Design

A within participants' design was implemented with all participants (N=18) in the following conditions:
System: Navigation and Route Guidance

- **HMI :** Navigation and Route Guidance visual display
- **HMI:** Navigation and Audio (Smart Helmet)
- **HMI:** Navigation and Haptic (Smart Helmet)

2.5. Procedure

The conditions conduction was counterbalanced in order to control for order and learning effects (i.e. route over-familiarisation). Prior testing participants were familiarised with the scooter in order to avoid any learning process effects impeding and, therefore, confounding the results. In addition, participants were briefed and informed consent was obtained before testing was initiated. Participants were assured that confidentiality act was followed. Participants were allocated a Unique Identification Number (UIN) and only the test leader had access to raw data. Raw data and paper materials will be kept in safe place until the end of the project.
Participants were debriefed and honoraria were given. In addition, participants were let know that in case they wanted to be informed about the findings of the testing, they could leave their details to the secretary desk.
All participants followed the same route in order to evaluate the Navigation and Route Guidance system. Tests were performed in good weather conditions. All steps such as briefing, consent, procedural steps were identical in all field trials. It is important to note that Navigation and Route Guidance system was evaluated for the three following HMIs:

- Navigation and Route Guidance visual display-*Visual*
- Acoustic signal and information (Smart Helmet)-*Acoustic*
- Tactile signal – (Smart Helmet) – *Haptic*

Participants were familiarised with both MP3 hybrid and the navigation system just after the briefing process. It was essential for them to understand the nature of guidance, the way it was provided (e.g. flagging, green light for routing) and the HMI details associated with the content and nature of information presented in all modalities in order to isolate misunderstanding due to information loss.
As most tests were part of a greater procedure, then the baseline assessment (no system on) was shared for OBIS field tests. According to the hypotheses tested in Navigation and Route Guidance system would increase perceived safety and usability (both acoustic and haptic).
It is essential to note that the OBIS systems again are being tested as a "unit" and not separate evaluation have been performed thus isolated weight and contribution of each sub-system is not possible to be investigated. Nevertheless, its applicability as a multi-component system may be of increased plausibility in real life settings which substantially increases its validity for future impact and application to motorbike industry.
Tests were conducted under good weather conditions. All participants consented prior participation. Insurance, safety and legal issues were ensured and taken into serious consideration to protect participants. As participants have not consented for video/photographic material, no such material is provided.
Pilots were conducted during daytime obviously for safety reasons. Moreover, the effect of weather conditions was a variable that it was decided not to be taken into account. In addition, the systems

interaction with weather conditions have not been verified, hence no testing was carried out in adverse weather conditions.

2.6. Statistical analysis

Data were entered and coded in an Excel file according to the existing template. Descriptive statistics were prepared depending on the data type. Ordinal variables were calculated as median values. However, the data consolidation procedure required mean scores to be presented. Current research emphasises the applicability of mean calculations -still with hesitation- when the number of participants is adequate. In this case, the number of participants for within participants' design suffice as it is above the "rule of thumb" (i.e. Nsample >16) (Cohen, 1988). Dichotomous variables were presented as percentages (%). Repeated measures non-parametric tests (Friedman tests) were performed wherever violation of the normality (Kolmogorov-Smirnov) and homoscedasticity (Levene's test) assumption were reported. The α level was set at .05. Tests applied were one-tailed due to adapting directional experimental hypotheses.

3. Results

3.1. Usability

The level of use with regard pragmatic and ergonomic value for the riders has been evaluated through the extremes questionnaires by intensity of quality. As shown below, the higher values with regard both usability (ergonomic quality composite scores) and acceptance (hedonic and appeal) are observed for the haptic HMI (5.5±1.21), then for the audio (4.51±0.84) and the lower for the visual display of the navigator (3.87±0.79). According to the riders' responses in the final interview, most participants (12/18) had full understanding of the NV+RG system and rated the haptic ride as the most preferable and safe one.

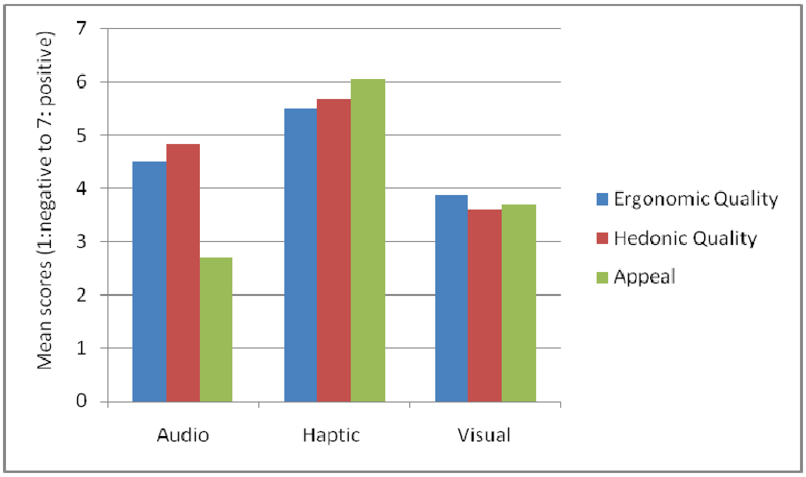

Fig. 2. Mean scores for Attrakdiff clustered into the three main quality groups for the evaluated HMIs

3.2. Workload

The adapted index (RALI) aimed at evaluating the load (e.g. visual, temporal demand) within each condition for the riders. According to the initial experimental hypotheses load should decrease with the assisting HMIs. As shown below (figure 15) the greater differences among conditions are observed in the “demand” and “required attention” items. In other words, sensory load is increased with the visual and audio HMI and decrease significantly ($p<.05$) with the vibration signals within the helmet. Therefore, the null hypotheses are accepted for the navigation and route guidance display and the auditory HMIs and rejected for the haptic. Moreover, the NV+RG experience was perceived as more stressful than the audio and haptic; with the latter being of significant magnitude ($p<.05$). The increased stress provoking condition compared to haptic sensations was the result of added demand on visual field adjustment. Participants noted that the NV+RG system was placed quite low on the scooter, leading to extra effort of attention in order to follow the route. Participants had to take their eyes off the road in order to check for the green route line leading to decrease of safety feeling during the riding task.

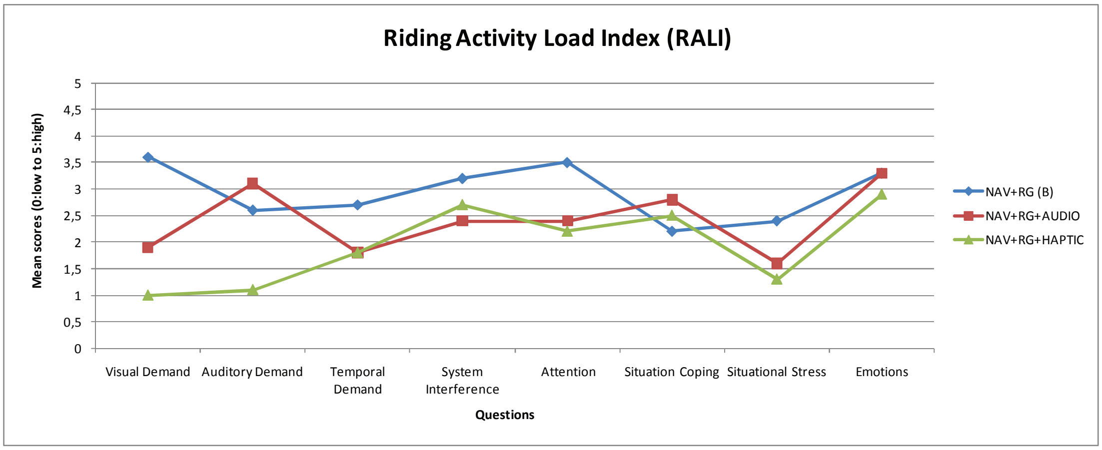

Fig. 3. Mean scores of load (RALI) for the NV+RG system

3.3. User acceptance

The haptic HMI was both the most enjoyable (5.67±0.92) and most appealing (6.06±1.23). However, the least appealing was the visual display (3.7±1.02). However, the experimenters –based on the comments and feedback received in the interview- suspect that the evaluation of the visual display incorporated evaluation of the NV+RG system as a whole and variations resulting from the attention distracting element identified during the tests. Additionally, riders who had a navigation system installed in their vehicles (passenger cars) were more positive towards the navigation system due to familiarisation and increased literacy for such type of information systems (feedback derived by the final interview).
With regard willingness to have (WtH) and willingness to pay (WtP), most riders showed interest towards both HMIs; for the audio (10/18) and the haptic HMI (11/18), respectively. However, the preferred amounts were higher for the haptic HMI (250-500€) compared to the audio alternative (100-250€). It seemed very interesting the fact that their willingness to have and pay highly correlated which could be interpreted into a desirable and marketable product.

3.4. Riding experience

Personal ride evaluations are depicted in the following graph. Statistically significant higher physical activity is required in the visually demanding condition (Navigation and Route Guidance display) compared to the haptic signalling condition (*p*=.015).

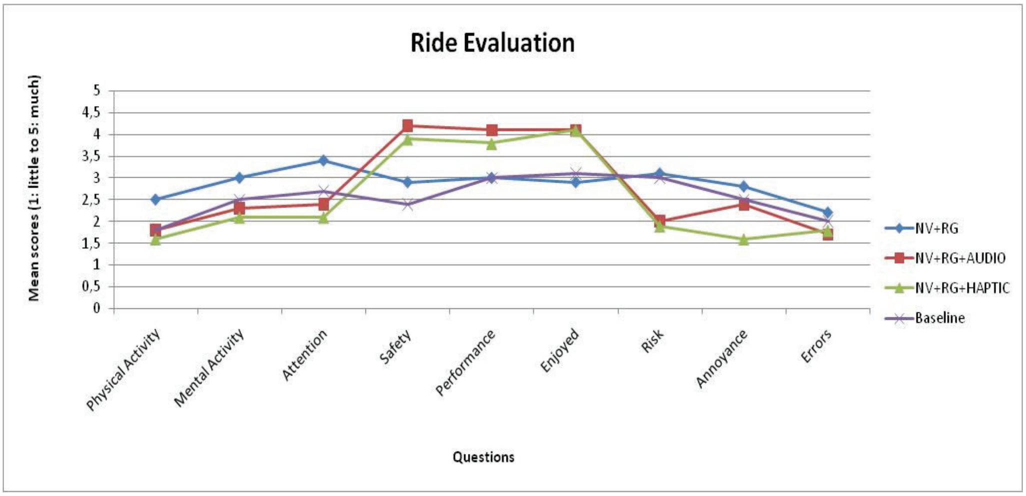

Fig. 4. Mean scores of Ride Evaluation questionnaire for Navigation and Route Guidance system

4. Conclusions

Overall, the haptic HMI was the most preferred and was perceived as safer for the Navigation and Route Guidance system. Moreover, most participants believed that they would use it in urban and unfamiliar traffic environments as it was more appealing and pleasant. In addition, timing was reported to be slow; however as it is an adjustment easily made, participants thought that the haptic option was a very "want-to-have on board" addition. On the contrary, the navigation system placement on the motorcycle was suggested to be changed in order not to be distracting and, hence, be a less safe option.

Most participants viewed the application of navigation support as innovative and acknowledged as useful. On the other hand, riders discussed about the need of certain time in order to habituate to the support of the navigation to their route choice. Time is important for riders in order to increase their confidence in the application of assistive devices. Therefore, naturalistic testing elements would support the acceptance of navigation systems for riders as it is already a common practice in Field Operational Tests (FOTs) for drivers.

The effectiveness of a system is closely connected to the HMI element particulars. It was obvious from the findings that participants showed strong preference towards the haptic version of receiving information through the specially designed helmet. Thus, further research efforts with regards imminent conditions should place emphasis on haptic signals and auditory information to be short and concise in order to avoid extra workload with consideration of timing of information. Temporal performance was slightly delayed and it a future consideration for adjustment. However, the later is a technical adjustment that could be easily standardised per navigation and route guidance system used in order not to interfere with the acceleration behaviour of the rider. Therefore, the distracting visual input by the navigation system interface (e.g. maps and route lines) should be supplemented by haptic and auditory feedback.

It is important to be taken into serious consideration the related effort (workload) required by the rider to in order to achieve a certain riding task (i.e. find the preferred route on the navigation system and follow it with taking into account the received haptic/auditory feedback) the accompanying stress produced by both the novelty of the situation but also by the non familiarity of the system tested and the differences between their own PTW and the demonstrator used during the field tests. Again, long term testing would increase their confidence and trust to the system used.

Most participants were positive towards the application of the system especially in unfamiliar routes as tourists (i.e. for long leisure rides). Hence, the choice of activation as a choice for the rider is an important element. Riders in general show increased willing to possess such a system on their PTWs. However they are hesitant as they believe the costs of both the instrumentation and the respective services might not be affordable. The latter is an important aspect for introducing the navigation and route guidance system with different HMIs to the relevant market.

Future relevant research endeavours should include large cohorts for a long period of time with strong naturalistic elements in their design and across various types of riders (e.g. leisure, commuting, young, novice, etc.) and PTWs accompanied by standardised and synchronised objective data in order to investigate potential correlations. Moreover, further testing would allow for customising the systems in order to avoid any potential conflict with supplementary or already existing systems on the PTWs.

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