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SAFETY RELATED ASPECTS OF HUMAN MACHINE INTERFACE REGARDING INVEHICLE ITS AND ELECTRIC VEHICLES

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Abstract: *The launch of electric vehicles and ITS initiated new challenges for design related ergonomics in the vehicles, especially in the field of Human Machine Interface (HMI). This research is motivated by the necessity for evaluation of current ergonomic and design solutions of contemporary vehicles. The presented study included a review of available literature and regulations, state of the art, as well as operational analysis based on detailed comparison between two vehicles. The assessment has been done between two existing vehicles of the same model, the first one powered by the internal combustion engine, and the other one powered by an electric engine. The information displays, vehicle controls and secondary vehicle controls of both vehicles were carefully analyzed and compared. The results of the study are presented as a source of preliminary understanding of the newly developed technology for designers, experts dealing with safety issues and other professionals.*

Keywords: SAFETY, ELECTRIC VEHICLE, ERGONOMICS, INTELLIGENT TRANSPORT SYSTEMS, HUMAN MACHINE INTERFACE, VEHICLE DESIGN.

1. Introduction

The general development of technology has an important impact in the world of vehicles design, not only on the exterior, but also on the vehicles interior, figure 1 [7]. At the same time, that process carries many risks and dangers which must be taken into serious consideration regarding the safety. One of the aspects critically related to the safety is the ergonomics. Ergonomics is associated with the technology development, so the designers of vehicles meet new challenges to fit their solutions to the safety needs. Cock-pit design and other interior design elements have well-known relation with automotive safety, both active and passive. Ergonomic aspects of the design have a complex influence on the automotive safety, and innovative solutions are always welcomed. On the other hand, innovations may create a chance for improvement of the ergonomic design which should be recognized and employed by designers.

Fig. 1 *Interior of a Mercedes SL from the 1970s compared with a Present day Mercedes SL*

Two areas of vehicles development are distinguished by their multi-disciplinary and innovation - the application of intelligent transport systems (ITS) and the rising development of electric vehicles (EV). There are a number of authors already tackling these issues. On the other hand, the number of vehicles with advanced ITS components, and electric vehicles in use, is still low which limits the amount of experiences how successful designers have been in this regard. It is yet to be found out how customers perceive these problems. It is a process related to time, figure 2, [7].

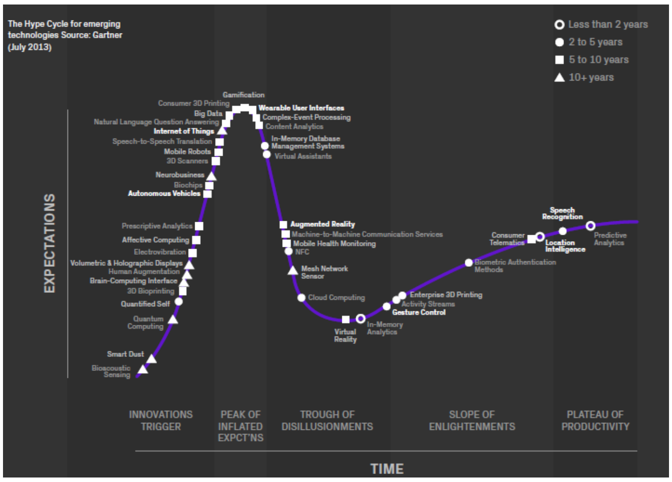

Fig. 2 *Expected emerging technologies through time*

Some ergonomic problems are typical only for electric vehicles. One of them is the lack of engine sound which could be dangerous for pedestrians. The results of the research of Bolkovac, Horvat and Jambrosik present the evident differences in acceptability of different IC engine sounds which could be potentially used as artificial warning sounds for hybrid and electric vehicles [1].

The common, quite new safety challenge related to the emerging technologies is the design of Human Machine Interface in vehicles, figure 3, [6], [8]:

"Aspects of safety:

1. Functional System Safety, which covers safety problems from hardware design and from software design. The particular focus is on technical reliability, the propensity for system malfunction and the potential to go into a dangerous and/or unanticipated system mode.

2. Human Machine Interaction (HMI), which focuses on interaction between the user and the system. Key issues are the design and location of buttons, controls and screens (size, brightness); menus; means of dialogue between the user and the system; the channel for information exchange (auditory or visual) between the user and the system; and feedback to the user (auditory, visual or haptic). Inappropriate design can lead to overload (too much effort required) or underload (the user no longer involved in the main task of driving) or to distraction from the driving task at inappropriate times.

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3. Traffic Safety whose concern is safe operation of the traffic system. It covers the outcome of both Functional System Safety and most but not all HMI problems (aspects of HMI design that do not affect safety, such as modes of operation not available while driving, are outside the traffic safety boundary). It also covers the ways in which the use of a particular system might influence road user behaviour and alter the interaction between the driver, the vehicle, the road infrastructure and other road users (including vulnerable road users such as pedestrians and cyclists) in such a way that safety is affected."

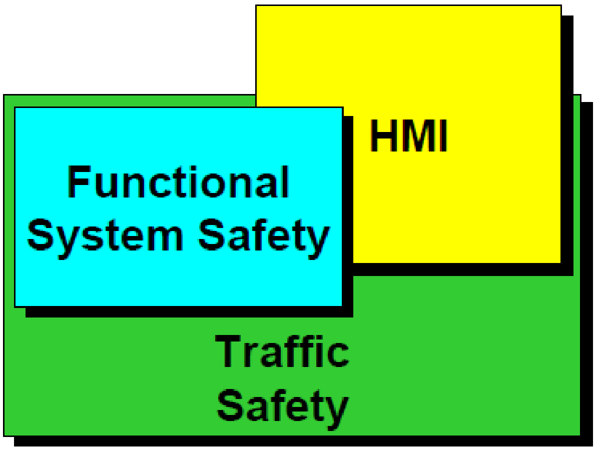

Fig. 3 *The three aspects of safety*

The rest of the paper presents a brief overview of the techniques and terminologies used in the areas of intelligent transport systems and electric and hybrid vehicles. Also it offers an initial assessment in driver behavior induced by the ergonomics, EV and ITS technologies regarding the overall safety. Furthermore, this paper presets a comparative Analysis of HMI environment between conventional and EV Versions of the same model of a vehicle. The conclusions that have risen during the performed research are presented in the final section of the paper.

2. ITS, Electric and Hybrid Vehicles – a breaf overview

Development and innovations in the field of vehicles design partially refer to introduction of electric vehicles and ITS components. As a result, there are a number of specific features from the aspects of design and ergonomics. In continuation of this section, short terminology and basic technical information related to the innovations mentioned will be given.

A. Intelligent Transport Systems ITS

Intelligent Transport Systems ITS technology allows connection and communication between vehicles, as well as between vehicles and road infrastructure. ITS covers a wide range of systems with a purpose to improve the complete picture of a safe, fluent and energy efficient road transportation. Starting from the car manufacturers implementing the new technology because of the expected wide application, interests in the development benefits caught the attention of the policy makers as well. The future of mobility is likely to be significantly changed looking at the wide range of technologies offered, starting from information of the current traffic state, collision avoidance systems, automatic emergency calls, etc. [4].

One of the most important impacts that goes alongside the intelligent transport systems is, of course, the drivers behavior. Optimizing and increasing the information that the driver gets as a feedback from the vehicle is crucial. The ergonomics and design of the vehicle have to offer clear and easy-to-understand information to the driver, and, at the same time, to avoid creating a distraction. Therefore, gathering information on the impact of the drivers' behavior to the intelligent transport systems is crucial [2].

Falko Dressler and Christoph Sommer [3] investigated the impact of human driver behavior on the quality of ITS. Their solution, which has been integrated into the publicly available Veins framework, allows running integrated simulation experiments taking the driver's behavior into account. They suggest that simple probabilistic models can be used to represent complex empirically generated models.

Classifying In-Vehicle ITS technologies according to the driver's behavior is useful in developing common understanding of these technologies. They may be thus classified into three categories: assistance by information presentation; assistance by warning under critical condition, and assistance by control under normal driving condition and under pre-crash condition. Figure 4 shows, based on this classification, the current status of In-Vehicle ITS. The typical examples include navigation systems in the field of information presentation, forward obstacle warning systems and LDWS in the field of warning; and CC under normal driving condition and CMBS (Collision mitigation braking system) under pre-crash condition in the field of control.

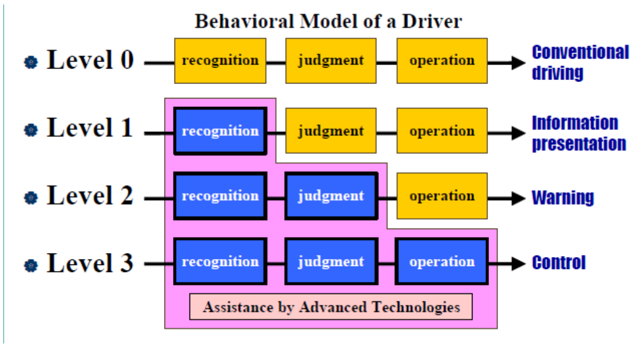

Fig. 4 *Behavioral model of a driver and level of driver assistance*

Besides the overall positive influence of the information presentation systems regarding the road safety, the excessive information presented visually and/or auditory during driving might distract the driver's attention. Regarding this notion, the information presentation systems could even impose a certain threat to the road safety.

As to the warning systems, there is not yet any common widely shared policy. Meanwhile, there is concern about confusion that might be caused among drivers by the presence of various types of warning systems on the market. It is hoped that a certain method for quantitatively evaluating these systems will be developed based on knowledge of HMI and in such a manner not to hinder advances in technologies. For example, the potential of confusing drivers is one of the subjects to be studied, including consistency with existing warning systems. Red lamps have been used, for instance, to warn against engine malfunction and brake malfunction. More recently, however, the use of colored warning signals has increased at the same rate as the increase in the number of new devices fitted into vehicles. Many of these rely upon a combination of color and symbol to describe to the driver the system that is faulty, following which the driver is expected to read the operation manual to find details of what action should be taken. While this might be acceptable for non-safety-critical systems, the basic idea of a red warning symbol is to warn the driver of an imminent danger and the indication should be clear and unambiguous.

In the field of control under normal driving condition, it seems appropriate to base it on the philosophy of the "Driver in the Loop," which means that the driver should be involved in driving operation. There are three main aspects within this philosophy: presence of driver operation in car driving; transition of control behavior from system to human driver; and driver override.

As to control under pre-crash condition, it is understood that such control is effective as damage-mitigation technology in circumstances where collision is no longer avoidable.

B. Electric and hybrid vehicles

It is very difficult to make a difference by their external appearance between the vehicles with internal combustion engine (ICE or conventional vehicles) on one hand, and the electric and hybrid vehicles on the other hand. Anyhow, the electric and hybrid vehicles have already placed a significant mark in the world of the vehicles. Even with a perception of their motion it is hard to notice any difference between conventional vehicles and electric and hybrid powered vehicles. The difference is, however, in the power-train, which is out of site of the vehicle users (Fig. 5).

Although the electric vehicle market is still at a relatively early stage of development, it has the potential to reshape the everyday use of vehicles. Having many ways of generating electricity, electric vehicles as a transformative new technology certainly find their way to feed the need of cost efficiency and ecological desirability.

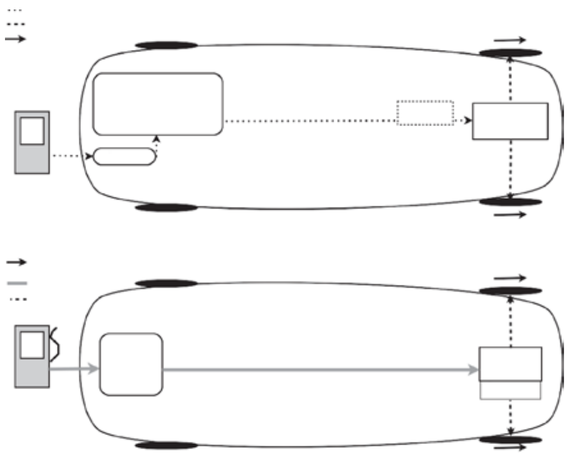

Fig. 5 *Fundamental differences between an internal combustion engine (ICE) vehicle and an electric vehicle (EV)*

3. Safety related vehicles ergonomics regarding in vehicle ITS and electric vehicles

In the last 20 years, the automotive industry experienced a massive expansion in the applied technology. From the electronics used in vehicles to the development of completely new systems, these rapid changes have created new challenges for automotive ergonomics as well. Modern technologies surround the driver in the vehicles today, starting from mobile phones, navigation, entertainment systems, etc., which pose risks of serious distractions, hence, significantly lowering the driver's attention. Undoubtedly, one of the main research challenges in the ergonomics is the visibility and drivers perception, studies of the visual attention and possible distractions.

Electric vehicles disclose a lot of new aspects related to the driver habits as well. Nevertheless, as much as the electric and conventional vehicles may seem alike from the outside, there are numerous differences in controls and cock-pit instruments which inevitably need to be designed in an ergonomic way.

In both cases (vehicles with ITS, and Electric vehicles), due to technical reasons, and the period they have intensive development, from ergonomic point of view human machine interface (HMI) appears to have important role from safety point of view.

A. Identification of the ITS elements with an ergonomic significance

Globally, the most widespread form of transport is not immune to the technologies that became a part of everyday life. Mobile phones, as the most used devices for communication, are commonly used while driving.

From automotive ergonomics point of view the in-vehicle information systems (IVIS) made a great progress by offering to the driver an access to the features such as navigation, voice control, Bluetooth, touch displays, etc., which satisfy many of the driver's needs, but, on the other hand, they entail a number of challenges and risks.

After the antilock braking system made an entrance in the active safety systems, vehicle ergonomics provided more attention to the technologies that work in preventing an accident. With introduction of the technology named advanced driver assistance systems (ADAS) it ultimately became an active safety system itself, creating completely improved driving experience. ADAS is designed to help drivers to avoid distractions by non-driving related activities, but it could also contribute to averting other kinds of distraction. ADAS is an indication that the idea of fully autonomous vehicle is not far away.

B. Identification of the elements of electric vehicles with an ergonomic significance

With the introduction of electric vehicles many challenges have emerged. Looking from the general view of conventional vehicle users the apparent "range-anxiety" was just one of the questions and worries that came along. With the rapid developing automotive industry most of the worries that were existent were put to bed early.

At-home charging being the only first option for electric vehicles was quickly accompanied by fast-charging infrastructures. Wireless charging and even more advanced batteries were implemented in the newer electric vehicles. However, the acceptance that comes from potential buyers of electric vehicles just starts here.

The necessity of "familiarity" while driving such a vehicle is also present. Therefore, the driver-vehicle interaction is as crucial here as with every other vehicle. Judging by their external look it is hard to tell the difference from conventional vehicles, and at the same time, the approaching interior of the EVs looks equally as well. When entering an electric vehicle, setting up the driver's sitting position, adjusting the steering wheel high, are just few of the procedures that are the same as the ones in any modern ICE vehicle.

Users of conventional vehicles with automatic transmission will find the EVs more familiar than users who drove only conventional vehicles with manual transmission.

The driver's behavior during the driving task could be considered on three mutually connected levels: maneuvering or control level, tactical level and strategic level [3].

The maneuvering level deals with steering inputs, gear shifting, operating the wipers and similar controls.

The tactical level (tasks that require some conscious decision making, often in response to the changing traffic environment) deals with tasks like deciding which route to take, taking a shortcut or not, adapting speed with weather driving conditions changes.

The strategic level (highly demanding cognitive tasks, learned behaviors, attitudes, and even beliefs that precipitate the relationship with the vehicle, other road users and the road environment) includes problem-solving mechanisms of plotting a route in a totally unfamiliar area, general attitudes towards speeding and risk taking, vehicle preferences, driving style and preferences, presumptions about other drivers, riders and pedestrians, and so forth.

Keeping the same three levels approach, it is noticeable that driver has to deal with changed HMI regarding the in vehicle ITS and electric vehicles. These changes are mostly related to the following aspects: Information Display, Vehicle Control and Secondary Controls (HVAC, Wipers, Charging Control) [3] as well as on the tactical and strategic level.

Information Display

Beyond the basic maneuvering level, information plays an important role to the tactical and the strategic level of driving (Michon, 1993) [3]. Electric vehicles are known as environment friendly, but the energy consumption information for the driver is of a top priority to be sure he or she will reach the destination. This information is both on the strategic and tactical level. More and more modern vehicles need to include energy demand prediction and charging facilities, as well as quickest and shortest routes. Therefore, many electric vehicles have included energy consumption information, often combined with eco-driving advice.

The type and contents of information normally are: estimated range and charging points, both visualized on the area map, instant flow of energy, battery information, and some form of longitudinal efficiency feedback based on the trip distance already covered [6].

The driver of an EV should be trained to use the power indicator instead of a tachometer in the conventional vehicle. This is very much related to the energy consumption and safety. Since there is no engine noise, which most of the drivers are used to, there persists a need of additionally developed driver's experience in order to avoid often monitoring of the indicator and the enormous power consumption.

As for the in vehicle ITS the vehicle's information display is enriched with additional symbols, tell-tails and identification of controls for each separate system or independent state. The driver needs some time to adapt to this information.

Vehicle Control

Vehicle control consists of longitudinal and lateral control.

The longitudinal control is realized through the operation of pedals and the gear level. Conventional vehicles mainly possess a classical manual gearbox, which means that the driver controls the clutch by a clutch pedal and the gearbox by a gear lever.

EVs do not need a clutch control because of the characteristics of electric motor which can start under load. Instead of a gear selector, EVs require a simple drive selector for the forward, backward and parking position. Additional driving modes such as 'eco' may be included. The drive selector is comparable with the lever of the conventional vehicle with automatic transmission. Furthermore, this is very much related to the technical solutions in the electric vehicles and the driver needs to understand these differences and to be trained how to handle that lever. It is necessary in order to avoid improper use of the gear lever and potential distraction of the driver, or even worse, unwanted behavior of the vehicle in traffic.

Secondary Controls (HVAC, Wipers, Charging Control)

Most of the secondary controls of the EVs are very similar or equal to those in the conventional vehicles: control of heating, ventilation and air-conditioning (HVAC), wipers control, and, in the case of EVs, charging control.

Control of heating, ventilation and air-conditioning (HVAC) in the electric vehicles is very much related to the total energy spending and therefore to the vehicle efficiency, which is related to the vehicle range.

Charging of electric vehicles, even with application of quick-charging equipment is incomparably longer than the filling of fuel of conventional vehicles. That empowers the need of management of the charging process and it's planning, which puts additional tasks on the driver on tactical and strategic level. This is a very important difference between conventional and electric vehicles.

On tactical level the driver takes some decisions, like deciding which route to take to the wanted destination, adapting the speed when the conditions change or making other decisions related to the changing of traffic environment. Driving an electric vehicle means that the driver should be aware of the influence of external temperature to the batteries, the electric engine and other electric systems, occasional higher quantities of water on the road and so on. Therefore, there is a necessity of such information which is normally available in user manuals. Changing the route to the final destination with electric vehicles, due to the limited possibilities of the charging, could sometimes lead to the powerless status, for example - in the case of traffic congestion in the changed route.

HVAC controls in EV allow the driver to input desired internal temperature. Since this is related to the energy consumption, and therefore to the vehicle range, there is a need for the driver to take correct decisions regarding the HVAC controls.

Charging is a new specific of electric vehicles which does not exist in the conventional vehicles. It includes several aspects, all related to this level. Those are - planning time and place of charging. There is one more task for the driver compared to conventional vehicles - to monitor battery level and to decide when to cancel the charging.

On strategic level the driver takes high demanding cognitive tasks. Most of the drivers are familiar with conventional vehicles and are capable of estimating new vehicles performances based on previous experiences. That is not a case with the electric vehicles and the drivers should be very much aware that the electric vehicles have different performances compared to the similar conventional vehicles. Without this awareness the drivers could take wrong decisions, which, having in mind the importance of this level, could lead to potentially dangerous traffic situations. Also, bad decisions of the driver could lead to empty batteries where there is no possibility of recharging.

HVAC has the similar influence on this level as on the tactical level. So, the same remarks are valid on this level, as well.

Charging of the vehicle is also related to this level. All aspects mentioned in tactical level have the same importance on this level too.

In vehicle ITS have influence on all levels of drivers behavior too. Depending on the level of in vehicle ITS, they have safety related as well as environmental impact. Cruise control system is probably the most widely used assistance system for lateral control in normal driving conditions. It is designed to maintain the preselected speed by the driver, regardless the driving conditions. This means that the system will maintain the speed on straight roads, on curves, on uphills and downhils. Pressing the throttle pedal, the driver can increase the cruising speed. After releasing the pedal, the vehicle's speed will decrease but not below the preset speed. The CC system is overridden with the break control or with the control on the steering column. During long journeys this system could contribute towards drivers comfort. The driver could stretch, slightly change his seating position and rest his legs. On the other hand this does not mean that the driver could relax on control, tactical or even on strategic level. On contrary, with the system active, the driver should increase his awareness on all three levels in order to maintain the safety level of conventional driving and to take into account the increased "energy" consumption. In conventional driving the driver maintains the desired speed mainly with the position of the throttle pedal. When the necessity for braking arises, the driver releases the throttle pedal, moves his foot on the brake pedal which is next to the throttle pedal and presses the pedal. At the very moment when the driver releases the throttle pedal, the vehicle loses power and the speed decreases. This process lasts till the driver presses the brake pedal, when the deceleration of the vehicle is intensified. When the CC system is active, the braking distance of the vehicle is longer and the driver has to be aware of this notion on tactical level. This is because of the increased driver reaction time and the functionality of the system. Namely, when the

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CC system is active, it automatically maintains the vehicle's speed. When the necessity for braking arises, the driver moves his right foot on the brake pedal and presses the pedal. Usually in this case the driver's right foot is further away from the brake pedal compared to the conventional driving. This leads to increased duration of the motoric reaction of the driver. Even if the motoric reaction of the driver is the same in both scenarios, the functionality of the CC system contributes towards increased braking distance. During the explained motoric action of the driver, the CC system is active and maintains the desired speed, i.e. during this time the power is not cut off and the vehicle does not decelerate. The power cut off and the initial braking come with pressing the brake pedal. This continuous movement of the vehicle instead of deceleration due to the external vehicle's loads and the higher initial vehicle's speed at the beginning of the braking process lead to increased braking distance. If the driver does not adapt his behavior on control and tactical level this could decrease the overall road safety. On strategic level, the driver has to be aware that the operation of the CC system could lead towards high energy demanding situations.

4. Comparative analysis of human-machine interface (HMI) environment between ICE and EV versions of the same model of a vehicle

A. Approach and operational activities

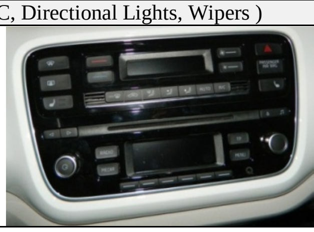
The general perception from the outside of the conventional and EV versions of Volkswagen UP confirms the already known fact that they are not different (Figures 6 and 7).

Although the electric engine seems to be the biggest difference it is certainly not the only one. The Human-Machine Interface (HMI) of the EVs differs to some degree from ICEs as well. The analysis of the differences is based on the operative review of both versions of Volkswagen Up (ICE and EV). All important aspects of the Human-Machine Interface (HMI) are checked on the vehicles and photos have been taken.


Fig. 6 External appearance of ICV Fig. 7 External appearance of EV

Table 1 shows parallel photos of information display, vehicle control and secondary controls for both vehicles. The table also contains comments for each important part of Human-Machine Interface (HMI).

Table 1: *Comparison of the controls of the both versions of Volkswagen Up*

<table>
<tr><td colspan="2">Information display</td></tr>
<tr><td>Volkswagen Up - ICE version</td><td>Volkswagen Up - E version</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Combined display
- The display is generally with the same configuration
- Speedometer in the EV version with lower maximum speed (160 km/h vs 220 km/h)
- The tachometer on the ICE version (left smaller cycle indicator) is replaced by power indicator on the electric vehicle
Fuel level indicator on the ICE version (smaller right cycle indicator) is replaced by indicator of battery level</td></tr>
<tr><td colspan="2">Vehicle control</td></tr>
<tr><td>Volkswagen Up - ICE version</td><td>Volkswagen Up - E version</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Gear control
- Both vehicles have gear control lever
- The ICE version has standard 5 gear manual transmission control lever
The EV version has “gear control” lever looking like an automatic transmission at ICE vehicles. The selectable positions are P – Parking, R – reverse, N – neutral, D – drive, B – braking which differs from the positions automatic gear lever of ICE vehicles has</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Foot control
- The ICE model has a standard configuration for manual transmission (clutch, brake and acceleration pedal)
The EV model doesn't have clutch pedal and has a wider brake pedal, as well as an acceleration pedal which makes the configuration the same as the one used in ICE vehicle models with automatic transmission</td></tr>
<tr><td colspan="2">Vehicle Secondary Controls (HVAC, Directional Lights, Wipers)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Control of heating, ventilation and air-conditioning (HVAC)
Comment:
- HVAC (Heating, Ventilation, Air Conditioning) controls take the central place on the console in both models
- The ICE model has a manual classical HVAC controls
- The EV model has HVAC control with a digital display
- The audio system controls are the same in both models</td></tr>
</table>

B. Analysis of findings

Based on the approach described above and on the content of Table 1, a comparative analysis of Human-Machine Interface between ICE and EV versions of the same model of vehicle was done. The analysis was divided on maneuvering, tactical and strategic level.

Maneuvering level

Steering input is performed via the same kind of interface - steering wheel. This activity does not differ between the analyzed vehicles. ICE vehicle possesses a classical manual gearbox. The electric vehicle does not have a clutch, therefore, the clutch pedal is missing. Regardless, the gear lever looks like the lever of in the ICE vehicle with automatic transmission, its function differs and that can be seen by the marks on the lever. The acceleration pedal is on the same place in both vehicles and its use is the same. Other controls on this level, like those for direction indicators and wipers, are the same in both vehicles.

Tactical level

The analyzed electric vehicle does not possess additional indicators which would assist the driver in taking the above elaborated decisions on tacktical level.

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Strategic level

The analyzed electric vehicle has no interface which could assist the driver in relation to the activities on this level. There are no such interfaces in the ICE vehicle as well.

5. Conclusion

The development of the ITS and electric vehicles is in a phase in which there is a need of complex approach towards instructing the drivers and other users how to take all the advantages they offer and avoid potential weaknesses. The ergonomic aspects from that point of view can be studied through human-machine interfaces. Such study should consider all three levels of the driver's activities on the maneuvering, tactical and strategic level.

The results of the analysis done in this paper show that, besides the fact that it belongs to a lower class of vehicles, the electric version of Volkswagen Up, HMI has an influence on all three levels of driver activities. Due to the lack of experience of the drivers with electric vehicles there is an obvious need for them to be equipped with components of advanced driver assistant systems (ADAS) which could protect the driver from taking wrong decisions on each level. For the time being that is to be expected in high classes of conventional end electric vehicles and due to the price limitation that will not be a case in cheaper electric vehicles. Therefore, there is a need for a specific training of the new electric vehicle users.

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