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ASSESSMENT OF SAFETY AND RIDE QUALITY BASED ON COMPARATIVE STUDIES OF A NEW TYPE OF UNIVERSAL STEERING WHEEL IN 3D SIMULATORS

OCENA BEZPIECZEŃSTWA I JAKOŚCI JAZDY NOWEGO TYPU KIEROWNICY UNIWERSALNEJ NA PODSTAWIE BADAŃ PORÓWNAWCZYCH NA SYMULATORACH 3D

The aim of this study was to investigate how a change in the design of steering wheel may affect the safety and quality of driving by the driver. The object of the research was a new universal steering wheel enabling driving the car using only hands - intended for use by both able-bodied and disabled people. In order to assess the functionality of the steering wheel, a comparative study was carried out, with respect to a classic steering wheel. The study was performed using a dynamic simulator; with methodology developed especially for this experiment, introducing the so-called reference trajectory. The use of this trajectory allowed the introduction of qualitative criteria of road tests based on a measure of distance. The article presents the defined criteria. Drives of 30 drivers in "route" and "slalom" type road test were carried out. The article discusses the results of the slalom test. In this test, the driver's task was to maintain the reference trajectory while passing through narrowing curves. Statistical analysis showed significant difference in the value of selected steering wheel assessment indicators.

Keywords: universal steering wheel, electric car, reference trajectory, "slalom" road test, "post-hoc" analysis.

Celem niniejszej pracy było zbadanie jak zmiana konstrukcji kierownicy może wpływać na bezpieczeństwo i jakość prowadzenia samochodu przez kierowcę. Przedmiotem badań była nowa kierownica uniwersalna umożliwiająca kierowanie samochodem wyłącznie z użyciem rąk - przeznaczona do użytku zarówno przez osoby sprawne jak i niepełnosprawne. W celu oceny funkcjonalności tej kierownicy przeprowadzono badania porównawcze funkcjonalności w stosunku do kierownicy klasycznej. Badania wykonano na symulatorze dynamicznym stosując w tym celu specjalnie opracowaną metodykę eksperymentu wprowadzającą tzw. referencyjny tor ruchu. Zastosowanie tego toru umożliwiło wprowadzenie kryteriów jakości przejazdów testów drogowych w oparciu o miary odległości. Artykuł przedstawia zdefiniowane kryteria. Zbadano przejazdy 30 kierowców w testach drogowych typu „trasa” i „slalom”. Artykuł omawia wyniki testu slalom. W tym teście, zadaniem kierowcy prowadzącego pojazd było utrzymanie referencyjnego toru ruchu podczas przejazdu przez zawężające się serpentyne. Analiza statystyczna wyniku ukazała istotne różnice wartości zastosowanych wskaźników oceny kierownic.

Słowa kluczowe: kierownica uniwersalna, samochód elektryczny, referencyjny tor ruchu, test drogowy „slalom”, analiza „post-hoc”.

1. Introduction

This article will present the results of comparative tests of the functionality of new type of a universal steering wheel, intended to use as HMI to drive a so-called ECO car by both disabled and able-bodied people. The already mentioned ECO car would be characterized, among other things, by electric drive and "steer by wire" system (which is of particular importance in designing adaptive human-vehicle interface). The car was designed as part of the "Eco-Mobility" project implemented under the Innovative Economy Operational Programme co-financed from European Regional Development Fund. The prototype of the car and some of its functions were demonstrated on the "eco-mobilność" website [4, 2].

An able-bodied person is sitting in a driver's seat (in the car's equipment), while the disabled person can drive the car sitting in their

own wheelchair. The functionality feature of the steering wheel which is distinctive from the classic steering system (classic steering wheel + pedals) is the opportunity to drive the vehicle using only hands (without using legs). The steering wheel developed as part of the ECO Mobility project is part of a system that allows a disabled person to use a car completely on their own (without any help from others). The same car can also be used by able-bodied people - hence the notion of its "universality".

ECO steering wheel is essentially adapted to drive cars with Steer-by-wire system [13, 6]. This solution makes it possible to program the steering angle corresponding to the maximum steering angle of the front wheels. There is a possibility to adjust the so-called melt steering ratio (obviously not while driving). In these studies, there were two different combinations included: 180° to 35° and 120° to 35°. These changes are intended to limit the angle of rotation of the steering

wheel during a turn so that people with partial locomotor dysfunction would not need to interrupt hand-steering wheel contact.

The concept of the aftermentioned research is based on carrying out an experiment on dynamic 3D vehicle simulators. In studies on 3D simulator was used validated car model of Kia cee'd mark. As is known in this type of model driving characteristics are strongly dependent on the model structure on tires and suspension [12]. These simulators are equipped with a new interface (in this case, a new steering wheel) and a classic steering system. The procedure of the study covered: developing 2 tests, making measurements of dynamic waveforms of selected parameters during implementation of the tests, defining their metrics and characteristics allowing for inference and evaluation of used interfaces.

Recently there has been quite a lot of research on the use for different types of HMI for driving a car by the elderly or disabled. They concern a wide variety of driving problems, where different systemic solutions are analyzed, such as, for instance, joystick [9], steering wheel [7, 8] or other mechatronic systems [5, 3]. There were also studies on the reaction of a disabled driver performed on 3D simulators [11], as well as analyses of the safety of a disabled driver in frontal impact conditions [10]. The research carried out under the ECO Mobility project is inherent to this area of work. The so-called ECO steering wheel, however, is different in its functionality from the ones described. Preliminary assumptions to the tests of functionality of this steering wheel were presented at two conferences [1]. This article will present the actual results of statistical analyses on passing the "slalom" test.

The aim of the research was to find answers to two questions. Firstly, how is the functionality of ECO steering wheel different in comparison to the classic system? Secondly, which ratio for the ECO steering wheels is better?

The basic scientific problem described in this article concerns the possibility of determining the statistic features of the steering wheel's functionality. The features of the stochastic process in this case depend on the type of steering wheel and the driver's temperament. Therefore, they can be strongly individualized. This means that there is a need for individual assessment of runs per driver, which translated into difficulty in the construction of the so-called "universal driver" - representing all the characteristics of the drives of the group of drivers involved in the experiment.

Fig. 1 shows: a) ECO car, b) ECO steering wheel (the subject of simulator studies), c) studies in a simulator.

2. Methodology of research

The research group in the experiment consisted of 26 men aged 20-23 years, all able-bodied and holding a driving license. Each driver drive the same stretch of the road, driving the car with three steering wheels. In total, each driver made three trips: with the classic steering system (this system will be called "normal" and marked NOR in the rest of the article), and with the ECO steering wheel with two lever

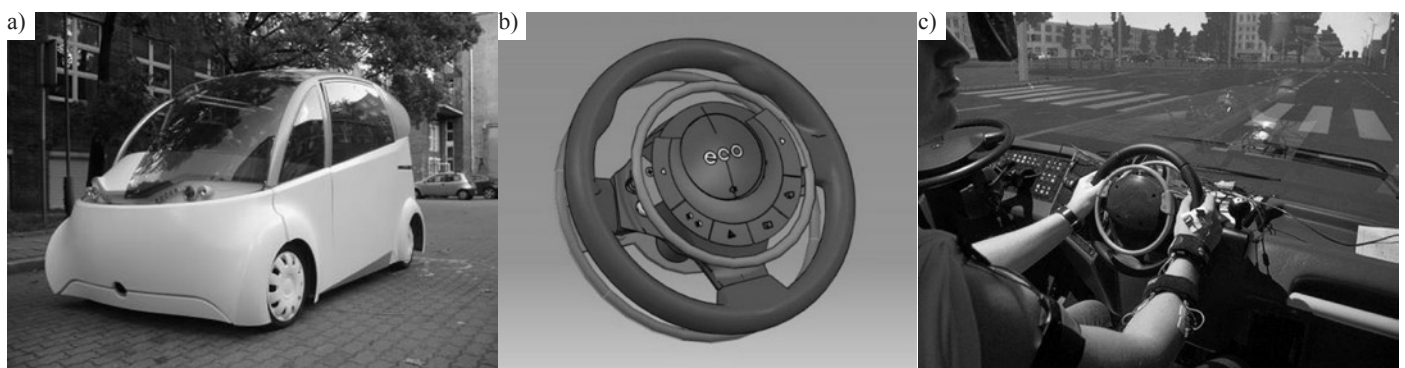


Fig. 1. The object of research: a) ECO car, b) ECO car's steering wheel, c) research station in dynamic simulator [1]

ratios: 180 and 120 (these steering wheels will be called and marked ECO 180 and ECO 120 in the rest of the article). The task of the drivers was to make a series of maneuvers: a turn, obstacle avoidance maneuver, a straight line, a slalom, avoiding a collision with a pedestrian suddenly appearing in the lane. The "slalom" test, the results of which will be discussed in the article, was planned in such a way that one can study the functionality of the steering wheel at a time where there is a need for a simultaneous change of direction and speed. An important novelty in the realization of this experiment was determining a so-called "reference trajectory", a line which was defined before the start of the experiment. The reference trajectory line was visible in the driver's cabin. Introducing this line to the experiment enabled the subsequent use of objective measures of assessment of the quality of the drive based on analyses of the distance between the geometric center of the vehicle from the reference trajectory [5, 3].

The implementation of the research required addressing the following tasks:

- Evaluation of the maneuvering and assigning each test a measure allowing for the evaluation of the maneuvers.
- Statistical evaluation of random events (involving obtaining the measure) in groups of steering wheels.

Ad a. In the first point, there are three important issues. Firstly, how to compare the drives, secondly, which state variable to measure and thirdly, how, with their timings, to determine these measures. The first problem seems most important for the correctness of the reasoning. This problem was solved quite originally in the discussed experiment, by introducing the so-called reference trajectory. The reference trajectory is defined here as a path ensuring safe drive and proper execution of the maneuvers. This path can be determined either by calculation on simulation models or by simulated drive performed by a professional driver. The task of the driver involved in the experiment was keeping up the vehicle with the line of reference trajectory with set speed (changing in time). The location of reference trajectory was presented to the drivers in the form of markers placed in the road (Fig. 2a). In order to evaluate the course of the experiment, the following assumptions were made: the maneuver should be considered valid if a vehicle did not go outside of its lane and did not cause collision. The object of the measurements were the variables of the vehicle's condition such as: movement coordinates - the location and velocity of the simulator reference system and parameters of vehicles steering used by the drivers - the steering angle of front wheels and the intensity of the impact on the speed change systems (in the form of value of "gas" and brake". The use of reference trajectory in the experiment allowed for evaluating the adequacy of the drive by means of two measures: firstly, a transverse distance between the geometric center of the vehicle and the line of reference trajectory (marked later in the article with the symbol h) and, secondly, the speed difference between the speed reference value (assigned to the track) and actual linear velocity of the vehicle (called later in the article the tangential speed difference and marked with the symbol δv). The way to define

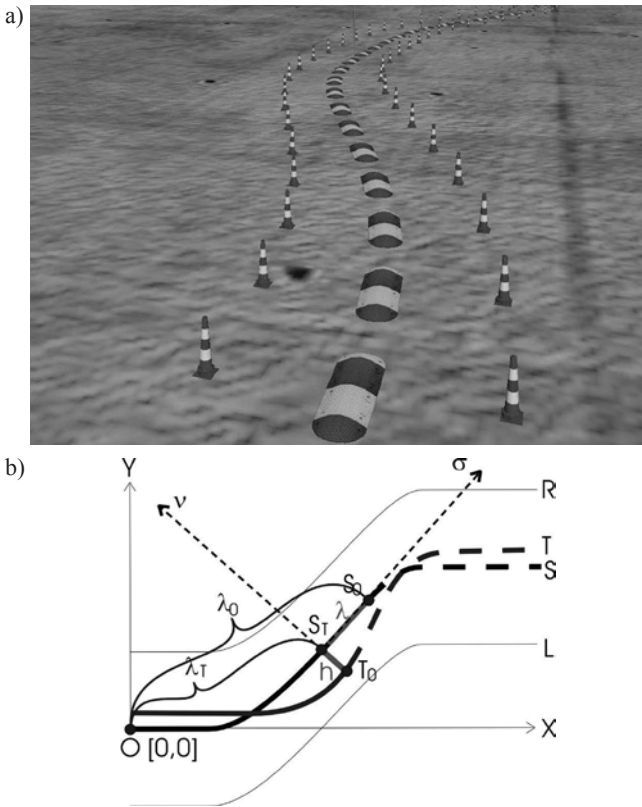


Fig. 2. Reference trajectory: a) presentation in the simulator; b) the method of assessing the path with distances in tangential and normal direction [1]

the measures is described in Fig. 2b. Distances marked: λ - distance in tangential direction, h - distance in direction normal to the reference trajectory. Path lines were marked as follows: R - line of the right edge of the lane, T - realized trajectory of the test driver, S - line of reference trajectory driver, L - line of the left edge of the lane. Points S_0 and T_0 represent the center of gravity for selected time t_0 , where S_0 - is reference location, and T_0 - location carried out when attempting to drive. The difference in tangential velocity is due to the changes in the distance in the tangential direction, which may be expressed as:

$$\delta v = \frac{d\lambda}{dt} \quad (1)$$

Using a reference trajectory sets apart the presented research methodology (the purpose of which is to analyse the driver behaviours) from the research on driving properties using, for instance, the "elk test" (aimed at analyzing the dynamic properties of the car).

- Research in dynamic simulator included 2 tests of a different kind:
- test 1 - a "route" type drive involving the study of stability of steering in the conditions of driving at a constant speed, including such "set pieces" as: straight section (1), turn (2), double lane change manoeuvre (3), second straight section (4) and avoiding a collision with a pedestrian (5),
 - test 2 - a "slalom" or "serpentine" type drive, requiring a simultaneous change in speed and direction of movement in repeating, "tightening" curves of the road.

The tests were performed with an innovative steering wheel, taking into account two leverage ratios of the steering system: $180^\circ/35^\circ$ (180) and $120^\circ/35^\circ$ (120) as well as a classic steering wheel (NOR).

This article is limited to the presentation of the results of analyses of the driving conditions waveforms in the "slalom" type test. The road system of the test is shown in Fig. 3.

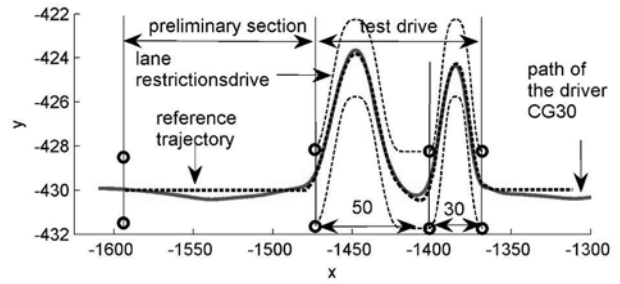


Fig. 3. The "slalom" test road system. Graphs were determined: thin dotted line - lane restrictions, bold dotted line - reference trajectory, bold solid line - path of the driver CG30 for drive using a normal steering wheel. The sections were marked: „preliminary section“ - initial phase of acceleration of the vehicle, for which there are no defined conditions of the drive, „test drive“ - "slalom" type phase of movement with restricted conditions of the drive, „50“ - fragment of the slalom with required travel speed of 50 km/h, „30“ - fragment of the slalom with required travel speed of 30 km/h

Ad. b. The collected comparative material included the results of drives by 26 drivers, made in such a way that each driver had one drive with each type of the studied steering wheel. For this reason, the research group of each driver includes 3 events. Three research groups of the steering wheels were created (each of 26 elements) and statistically analyzed.

In order to perform the analyses, the following are assumed:

1. The signals describing the drives of individual drivers using different types of steering wheels are treated as representations of random processes, stationary and ergodic
2. Signals can be described by such characteristics as:
 - a) Maximum transverse distance of the geometric center of the vehicle from the line of reference trajectory (this measure will be later identified as $\text{Max}(\text{abs}(H(t)))$),
 - b) Transverse distance RMS waveform (marked $\text{rms } H(t)$),
 - c) Tangential velocity difference RMS waveform (marked $\text{rms } \delta V(t)$),
 - d) Amplitude of the alternating component of the transverse distance waveform (marked $A(H(t))$),
 - e) Amplitude of the alternating component of the tangential velocity difference waveform (marked $A(\delta V(t))$),
3. Quality indicators are defined based on the measures of the five characteristics described above, where the indicator (a) informs about the possibility of falling out of the lane, (b) - specifies the substitute distance, (c) - the substitute speed difference, (d) - intensity of yawing and (e) - intensity of the speed oscillation,
4. Defined indicators are treated as random variables (because they are the characteristics of stationary and ergodic processes),
5. Variables are described as quantitative (since they are expressed in numbers),
6. Defined variables are dependent on the person performing the test and applied steering wheel type,
7. Variables related to the same type of steering wheel can create a group - three groups of random variables can be created for different steering wheels,

Statistical analysis was carried out in a following manner:

1. Due to the possibility of creating three groups of random variables, the analysis must take into account the mode of conduct (for many groups of variables).
2. The distribution of indicator measures in the groups do not have to be normal. The hypothesis on normal distribution will be checked using the Shapiro-Wilk parametric hypothesis test of composite normality.

- If part of the distributions is not normal, then in order to realize the same test procedure in all cases there will be performed a nonparametric test for differences between distributions. The performed test will be Friedman nonparametric two-way analysis of variance.
- The level of significance of the test will be chosen, so that the differences in distributions are emphasized - the appropriate level of significance is 0.15.

In order to identify groups of random variables where distributions are different from each other, "post-hoc" tests can be performed, such as Wilcoxon signed rank test for zero median (Bonferroni's correction will be omitted).

3. Measurement signals and quality indicators of the drive performance

Fig. 4 shows the characteristics of transverse distance $h(t)$ of the geometric center of the vehicle from the line of reference trajectory for a "slalom" type drive made on 2015-04-20 by driver code-named CG30: a) signal waveforms, using three steering wheels: normal (marked: „NOR”), ECO 180 with steering gear ratio $180^{\circ}/35^{\circ}$ (marked: „180”) and ECO 120 with steering gear ratio $120^{\circ}/35^{\circ}$ (marked: „120”). b) distributions of amplitude spectrum of the AC components of these waveforms. The drive conditions in Fig. 4a were

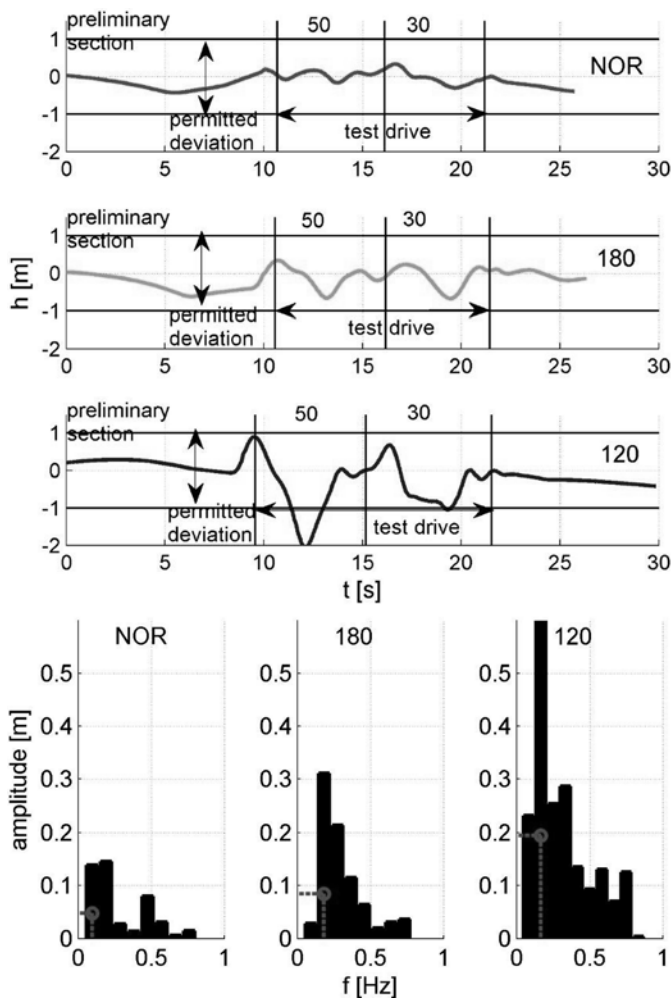


Fig. 4. The characteristics of the transverse distance signal $h(t)$ obtained for "slalom" drive by driver CG30 using three steering wheels: a) waveform, b) distribution graph of the alternate component amplitude spectrum. Graphs marked with symbols: „NOR” – normal steering wheel, „180” – ECO steering wheel with steering gear ratio $180^{\circ}/35^{\circ}$, „120” – ECO steering wheel with steering gear ratio $120^{\circ}/35^{\circ}$.

marked as follows: „preliminary section” – initial phase of acceleration of the vehicle, for which there are no defined conditions of the drive, „test drive” – “slalom” type phase of movement with restricted conditions of the drive, „50” – fragment of the slalom with required travel speed of 50 km/h, „30” – fragment of the slalom with required travel speed of 30 km/h, „permitted deviation” – the permissible width of the lane where the center of the vehicle’s gravity should be. The subject of evaluation can only be the fragment marked “test drive” for which there are specific conditions to be met by the driver. Fig. 4a shows the distance waveforms may differ as to the value of deviations and pulsation. The graph in Fig. 4a „120” shows that the geometric center of the vehicle did not fit in the required area of permissible width of the lane – therefore it did not meet the basic conditions of drive security. For this reason, next to the quantitative evaluation (transverse distance deviation RMS indicator) for these drives there should also be a qualitative assessment of admissibility of the drives in terms of traffic safety, by means of two classifiers: 1 – admissible, 0 – inadmissible. The graphs in Fig. 4a also show that the transverse distance waveforms of the three steering wheels can be characterised in terms of pulsation.

Fig. 4b shows the alternating components distribution amplitude spectrum of these waveforms. The red dot is the geometric center of the spectrum chart, the coordinates of which are set with replacement values of frequency and amplitude. These measures may also be useful to assess the quality of the drives. Fig. 4b shows distinct changes in the amplitude of the replacement component alternate of the described drives with three types of steering wheels.

4. Statistical analysis of the quality indicators characterizing the position of the vehicle when driving the slalom

Table 1 shows the distribution of the quality indicators of the drives in the groups of random variables: drivers (rows) and steering wheels (columns). From the point of view of the functionality of the steering wheels in terms of quality index, what is important is the distributions in steering wheel groups. Assessing the functionality of the steering wheel for safety of the drive, we take into account the event consisting of exceeding the allowable distance from the axis of the lane (Fig. 4a). The value of the permissible deviation from the axis of the lane is a parameter of calculations which can affect the results of the assessment (and therefore is a heuristic assumption). In order for the value of this parameter to be determined reliably, a supplementary assumption was made that the value of the width of the permissible deviation from the axis of the lane had a value of about 1m and was chosen quite restrictively (by restrictive we mean such a choice of the value so that the differences in the number of drives outside the permissible lane were as many as possible). Such a value of maximum permissible width of the lane is, for example, the value of 1.00 m.

The results of statistical analysis of the compliance of distributions are presented in table 1. Columns P determine the significance level of the null hypothesis that the presented pairs of distributions are identical (the probability of I type error of the false positive type, involving rejection of the null hypothesis despite it being true). Because the tests are primarily to show the differences in distribution, the maximum level of significance used to verify the hypothesis was adopted strictly in order to emphasize the differences: $\alpha = 0.15$. Columns H describe the accepted values of the hypothesis (0 - accept, 1 - reject). The line “out” refers to the distribution of the indicator “exceeding the permissible area of the lane”. The results presented in table 2 show that with the adopted significance level $\alpha = 0.15$ the hypothesis on the compliance of distributions NOR & 120 and 180 & 120 can be discarded. The line H of table 2 describes the results of tests performed based on transversal distance H rms distributions. These results show that this indicator does not differentiate the functionality of the steer-

Table 1. Statistics

test	FRIDMAN		Wilcoxon signed rank test for zero median					
	P	H	P			H		
			NOR & 180	NOR & 120	180&120	NOR & 180	NOR & 120	180&120
out	0.10	1	1	0.13	0.11	0	1	1
H	0.34	0	-	-	-	0	0	0
δV	0.15	1	0.03	0.09	0.73	1	1	0
A(H)	0.48	0	-	-	-	0	0	0
A(δV)	0.03	1	0.43	0.01	0.07	0	1	0

Table 2. The ranking results of groups of events for random steering wheels for the considered indicators

test	class	Ranking					
		L			P		
		-1	0	1	-1	0	1
out	NOR&180	3	20	3	-	-	-
	NOR&120	5	10	11	0.19	0.87	0.13
	180&120	2	16	8	0.08	0.61	0.31
rmsH	NOR&180	7	8	11	-	-	-
	NOR&120	8	7	5	-	-	-
	180&120	11	12	12	-	-	-
rms δV	NOR&180	15	4	7	0.58	0.15	0.27
	NOR&120	15	3	8	0.58	0.11	0.31
	180&120	9	4	13	-	-	-
A(H)	NOR&180	8	3	15	-	-	-
	NOR&120	7	5	11	-	-	-
	180&120	11	4	11	-	-	-
A(δV)	NOR&180	11	5	10	-	-	-
	NOR&120	16	6	4	-	-	-
	180&120	12	9	5	0.46	0.35	0.19

ing wheel. The line δV of table 2 shows the results of tests performed based on the tangential velocity NOR&(180V120) differ from each other while there are no differences between the distributions 180 & 120. The line A(H) of table 2 describes the results of tests performed based on the distribution of amplitude of the replacement component of alternating rums of transverse distance H. The results show that this indicator does not differentiate the functionality of the steering wheel. Line A(δV) of table 2 shows the results of tests performed based on the distribution of the amplitude of the alternating component of the substitute tangential velocity V difference waveform. The results show that the distributions NOR&120 differ while there are no difference between the distributions NOR&(120V180).

The ranking results of groups of events for random steering wheels for the considered indicators are summarized in table 2. The table also shows the probability of contingencies for pairs of groups where the Friedman test (table 2) showed non-random differences.

5. Discussion and summary

The article presents the results of research and evaluation of functionality of two different types of steering wheels:

- A normal steering wheel constituting the classic system with pedals (where maximum steering angle of the front wheels

with the value of 35° is achieved at an angle of the steering wheel with a value of 460°),

- A universal steering wheel intended to be used both by disabled people driving the car from the position of a wheelchair and the able-bodied people sitting in a driver's seat located in the car.

The universal steering wheel is handed only by hand. Its system consists of the actual wheel and supplementary O-ring to adjust the speed with the buttons of speeding and braking. The steering wheel is designed to work with a steer by wire system of an electric car. For this reason, the steering ration of the steering wheel (the ratio between angle of the steering wheel and the angle of the front wheel) can be set before starting the drive (never while moving). The subject of the study were two ECO steering wheels with two settings; 180 – ratio of $180^\circ/35^\circ$ and 120 – ratio of $120^\circ/35^\circ$. The experiment was planned in such a way as to be able to examine the functionality of the steering wheel when there is a need for a simultaneous change in direction and speed. Such a situation occurs in a “slalom” type test. The research was performed according to a new original methodology, the novelty of which is the introduction of the so-called reference trajectory. The reference trajectory is defined here as a path ensuring safe drive and proper execution of the maneuvers. Reference trajectory is visible from the driver's cabin. This trajectory is also understood as the predetermined path of movement. The second present parameter defining the traffic conditions was the driving speed. Determining driving conditions using reference trajectory and speed

also provides the basis for evaluating the quality of performance in terms of keeping the traffic conditions. The essence of this assessment the possibility of determining the waveforms of two variable distances (defined in Fig. 2b): the normal h and tangential λ . Created distance waveforms (treated as signals) may be characterized based on different characteristics, including: average value, average absolute value, standard deviation, effective value or harmonic amplitudes of the variable component. The created waveforms of transverse distance h and speed deviation in the tangential direction δv (treated as signals) allowed the use of a “post-hoc” stochastic analysis method to assess the functionality of the steering wheel based on the analysis of the similarities or differences in the statistical distributions of the five quality indicators. The quality indicators were defined based on the following characteristics of measured signals: exceeding the allowed distance of the geometric center of the vehicle from the line of lane axis, transverse distance rms, tangential velocity difference rms, substitute amplitude of the alternate component of transverse distance and tangential velocity difference waveforms.

The results of statistical analysis (with significance level $\alpha=0.15$) formed on the “slalom” type section of the road showed that:

1. The indicator “exceeding the allowed distance of the geometric center of the vehicle from the line of the axis of the lane” allows to evaluate both ECO steering wheels (180 or 120) as increasing the risk of leaving the lane. With respect to drives performed correctly using the NOR steering wheel, the probability of falling out of the lane is increased for 180 steering wheel by the value of 8/20 and for the 120 steering wheel by 11/26. Due to this indicator the ECO steering wheels are decidedly less secure than a normal steering wheel.
2. The indicator of rms of transverse distance between the geometrical center of the car and the line of the axis of lane H does not differentiate the characteristics of functionality of the steering wheels.
3. The indicator of the difference in tangential velocity δV differentiates the functionality of the normal steering wheel and ECO steering wheel. In relation to the values used in drives with NOR steering wheel, the use of ECO steering wheel (180 or 120) allows to decrease the value of tangential velocity difference δV rms with the probability of 15/26. Due to this indicator the ECO steering wheel is better than the normal steering wheel.
4. The indicator of substitute amplitude of the alternate component of the transverse distance A(H) does not differentiate the functionality of the steering wheel. Thus, in drives with different types of steering wheels there are no changes in the intensity of the phenomenon of “yawing” of the vehicle.
5. The indicator of substitute amplitude of the alternate component of the tangential velocity difference A(δV) differentiates the functionality of normal steering wheel and 120 steering wheel. It does not differentiate the functionality of normal and 180 steering wheel and does not allow to compare the functionality of 180 and 120 steering wheels. Using the 120 steering wheel allows to reduce the amplitude of the alternating component of the tangential velocity difference δV (compared to the values obtained in drives with normal steering

wheel) with the probability of 17/26. This result also means less tangential velocity oscillation for drives using the 120 steering wheel.

In conclusion, it was found that the use of ECO steering wheel reduces the driving safety. Moreover, the use of ECO steering wheel does not affect the intensity of the “yawing” phenomenon and can improve the implementation of travel due to reducing the “oscillation” of speed.

It should be assumed that the deterioration of driving safety using ECO steering wheel is connected with the necessity of simultaneous change of speed and direction movement (error of coordination). The test results do not allow differentiation which of the two actions which must be performed at the same time by the driver during the “slalom” test, contributes to the deterioration of driving conditions. In order to find answers to this questions, there should be a comparative study done in the future of normal and ECO steering wheels with an adjusted normal angle ratio of the steering system.

The fundamental question of the study should, however, address the problem of whether the presented research methodology of interface studies and the proposed ways of evaluation may be of interest to researchers involved in HMI design. To answer this question, the author notes that the results of the study should be taken into account by researchers of driving cars with SBQ systems, especially by the elderly and people with disabilities of lower limbs.

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