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EXAMINATION AND ASSESSMENT OF ELECTRIC VEHICLES' OPERATIONAL SAFETY

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Summary

Increasingly stringent environmental protection requirements and the implementation of the most modern technologies compel automotive manufacturers to develop the production of environment-friendly vehicles with electric drive systems. In difficult road conditions, vehicle participants are exposed to various hazards, especially to health and life. This forced the Automotive Industry Institute (PIMOT) to attack the important problem named "Electric Vehicles' Operational Safety (EVOS)", which is related to a number of new issues, not sufficiently explored yet. The tests carried out until now on electric vehicles to check their conformity with the Regulations and Directives in force do not cover many issues that were identified within this project as having an important impact on vehicle riding safety and comfort. This work included the formulation and implementation of a three-level EVOS examination and assessment concept.

This article presents results of comparative testing and assessment of the EVOS level for four electric vehicles, i.e. Mega E-City, Citroen C-Zero (Mitsubishi i-MiEV car manufactured by Citroen under a licence), Renault Fluence, and Opel Ampera. The presented results of testing the sample electric vehicles show how much the vehicles differ from each other and how much work still has to be done for improvement of the safety of their operation. Based on the work results, detailed EVOS assessment criteria may be prepared.

Keywords: electric vehicle, tests of electric vehicle, safety of electric vehicle

1. Introduction

Increasingly common use and growing trend towards the popularization of electric vehicles induce the necessity to tackle the problem of safety of electrically driven vehicles of new types. Their use may be accompanied by new safety-related phenomena that

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have not been sufficiently explored so far and have not been addressed in the UN ECE Regulations and EU Directives in force.

This paper presents a three-level concept of examining and assessing the Electric Vehicles' Operational Safety (EVOS), implemented at PIMOT.

1° – The EVOS 1 assessment is carried out in respect of criteria related to mechanical vibrations of vehicle body, internal noise, electromagnetic compatibility (EMC), and protection against electric shock.

2° – The EVOS 2 assessment is an expanded version of the EVOS 1, where criteria concerning the vehicle's safety equipment are added. At the EVOS 2 assessment, a "safety systems factor" is introduced to take into account the current technological progress in this field and the safety equipment provided in the electric vehicles under consideration.

3° – The granting of EVOS classes: there are 5 different EVOS classes, which may be granted to a specific EV type and to individual sets of equipment offered as options to vehicle users, based on the EVOS 2 assessment.

Results of comparative tests and EVOS assessment carried out for four electric vehicles, i.e. Mega E-City, Citroen C-Zero (Mitsubishi i-MiEV car manufactured by Citroen under a licence), Renault Fluence, and Opel Ampera, have also been given. The presented results of testing the sample electric vehicles show how much the vehicles differ from each other and how much work still has to be done for improvement of the safety of their operation.

During the operation of electric vehicles, numerous hazards may be encountered. Particularly dangerous would be the appearance of a voltage that would pose a risk of electric shock to people. It is important, therefore, that such a voltage should not appear on equipment casings or on the vehicle body even in result of a collision. Hence, equipment casings and enclosures with high electric and mechanical strength should be developed. The possibility of a battery fire is a separate issue. The vehicle structure should be in conformity with the requirements of UN ECE Regulation No. 100. Another hazard is caused by the impact of the electromagnetic field generated by vehicle equipment and wiring. The basic requirements in this respect are laid down in the type-approval regulations to be met by electric vehicles. In consideration of limited testing possibilities, only the most characteristic parameters have been proposed herein for discussion, if undertaken, and for further work on this issue.

The safety examination criteria applicable to electric vehicles according to the normative documents in force and to the EVOS system have been illustrated in Fig. 1.

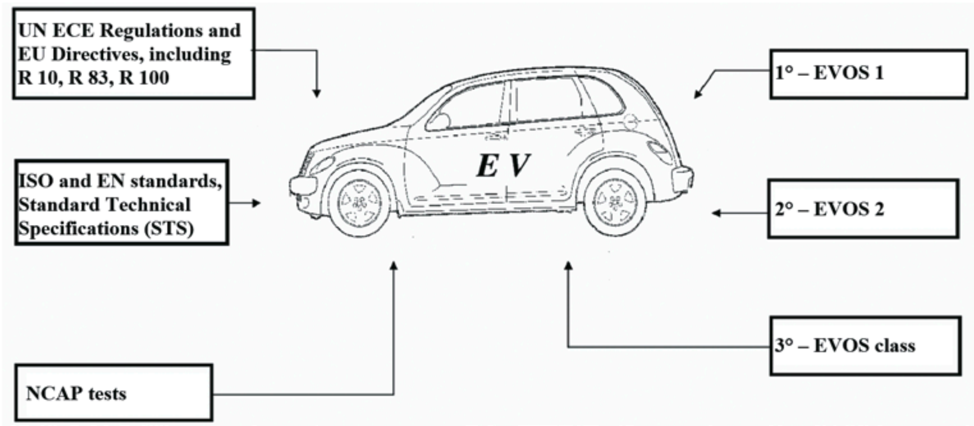

Fig. 1. Electric vehicle safety examination and assessment systems with taking into account the EVOS system

The most important aspect of using the EVOS system should be the improvement in the safety level that might be achieved by showing which electric vehicles are better from others in these terms.

The criteria prepared may be utilized at research works on electric vehicles, at the production of such vehicles and their components, and at the selection of vehicles, especially by transport companies. The implementation of the EVOS criteria having been prepared should help to improve the road traffic safety by reducing the hazards revealed in the tests. Within the further works, it would be reasonable to develop an EVOS assessment procedure for vehicles with hybrid drive systems, which have already become a considerable segment of the market.

2. Technical requirements related to the EVOS

2.1. Identification of electric vehicles

The electric vehicle submitted for testing is identified on the grounds of the data provided in an excerpt from the type-approval certificate (for new vehicles) or the data provided in the vehicle registration certificate (for used vehicles).

2.2. Requirements concerning mechanical vibrations

The requirements concerning the mechanical vibrations of an electric vehicle are based on determining the levels of discomfort according to standards ISO 2631-1 and BS 6841; they have been specified in Table 1 below, with the corresponding scores proposed for the assessment having been given in the third column of the Table.

Table 1. Scores proposed for specific discomfort degrees (based on measurements of the RMS values)

Acceleration, RMS [m/s²]	**Discomfort scale**	**Score [points]**
Less than 0.315	Not uncomfortable	6
0.315-0.63	A little uncomfortable	5
0.5-1.0	Fairly uncomfortable	4
0.8-1.6	Uncomfortable	3
1.25-2.5	Very uncomfortable	2
Greater than 2	Extremely uncomfortable	1

Instead of specifying the measured RMS acceleration values translated into discomfort feelings, the intensities of subjective human's sensations may be optionally defined

on the grounds of measured vibrations of the electric vehicle under test, as presented in Table 2 below; the corresponding scores proposed for the assessment have been given in the third column of the Table.

Table 2. Scores proposed for subjective human's sensations (based on measurements of the acceleration values)

Relative acceleration values [m/s²]	**Subjective sensation felt**	**Score [points]**
< 0.001	Imperceptible vibration	6
< 0.01	Barely perceptible vibration	5
< 0.1	Distinctly perceptible vibration	4
< 1	Unpleasant subjective sensation of low intensity	3
< 10	Unpleasant subjective sensation	2
> 10	Unpleasant subjective sensation of very high intensity	1

An analysis of the impact of vibrations on vehicle occupants has been presented, *inter alia*, in publication [16].

2.3. Requirements concerning internal noise

The requirements concerning internal noise in an electric vehicle are not mandatory and no such requirements have been laid down in the UN ECE Regulations and EU Directives.

The internal noise in a motor vehicle may be measured in accordance with Polish Standard PN-90/S-04052. This standard was established for motor vehicles with internal combustion engines (ICE) and it is still in force.

There is no separate standard that would be applicable to electric vehicles in this respect. Pursuant to the said Polish Standard, the maximum acceptable level of internal noise in passenger cars is 79 dB(A). For motor vehicles with a single row of seats, the measurements are carried out for a single measuring point situated at driver's seat. For passenger cars with two rows of seats, the noise is additionally measured at one more measuring point. The measurements are carried out when the vehicle is accelerated from an initial speed as specified in the standards to 120 km/h or 90 % of the vehicle speed corresponding to the maximum-power engine speed, whichever is lower.

In the tests carried out by automotive magazines, the measurements are carried out at constant vehicle speeds of 50 km/h, 100 km/h, and 130 km/h. The background noise level should be lower by at least 10 dB than the noise values measured.

The following scores have been proposed for the assessment of internal noise:

76 dB – 1 point;
74 dB – 2 points;
72 dB – 3 points;
70 dB – 4 points;
68 dB – 5 points;
66 dB – 6 points.

The requirements adopted here are more stringent in comparison with those of the Standard referred to above, in consideration of the time elapsed from the Standard publication date, the progress made in the car noise damping technology, and the fact that the noise generated by electric vehicles is lower than that emitted by vehicles with internal combustion engines.

An analysis of the sources of noise emitted by transport facilities, especially motor vehicles, has been described, *inter alia*, in publication [1].

2.4. Requirements concerning electromagnetic compatibility (EMC)

The EMC requirements are based on the provisions of UN ECE Regulation No. 10 and the corresponding EU Directive 2004/104/EC (current version). For an electric vehicle, measurements are carried out in a test site with the lowest possible electromagnetic background emission or in a semi-anechoic chamber. The assessment is performed by comparing broadband emissions. The emission limits for a 3 m distance between the measuring antenna and the vehicle have been shown in the form of a graph in Fig. 2. The levels represented by line L_1 are defined by the requirements laid down in the normative documents referred to above. The levels represented by lines L_2 and L_3 are lowered by 10 dB and 20 dB, respectively, in relation to level L_1 and show tightened requirements.

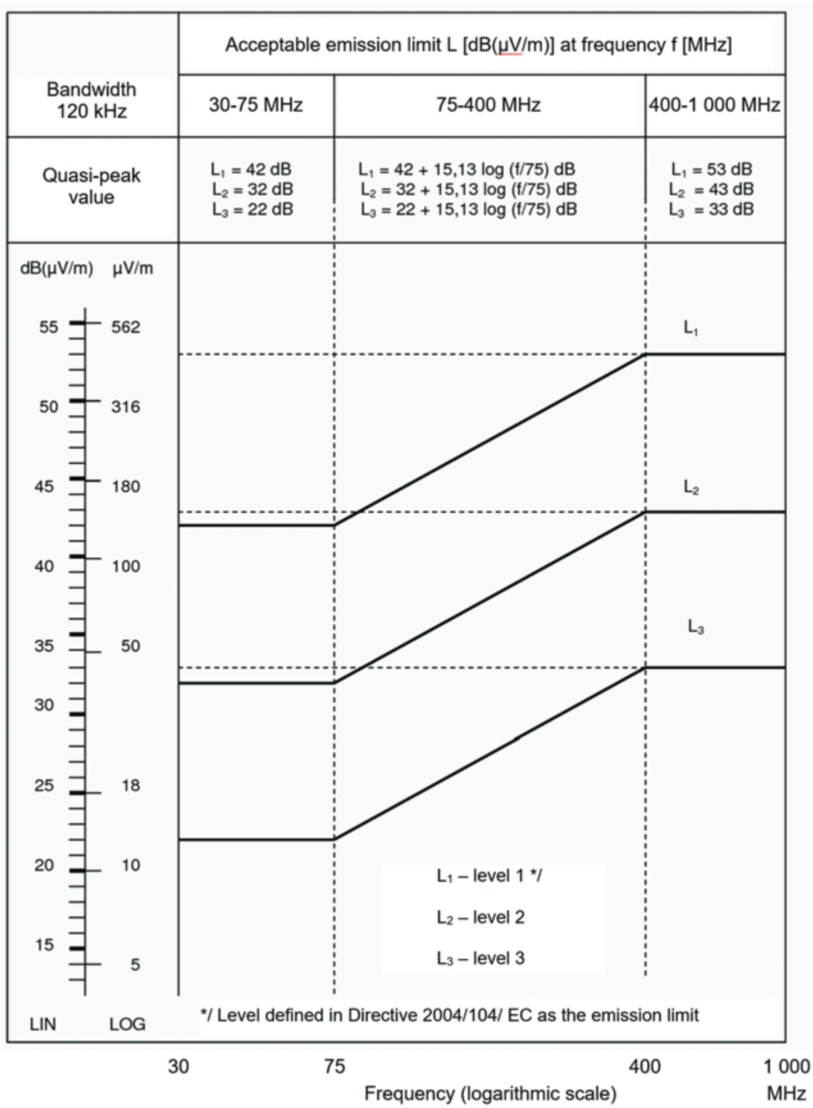

Fig. 2. Proposed reference levels of broadband electromagnetic emissions for vehicles

For an antenna-vehicle separation distance of 10 m, the levels represented by lines L_2 and L_3 are adopted as lowered by 8 dB and 16 dB, respectively, in relation to level L_1.

The concept of assessing the electromagnetic emission levels with taking lines L_1, L_2, and L_3 as a reference has been presented in publication [5].

The scores proposed for the assessment have been given in Table 3 below.

Table 3. Scores proposed for electromagnetic radiation (broadband electromagnetic emissions)

Electromagnetic emissions	Score [points]
Below L_3	6
Between L_3 and L_2	4.5
Between L_2 and L_1	3
Exceeding L_1 but by no more than 2 dB	1.5 *
Higher than the above	0.0

At the broadband emission assessment method adopted, some small exceedances (by up to 2 dB) may be accepted in consideration of the fact that the tests may also be carried out on used vehicles, retrofitted with electronic systems or devices of varying quality. The asterisk (*) means that this score may only be applied to used vehicles.

2.5. Requirements concerning electrical safety

These requirements concern the assessment of safety related to the possibility of electric shock to a person or persons present inside the vehicle or close to it when it is not in motion as well as e.g. during the battery charging process. The electrical installation of an electric vehicle must meet the requirements of UN ECE Regulation No. 100 and the corresponding EU Directive.

For the preliminary assessment, three major factors have been chosen from many factors that have an impact on the electrical safety related to the use of electrical equipment and power supply systems in electric vehicles:

- degree of protection of electrical enclosures (IP Code);
- working voltage in electric drive and control systems;
- insulation resistance.

The meaning of individual digits in the IP Code has been explained in Table 4 below.

Table 4. Meaning of individual digits in the IP Code, defining the electrical equipment protection classes

<table>
<tr><th colspan="3">IP Code breakdown</th></tr>
<tr><th>Symbol</th><th>Meaning</th><th>Remarks</th></tr>
<tr><td>IP letters</td><td>Protection against accidental contact with human body parts and ingress of solid objects and water</td><td>"IP" stands for "International Protection"</td></tr>
<tr><td>1st digit: 0 to 6</td><td>Degrees of protection against contact with human body parts and ingress of solid foreign matter, e.g. dust</td><td rowspan="2">In the case of a large number of electricity receivers, not all digits may be present in the IP Code</td></tr>
<tr><td>2nd digit: 0 to 8</td><td>Degrees of protection against ingress of water</td></tr>
<tr><td colspan="3">If only one digit is present in the IP Code, then letter X is put in the place for which the degree of protection is not specified.</td></tr>
</table>

Explanation of individual digits in the IP Code		
Protection symbol	**Meaning**	**Remarks**
Protection against accidental contact with human body parts and ingress of solid foreign matter		
IP 0X	No protection against contact with human body parts and against ingress of solid foreign matter	(Corresponding graphic symbols as defined below)
IP 1X	Protection against ingress of solid foreign matter ≥ 50 mm dia.	„Protected from touch by hand"
IP 2X	Protection against ingress of solid foreign matter ≥ 12.5 mm dia.	„Protected from touch by finger"
IP 3X	Protection against ingress of solid foreign matter ≥ 2.5 mm dia.	„Protected from touch by tools"
IP 4X	Protection against ingress of solid foreign matter ≥ 1 mm dia.	„Protected from touch by wires"
IP 5X	Protection against harmful dust deposition inside	„Protected from ingress of dust"
IP 6X	Total protection against dust ingress	„Dust tight"
Protection against ingress of water		
IP X0	No protection against ingress of water	
IP X1	Protection against water drops falling vertically	"Drip proof"
IP X2	Protection against water drops falling at an angle of up to 15 ° from vertical	"Rainproof"
IP X3	Protection against water spray received at an angle of up to 60 ° from vertical	"Semi splash-proof"
IP X4	Protection against water spray received from any direction	"Splash-proof"
IP X5	Protection against low-pressure water jets	"Hose-proof"
IP X6	Protection against high pressure water jets received from any direction	"Semi watertight"
IP X7	Protection against short-term water immersion	"Watertight"
IP X8	Protection against long-term water immersion	"Pressure watertight"

The following scores have been proposed for electric vehicle drive and control systems:

IP 42 – 2 points;
IP 44 – 3 points;
IP 54 – 4 points;
IP 56 – 5 points;
IP 66 – 6 points.

As regards the assessment of working voltage, the scores as specified in Table 5 have been proposed.

Table 5. Scores proposed for working voltage

Working voltage [V]	Score [points]
< 60	6
60-100	5
100-200	4
200-300	3
300-400	2
400-500	1

The scores proposed for the assessment of insulation resistance have been given in Table 6.

Table 6. Scores proposed for insulation resistance

Insulation resistance [Ω/V]	Score [points]
500-750	3
750-1 000	4
1 000-1 250	5
> 1 250	6

For the overall assessment, the average value of the above electrical safety factors is adopted. The IP Code system of classifying the degree of protection of electrical enclosures has been presented in Table 4.

2.6. Requirements concerning the safety equipment of electric vehicles

The road traffic safety hazards that accompany the motorization stimulate development of systems designed to improve the active (pre-accident) and passive (post-accident) safety of motor vehicles and their users. This is fostered by technological development, in particular by achievements in the field of sensors used to measure mechanical quantities, radars, lidars, digital cameras, positioning systems based on the GPS (Global Positioning System) technology, radio data transmission systems (especially GSM, i.e. Global System for Mobile Communication), signal transducers, microprocessors and computers with software for real-time data processing, data transmission networks (especially local network named CAN, i.e. Control Area Network), as well as precisely operating servomechanisms and other actuating devices. Based on the elements mentioned above, many mechatronic systems and devices have been developed that perform fragmentary tasks related to related to safety, monitoring, and automatic control in motor vehicles [11].

Below is a list of some examples selected from the multitude of such solutions.

ABC – Active Body Control, preventing vehicle body roll;

ABD – Automatic Blocking of Differential;
ABS – Antilock Brake System, preventing the wheels lock up under braking;
ACC – Active Cruise Control, maintaining a safe distance from the vehicle ahead;
ACR – Automatic Code Reader, i.e. an automatic diagnostic instrument to read trouble codes from the vehicle's computer system;
AFS – Adaptive Front-lighting System;
ALL – Automatic Load Levelling, levelling the vehicle regardless of its load;
ALR – Automatic Locking Retractor, automatically locking the seat belt tensioners;
ALS – Advanced Lighting System, controlling vehicle headlamps when cornering;
APS – Acoustic Parking System, i.e. an acoustic system to assist the driver in parking;
AS – Active Suspension;
ASC – Anti Slip Control, preventing the wheels from spinning;
ASR – Acceleration Slip Regulation, automatically controlling the traction force;
BA – Brake Assist, i.e. a system to assist the driver in emergency braking;
BAS – Brake Assist System, i.e. an electronic system to control vehicle brakes;
CBS – Combined Braking System, to link the front and rear brakes on a motorcycle or scooter;
CCS – Cruise Control System, to regulate the vehicle speed at a pre-selected value;
CDL – Central Door Locking;
EAS – Electronically Assisted Steering;
EBD – Electronic Brake Distributor, i.e. an electronic system to control the distribution of braking force among individual vehicle's axles;
EBS – Electronic Braking System;
EC4WD – Electronically Controlled 4WD (four-wheel drive);
EC4WS – Electronically Controlled 4WS (four-wheel steering);
ESC – Electronic Stability Control;
ESP – Electronic Stability Program;
FLS – Forward Looking System, to detect obstacles ahead of the vehicle;
HDC – Hill Descent Control;
HUD – Head Up Display, i.e. a system to display information on vehicle's windscreen;
ICC – Intelligent Cruise Control, i.e. a system to control vehicle speed according to the speed of the vehicle ahead;
ISS – Integrated Safety System (Delhi);
LAS – Lane Assist System, to assist the driver in keeping vehicle lane;
OBD – On Board Diagnostics;
OCS – Occupant Characterization System, to characterize the occupancy of passenger's seat;
PA – Park Assist;
PAS – Power Active Steering (or Power-Assisted Steering);
PDC – Park Distance Control, to indicate the distance to obstacles behind and in front of the vehicle when parking;
PDL – Powered Door Locks;
PHS – Parking Heater System;
PTS – Parktronic System (a parking aid);
RABS – Rear Antilock Brake System, preventing the rear wheels' lock up under braking;
RCM – Restraint Control Module, to control the airbags;

RDS – Rear Detect System, to detect rear-end collision hazards;
SAHR – Saab Active Head Restraint;
SBDS – Service Bay Diagnostic System, i.e. an all-embracing Ford diagnostic system;
SCS – Stability Control System;
SDS – Side Detect System, to detect side collision hazards.

In the field of the mechatronic systems and devices aimed at improving the motor vehicle safety, a continuous trend to increase the level of integration can be observed. An example may be the ESC II system presented in Fig. 3 [17], where the basic ESC functions of stabilizing

the vehicle travel path by interventions in the driving and braking systems have been supplemented by additional couplings with controllers of the active steering system and active suspension system.

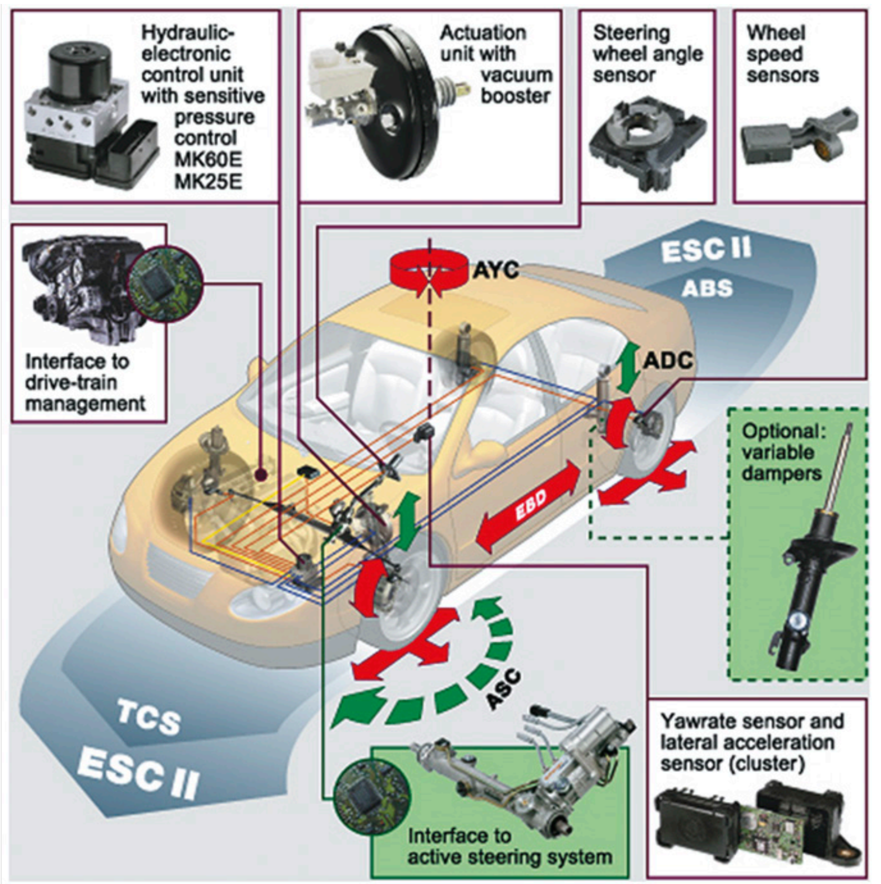

Fig. 3. Schematic diagram of the ESC II system [17]

There are a lot of systems, separate technical units, and modules that constitute the Vehicle Safety System (VSS) and 10 items, specified in Table 7 below, have been selected from among them for the assessment. Item S10 has been defined as "others", where other equipment, important for the improvement of vehicle's operational safety and provided in the vehicle submitted for testing, may be covered. In this part of the EVOS assessment procedure, scores of 0 to 10 may be given for each of the items S1, S2, … to S10, which would make up to 100 points in total. For the overall EVOS assessment, these partial scores are converted into an appropriate safety systems factor B_x, added to the overall assessment score.

Table 7. Scores proposed for the safety equipment of an electric vehicle

Equipment symbol	Description of the system or separate technical unit	Manufacturer's symbol	Score [points]
S1	Seat belts with pretensioners	SRS	0-10
S2	Airbags	Various	0-10
S3	Antilock and anti-slip system	ABS, ASR, EBO, EBS, others	0-10
S4	Vehicle travel path stabilization system	ESP	0-10
S5	Active cruise control system	ACC	0-10
S6	Obstacle detection system and system of automatic braking to 50 km/h	Various	0-10
S7	Warning systems, monitoring driver fatigue or lane departure	Various	0-10
S8	Lighting and visibility improving systems	Various	0-10
S9	Monitoring of road incidents	e-Call	0-10
S10	Others		0-10
	Total, maximum		**100**

3. EVOS assessment criteria

Pursuant to the concept adopted as described in Section 1 herein, the EVOS assessment

is carried out at three levels:

1° – EVOS 1 assessment;

2° – EVOS 2 assessment;

3° – Granting of an EVOS class.

1°. EVOS 1 assessment

The EVOS 1 assessment is carried out based on results of the tests for conformity with the requirements described in subsections 2.1 to 2.5 herein. The assessment results are obtained by calculating the "overall EVOS assessment index" from the weighted average calculation formula as given below. For the four quantities adopted as indicators (W1, W2, W3, and W4), this formula takes the form:

$$W_{B1} = \frac{W_1 * u_1 + W_2 * u_2 + W_3 * u_3 + W_4 * u_4}{u_1 + u_2 + u_3 + u_4} \quad (1)$$

where: W_{B1} – overall EVOS 1 assessment index;
W_1 – score given in the assessment of mechanical vibrations;
W_2 – score given in the assessment of internal noise;
W_3 – score given in the EMC assessment;
W_4 – score given in the assessment of electrical safety;
u_1, u_2, u_3, u_4 – weights of individual scores in the overall index.

In result of an analysis carried out, the following weights were adopted, with $\sum u = 1$:

u_1 = 0.25;
u_2 = 0.20;
u_3 = 0.25;
u_4 = 0.30.

For the above weight values, the formula (1) used for determining the W_{B1} index takes the following form, easy for calculations:

$$W_{B1} = 0.25\ W_1 + 0.20\ W_{B2} + 0.25\ W_{B3} + 0.30\ W_4 \quad (2)$$

2°. EVOS 2 assessment

For the EVOS 2 assessment, results of the tests and assessment of the electric vehicle to the EVOS 1 procedure are utilized. The scope of this assessment is widened by additionally taking into account the VSS provided. The overall EVOS 2 assessment index is determined from the following formula:

$$W_{B2} = W_{B1} * (B_x + 1), \quad (3)$$

where B_x is the safety systems factor for the vehicle under assessment.

When equation (1) is substituted to equation (3), the following formula is obtained for determining the overall EVOS 2 assessment index:

$$W_{B2} = \frac{W_1 * u_1 + W_2 * u_2 + W_3 * u_3 + W_4 * u_4}{u_1 + u_2 + u_3 + u_4} * (B_x + 1) \quad (4)$$

with B_x being calculated from the following equation, for the number l of the systems and separate technical units dedicated to vehicle safety as adopted in Table 7:

$$B_x = \frac{\sum_{i=1}^{i=k} s_i}{l_p} \quad (5)$$

where: $\sum_{i=1}^{i=k} s_i$ – actual total score;

l_p – maximum possible total score

If, according to Table 7, the maximum possible total score is l_p = 10 × 10 = 100 and

$$\sum_{i=1}^{i=k} s_i = s_1 + s_2 + \ldots\ldots\ldots\ldots\ldots + s_{10} \tag{6}$$

then formula (5) may be written in the following form, convenient for calculations:

$$B_x = \frac{s_1 + s_2 + \ldots\ldots\ldots\ldots\ldots + s_{10}}{100} \tag{7}$$

In result of the assessment, every system and separate technical unit installed in the vehicle under consideration and dedicated to vehicle safety (represented in Table 7 by symbols S1, S2, ..., S10) is given a specific score (s_1, s_2, …, s_{10}, respectively). When the sum of these scores is put into equation (7), the safety systems factor B_x can be calculated. In graphical form, the function $W_{B2} = f(B_x)$ is represented by curves shown in Fig. 4. Four initial values W_{B1} = 3, 4, 5, and 6 were assumed for a preliminary analysis.

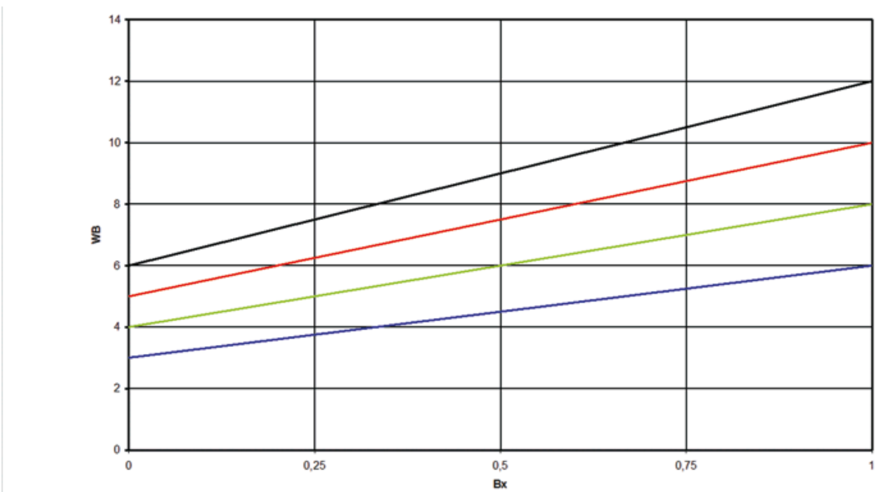

Fig. 4. Curves representing the function WB2 = f(Bx) for WB1 = 3, 4, 5, 6

3°. Granting of an EVOS class

An EVOS class may be granted to an electric vehicle that has satisfactorily passed the EVOS 2 assessment.

For individual classes, the scores as specified in Table 8 below and in Fig. 4 have been adopted.

Table 8. EVOS classes proposed depending on the scores gained

EVOS class	EVOS 2 score [points]
AA	10.0–12.0
A	8.0–10.0
B	6.5–8.0
C	5.0–6.5
D	4.0–5.0

4. Testing of selected electric vehicles

Objective

The objective was to carry out comparative tests of selected electric vehicles for conformity with the technical requirements presented in Section 2 herein and established within this work as criteria of assessment of the Electric Vehicles' Operational Safety (EVOS).

Test specimens

The tests were carried out on four currently manufactured passenger cars with electric drive systems:

1. MEGA E-CITY;
2. CITROEN C-ZERO (Mitsubishi i-MiEV car manufactured by Citroen under a licence;
3. RENAULT FLUENCE;
4. OPEL AMPERA.

Photographs of vehicles Nos. 1, 2, 3, and 4 have been presented in Figs. 5-8.

Fig. 5. MEGA E-CITY

Fig. 6. CITROEN C-ZERO

Fig. 7. RENAULT FLUENCE

Fig. 8. OPEL AMPERA

Test results

In result of an identification of vehicles Nos. 1, 2, 3, and 4, the data provided in the vehicle documents (vehicle registration certificates) were found to be in conformity with the actual characteristics of the vehicles submitted for testing.

Mechanical vibration tests

The tests were carried out in compliance with subsection 2.2. The test results have been presented in Table 9.

Table 9. Results of measurements of mechanical vibrations of the vehicles under test

Vehicle No.	RMS acceleration values [m/s²]	Score [points]
1	1.1	3
2	0.75	4
3	0.66	4
4	0.43	5

Internal noise tests

The tests were carried out in compliance with subsection 2.3. The test results have been presented in Table 10.

Table 10. Results of measurements of internal noise in the vehicles under test

Vehicle No.	Acoustic pressure values [dB(A)]	Score [points]
1	71.6	3
2	67.3	5
3	66.2	5
4	66.9	5

EMC tests

The tests were carried out in compliance with subsection 2.4 within the scope of broadband electromagnetic emissions in two frequency ranges: 30-300 HHz and 300-1 000 MHz, with the use of two antenna systems. The test results have been presented in Table 11. Example curves representing the broadband emissions measured for the MEGA E-CITY vehicle illustrate the graphs in Figs. 9 and 10.

Table 11. Results of testing the EMC of the vehicles under test (broadband emissions)

Vehicle No.	Electromagnetic emission values	Score [points]
1	See the graphs presented in Figs. 9 and 10 herein	3
2	See the graphs presented in the PIMOT Problem Study *	3
3	See the graphs presented in the PIMOT Problem Study *	4.5
4	See the graphs presented in the PIMOT Problem Study *	4.5

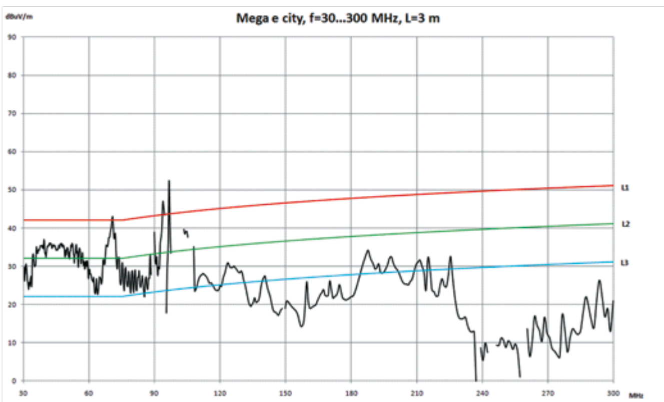

Fig. 9. Example curve representing the broadband emissions measured for the MEGA E CITY vehicle; f = 30-300 MHz

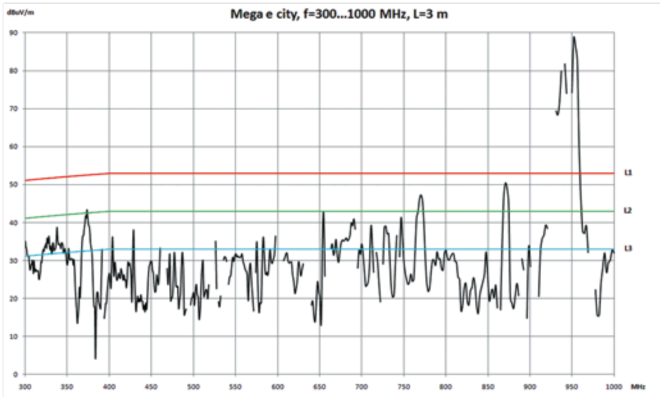

Fig. 10. Example curve representing the broadband emissions measured for the MEGA E CITY vehicle; f = 300-1 000 MHz

Electrical safety tests

The tests were carried out in compliance with subsection 2.5. The test results have been presented in Table 12.

Table 12. Results of checking the electrical safety within the scope of the IP Code system of equipment protection classes and the working voltage of the equipment

Vehicle No.	IP Code	IP score [points]	Working voltage [V]	Voltage score [points]	Overall score [points]
1	42	2	48	6	4.0
2	44	3	330	2	2.5
3	44	3	398	2	2.5
4	54	4	950	0	2.0

In the preliminary tests, the insulation resistance was not tested; instead, an assumption was made that the minimum acceptability level of 500 Ω/V as required by UN ECE Regulation No. 100 was met.

Determining of the safety systems factor B_x

The safety systems factor B_x was determined in compliance with subsection 2.6. The test results have been presented in Table 13.

Table 13. Results of determining the safety systems factor B_x of the electric vehicles under test

Vehicle No.	Symbols of vehicle equipment and separate technical units										$\sum s_i$ [points]	B_x [points]
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10		
1	2	0	0	0	0	0	0	2	0	0	2	0.04
2	5	4	2	0	0	0	0	5	0	0	16	0.16
3	8	8	6	5	0	0	0	5	0	0	33	0.33
4	8	8	8	5	0	0	0	5	0	5	39	0.39

5. Analysis of the results

The comparative examinations carried out to assess the vehicles under consideration and their safety systems enabled practical verification of the EVOS assessment method prepared in the form as proposed in the concept presented in Section 1 herein.

1°. Results of the EVOS 1 calculations based on formula (2), carried out for the vehicles under test, have been presented in Table 14.

Table 14. Results of the EVOS 1 assessment of the vehicles under test

Vehicle No.	Make and model	Score [points]				EVOS 1
		W_1	W_2	W_3	W_4	W_{B1}
1	MEGA E-CITY	3	3	3	4.0	3.2
2	CITROEN C-ZERO	4	5	3	2.5	3.5
3	RENAULT FLUENCE	4	5	4.5	2.5	3.9
4	OPEL AMPERA	5	5	4.5	2.0	4.1

2°. Results of the EVOS 2 calculations based on formula (3) and the Bx factor values determined have been presented in Table 15.

Table 15. Results of the EVOS 2 assessment of the vehicles under test

Vehicle No.	IP Code	WB1 (EVOS 1 assessment)	B_x factor	EVOS 2 W_{B2}
1	MEGA E-CITY	3.2	0.04	3.33
2	CITROEN C-ZERO	3.5	0.16	4.06
3	RENAULT FLUENCE	3.9	0.33	5.19
4	OPEL AMPERA	4.1	0.39	5.70

The EVOS 1 and EVOS 2 calculation results in graphical form for the four vehicles under test have been presented in Figs. 11 and 12.

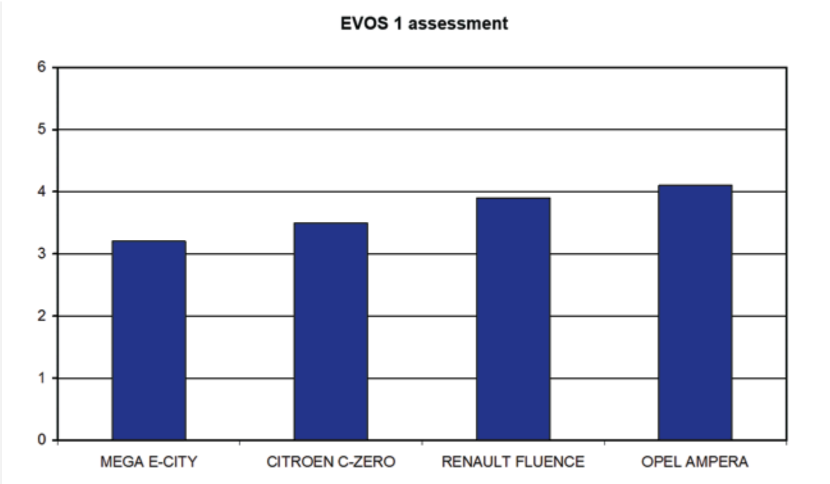

Fig. 11. WB1 calculation results

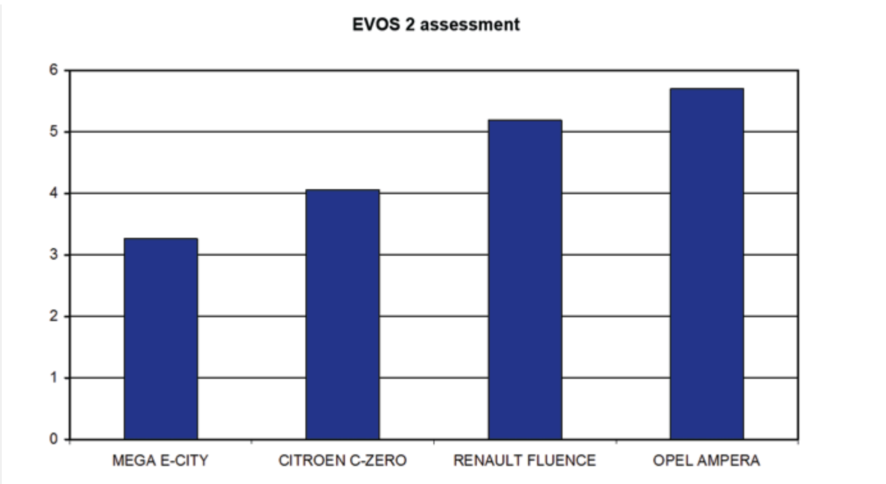

Fig. 12. W_{B2} calculation results

The average W_{B1} value was 3.67 points, as against a maximum of 6 points.

The average W_{B2} value was 4.57 points, as against a maximum of 12 points.

The relatively low value of the WB2 index shows, *inter alia*, that electric vehicles are rather poorly equipped with safety systems as against the standards adopted by leading motor vehicle manufacturers.

3°. In result of the EVOS 2 examinations carried out, the electric vehicles under consideration may be granted the EVOS classes as specified below, according to Table 8 in Section 3.

Table 16. The EVOS classes granted to the vehicles under test

Vehicle No.	IP Code	EVOS class
1	MEGA E-CITY	–
2	CITROEN C-ZERO	D
3	RENAULT FLUENCE	C
4	OPEL AMPERA	C

6. Recapitulation

1. The objective of this work was to prepare preliminary technical requirements for the purposes of evaluation of Electric Vehicles' Operational Safety (EVOS) and to carry out comparative tests.

2. The essence of the research task was to verify the EVOS assessment criteria, especially in respect of mechanical vibrations, internal noise, electromagnetic radiation, protection against electric shock, and additional factors, on specific models of electric cars.

3. Within the work, a three-level EVOS assessment concept was prepared and implemented. This concept, presented herein, covered:
   1° – EVOS 1 assessment;
   2° – EVOS 2 assessment;
   3° – Granting of an EVOS class.

   The EVOS 1 assessment is carried out in respect of the criteria described in subsections 2.1 to 2.5 herein.

   The EVOS 2 assessment is an expanded version of the EVOS 1, where criteria concerning the safety equipment of the vehicle are added. At the EVOS 2 assessment, a "safety systems factor" has been introduced to take into account the current technological progress in this field and the safety equipment provided in the electric vehicles under consideration.

   As regards the granting of EVOS classes, there are 5 different classes, which may be granted to a specific EV type and individual sets of its optional equipment, based on the EVOS 2 assessment.

4. The results of testing the sample electric vehicles show how much the vehicles differ from each other and how much work still has to be done for improvement of the safety of their operation. For one of the vehicles under test, no EVOS class was granted; among the others, one vehicle obtained class D and two were granted class C.

5. Based on the results of this work, detailed EVOS criteria may be prepared, e.g. in the form of Standard Technical Specifications (STS), for the assessment of electric vehicles. The STS may constitute a basis for the certification carried out by accredited units, e.g. PIMOT. Within the further works, it would be reasonable to develop an EVOS assessment procedure for vehicles with hybrid drive systems, which have already become a considerable segment of the market.

6. The criteria prepared may be utilized at research works on electric vehicles, at the production of such vehicles and their components, and at the selection of vehicles, especially by transport companies. The implementation of the EVOS criteria having been prepared should help to improve the road traffic safety by eliminating or lessening the hazards revealed in the tests.

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The full text of the article is available in Polish online on the website
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Tekst artykułu w polskiej wersji językowej dostępny jest na stronie
http://archiwummotoryzacji.pl.

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