

# A concept of the assessment of Electric Vehicles' Operational Safety (EVOS)

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**Abstract.** The Electric Vehicles' Operational Safety (EVOS) is becoming an important issue due to the fact of the popularization of environment-friendly electrically driven vehicles. The expansion of new types of electric vehicles releasing by automotive companies may lead to yet unknown safety-related problems. The paper presents a three-level concept of examining and assessing the EVOS developed at PIMOT. The proposed criteria 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.

## 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 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), developed at PIMOT:

- 1<sup>o</sup> - 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<sup>o</sup> - 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<sup>o</sup> - 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.

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

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 terms of EVOS.

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



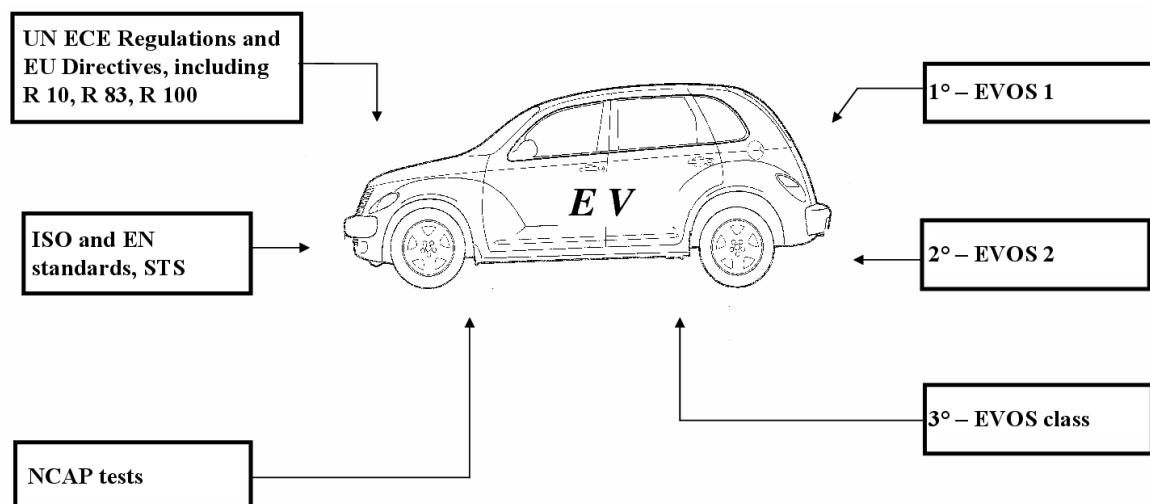


**Figure 1.** Electric vehicle safety examination and assessment systems with taking into account the EVOS system.

by eliminating or lessening the hazards revealed in the tests. Within the next 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                                  |                         |                   |
|------------------------------------------|-------------------------|-------------------|
| Acceleration, RMS<br>(m/s <sup>2</sup> ) | Discomfort scale        | Score<br>(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. An analysis of the impact of vibrations on vehicle occupants has been presented, inter alia, in publication [16].

**Table 2**

| Relative acceleration<br>values (m/s <sup>2</sup> ) | Subjective sensation felt                                 | Score<br>(points) |
|-----------------------------------------------------|-----------------------------------------------------------|-------------------|
| < 0.001                                             | Imperceptible vibration                                   | 6                 |
| < 0.01                                              | Barely perceptible vibration                              | 5                 |
| < 0.1                                               | Distinctly perceptible vibration                          | 4                 |
| < 1                                                 | Unpleasant subjective sensation<br>of low intensity       | 3                 |
| < 10                                                | Unpleasant subjective sensation                           | 2                 |
| > 10                                                | Unpleasant subjective sensation<br>of very high intensity | 1                 |

### 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, 90 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 lower 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 UNECE 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 figure 2. The levels represented by line L1 are defined by the requirements laid down in the normative documents referred to above. The levels represented by lines L2 and L3 are lowered by 10 dB and 20 dB, respectively, in relation to level L1 and show tightened requirements.

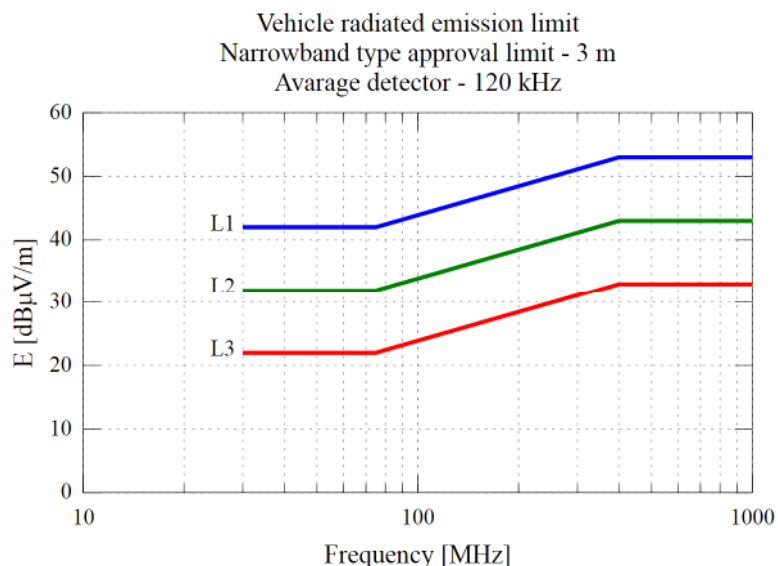


**Figure 2.** Proposed reference levels of broadband electromagnetic emission for vehicles (for a 3 m distance between the measuring antenna and the vehicle).

For an antenna-vehicle separation distance of 10 m, the levels represented by lines L2 and L3 are adopted as lowered by 8 dB and 16 dB, respectively, in relation to level L1.

The concept of assessing the electromagnetic emission levels with taking lines L1, L2, and L3 as a reference has been presented in publication [5].

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

**Table 3**

| Electromagnetic emissions             | Score<br>(points) |
|---------------------------------------|-------------------|
| Below L3                              | 6                 |
| Between L3 and L2                     | 4.5               |
| Between L2 and L1                     | 3                 |
| Exceeding L1 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 outside 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**

| IP Code breakdown                                                                                                                   |                                                                                                            |                                                                                                      |
|-------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
| Symbol                                                                                                                              | Meaning                                                                                                    | Remarks                                                                                              |
| IP letters                                                                                                                          | Protection against accidental contact with human body parts and ingress of solid objects and water         | “IP”stands for “International Protection”                                                            |
| 1 <sup>st</sup> digit: 0 to 6                                                                                                       | Degrees of protection against contact with human body parts and ingress of solid foreign matter, e.g. dust | In the case of a large number of electricity receivers, not all digits may be present in the IP Code |
| 2 <sup>nd</sup> digit: 0 to 8                                                                                                       | Degrees of protection against ingress of water                                                             |                                                                                                      |
| 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. |                                                                                                            |                                                                                                      |
| 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**

| 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**

| Insulation resistance ( $\Omega/V$ ) | Score (points) |
|--------------------------------------|----------------|
| 500-750                              | 6              |
| 750-1000                             | 5              |
| 1000-1250                            | 4              |
| >1250                                | 3              |

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 electrical 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 the monitoring and automatic control in motor vehicles [11].

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 Bx, added to the overall assessment score.

**Table 7**

| 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               | Braking systems: anti, anti-slip and supportive                      | 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 in traffic | Various                    | 0-10           |
| S7               | Warning systems, monitoring driver fatigue or lane departure         | Various                    | 0-10           |
| S8               | Lighting, signalling 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.

#### 3.1. 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 results of an analysis carried out, the following weights were adopted, with  $\sum u = 1$ :

$$\begin{aligned} u_1 &= 0.25; \\ u_2 &= 0.20; \\ u_3 &= 0.25; \\ u_4 &= 0.30. \end{aligned}$$

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

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

### 3.2. 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  $k$  of the systems and separate technical units dedicated to vehicle safety as adopted in table 7:

$$B_x = \frac{\sum_{i=1}^{i=k} S_i}{k_p}, \quad (5)$$

where:  $\sum_{i=1}^{i=10} S_i$  – - actual total score;

$k_p$  – - maximum possible total score.

If, according to table 7, the maximum possible total score is  $k_p = 10 \times 10 = 100$  and

$$\sum_{i=1}^{i=k} S_i = S_1 + S_2 + ..... + S_{10}, \quad (6)$$

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

$$B_x = \frac{S_1 + S_2 + ..... + S_{10}}{100} \quad (7)$$

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  $S_1, S_2, \dots, S_{10}$ ) is given a specific score ( $s_1, s_2, \dots, s_{10}$ , 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 figure 3. Four initial values  $W_{B1} = 3, 4, 5$ , and 6 were assumed for a preliminary analysis.

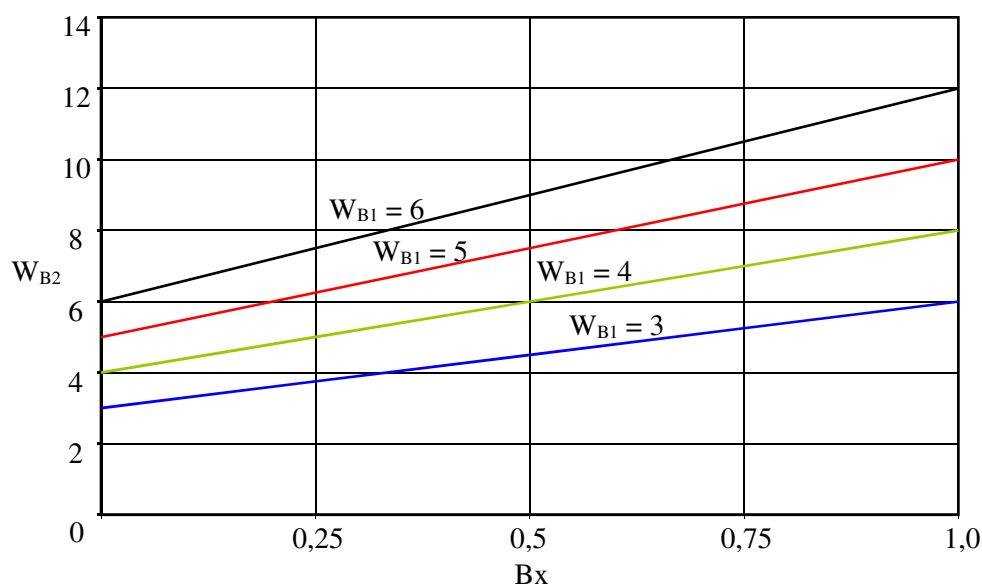


**Figure 3.** Curves representing the function  $W_{B2} = f(B_x)$  for  $W_{B1} = 3, 4, 5, 6$

### 3.3. 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 figure 3 have been adopted.

**Table 8**

| EVOS class | EVOS 2 score<br>(points) |
|------------|--------------------------|
| AA         | 10.0 - 12.0              |
| A          | 8.0 - 10.0               |
| B          | 4 - 8.0                  |
| C          | 3 - 6.5                  |
| D          | 2 - 5.5                  |

## 4. Recapitulation

- The objective of this work was to prepare preliminary technical requirements for the purposes of evaluation of Electric Vehicles' Operational Safety (EVOS).
- In this study, a three-level EVOS assessment concept has been presented, which 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” is 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.

- 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 next 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.
- 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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